Concussion in Elite Scottish Rugby:

A Study of Epidemiology, Risk Factors, and a Preventative Measure

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A thesis submitted in partial fulfilment of the requirements of Edinburgh Napier University, for the award of Doctor of Philosophy

This work is dedicated to my Mum and Dad, without who none of this would have been possible, and to my late sister Kirsty:

"We'll be friends forever, won't we Pooh?" asked Piglet.

"Even Longer" Pooh answered.

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"If there ever comes a day when we can't be together, keep me in your heart, I'll stay there for ever."

A.A. Milne

SIGNED DECLARATION

The work presented in this thesis has not been submitted for any other degree or professional qualification and is the result of my own independent work.

Two abstracts have been published with data collected that is also presented in this thesis, as well as one conference poster presentation. These are listed on page 18 and shown in appendices nine, ten, and eleven.

Signed: [redacted]

Stuart Bailey

Date: 25/9/2020

ABSTRACT

Concussion is a traumatic brain injury which is common in rugby union across the world, yet knowledge of concussion epidemiology in professional Scottish rugby union was previously limited. This thesis therefore investigated epidemiology, aetiology and a potential preventative measure of concussion in professional rugby union in Scotland by following van Mechelen's "Sequence of Prevention of Sports Injuries" model (van Mechelen et al, 1992) and other injury investigation methodologies (Fuller & Drawer, 2004; Meeuwisse et al, 2007). Following research recommendations from the rugby research consensus (Fuller et al, 2007d), medically collected injury data and GPS match and training exposure demonstrated concussion was the primary match injury in four of the five professional cohorts in Scotland during the 2017/18 and 2018/19 seasons. Concussion incidences were 22.5-37.3/1000 player match hours. Regression analysis of intrinsic concussion history and extrinsic contact event specific risk factors for concussion outcome found severity of most-recent concussion, high impact forces and being struck on the head and shoulder to statistically increase probability of concussion in tackle situations. The results imply that rule changes to the game of rugby and implementation of individualised concussion recovery protocols may reduce probability of concussion outcomes. A novel neck training programme to improve neck function and reduce concussion incidence was found to result in statistical improvements in neck strength and endurance for the intervention group compared with the control. Match concussion incidences were 7.7 (intervention) and 18.4/1000 player match hours (control). As a result, further work to implement this programme on a wider scale throughout Scottish Rugby was recommended. Concussion can cause various short- and long-term implications for individual players and professional rugby union squads. This thesis suggests possible future areas of research that are hoped to be developed to attempt to reduce concussion incidence in both Scottish and world-wide professional rugby union.

CONTENTS

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LIST OF FIGURES

LIST OF TABLES

LIST OF PUBLICATIONS AND PRESENTATIONS

Published Abstracts

Bailey, S., Martindale, R., Sweeting, J., Deacon, J., Laing, F., Leck, C., & Palmer, D. (2020). Effects of a strength and proprioceptive training programme on neck function and concussion injury risk in elite Scottish rugby union players. *British Journal of Sports Medicine*, *54*(Suppl 1), A8.

Bailey, S., Martindale, R., Robson, J., & Palmer, D. (2020). Epidemiology of injuries in Scottish male professional rugby union. *British Journal of Sports Medicine*, *54*(Suppl 1), A102.

Published abstracts shown in appendix nine and appendix ten.

Conference Poster Presentation

Bailey, S., Martindale, R., Sweeting, J., Deacon, J., Laing, F., Leck, C., & Palmer, D. (2019). Effects of a strength and proprioceptive training programme on neck function in elite Scottish Rugby Union players. Presented at: *The Edinburgh Sport & Exercise Medicine Conference 2019*, Edinburgh, 2019.

Poster shown in appendix eleven.

Internet Blog

Bailey, S., (2018, November 16). Rugby Union injuries: future research. Retrieved from: https://blogs.bmj.com/

Blog text shown in appendix twelve.

LIST OF ABBREVIATIONS

1 RM	One Repetition Maximum
ANOVA	Analysis of Variance
APOE	Apolipoprotein E gene
ATP	Adenosine Triophosphate
CI	Confidence Interval
CNS	Central Nervous System
CTE	Chronic Traumatic Encephalopathy
CTR	Configurable Team Report
df	Degrees of Freedom
D_M	Duration of Match
GPS	Global Positioning System
HIA	Head Injury Assessment
HNCA	Acute Concussion
HNCX	Concussion
HR	Heart Rate
Hz	Hertz
IMVC	Isometric Maximal Voluntary Contraction
IRB	International Rugby Board
IRR	Incidence Rate Ratios
Kg	Kilograms
MAPT	Microtubule-Associated Protein Tau gene
MHR	Maximum Heart Rate
mmHg	Millimetres of Mercury
MVC	Maximal Voluntary Contraction
N_M	Number of Matches
NWB	Non-Weight Bearing
OSICS	Orchard Sports Injury Classification System
P_M	Players per Match
PNS	Peripheral Nervous System
Q1	Quarter 1 (0 - 20 mins)
Q2	Quarter 2 (21 - 40 mins)
Q3	Quarter 3 (41 - 60 mins)
Q4	Quarter 4 (61 - 80 mins)
RFU	Rugby Football Union
RWC	Rugby World Cup
SCAT	Sport Concussion Assessment Tool
SD	Standard Deviation
UK	United Kingdom
USA	United States of America
VIF	Variance Inflation Factors
VL	Load x Reps
WB	Weight Bearing
WRWC	Women's Rugby World Cup
χ^2	Chi-square

CHAPTER 1: THESIS INTRODUCTION

1.1: Introduction

1.1.1: Rugby and Concussion

Rugby Union (from here-on referred to as "rugby") is a full contact sport, which can be played in either a 15 or 7-a-side (rugby sevens) format for both men and women. Rugby matches last for 80 minutes, split into two halves of 40 minutes separated by a 10-15 minute break. The ball tends to be in play for approximately 32-36 minutes across the full game (Quarrie, Hopkins, Anthony, & Gill, 2013; Williams, Hughes, & O'Donoghue, 2005). Players typically cover 5-7 km during a match, with bouts of high intensity running/contact events (tackles, rucks, mauls and scrums) interspersed with extended periods of low intensity activity (Austin, Gabbett, & Jenkins, 2011; Cahill, Lamb, Worsfold, Headey, & Murray, 2013; Lindsay, Draper, Lewis, Gieseg, & Gill, 2015; Quarrie et al, 2013). Rugby sevens incorporates the same basic skill set and rules of rugby, aside from the number of players in a team (seven), match duration (two halves of 7 or 10 minutes, with 1-2 minute half-time), and number of players in a scrum (3 players from each team). Rugby sevens matches are played at a greater relative intensity (Ross, Gill & Cronin, 2014), with players in general covering 45% greater distance per minute and 135% greater distances per minute at high speed compared with rugby players (Higham, Pyne, Anson & Eddy, 2012).

Injuries are a common occurrence in competitive sport (Hootman, Dick, & Agel, 2007), and governing bodies and sport administrators in the United Kingdom have a duty of care to be aware of the risks and hazards to player welfare that are present due to injury occurrence (Fuller, 1995). Sports which allow player contact tend to have higher levels of injury incidence. Previous studies have found high injury incidences for rugby and rugby sevens of 90.1/1000 player match hours (men's international rugby), 99.9/1000 hours (men's professional club rugby), 109.7/1000 hours (men's international rugby sevens) and 109.4/1000 hours (women's international rugby sevens) (Fuller, Taylor, Kemp, & Raftery, 2017b; Fuller, Taylor, & Raftery, 2017c; Schwellnus et al, 2018). This is in comparison with match injury incidences in non-contact sport of 3.8/1000 hours (men's, women's, and junior international volleyball) and 7.1/1000 hours (men's international cricket), semi-contact sport of 29.3/1000 hours (men's international soccer) and full contact 52.1/1000 hours (men's international ice hockey) (Bere, Kruczynski, Veintimilla, Hamu, & Bahr, 2015; Junge & Dvořák, 2015; Ranson, Hurley, Rugless, Mansingh, & Cole, 2013; Tuominen, Stuart, Aubry, Kannus, & Parkkari, 2015). Recent injury surveillance studies have reported that concussion is the most frequent match injury reported in men's international rugby (Fuller et al, 2017b), men's professional club rugby (RFU, 2019), and men's and women's international rugby sevens (Fuller et al, 2017c), as well as the third most frequent training injury in men's professional club rugby (RFU, 2019). Concussion is defined as "A traumatic brain injury induced by biomechanical forces", caused either by direct impact to the head, or elsewhere on the body with the resultant energy transferred to the head (McCrory et al, 2017; Zhang, Yang, & King, 2004). The energy transferred to the brain causes lesions due to linear and rotational acceleration (Hardy, Khalil, & King, 1994; King, Yang, Zhang, Hardy, & Viano, 2003), resulting in a cascade of events which ends with the brain in a hypometabolic state (Dashnaw, Petraglia, & Bailes, 2012; Giza & Hovda, 2014; King et al, 2003; Pabian, Oliveira, Tucker, Beato, & Gual, 2016). During this time it is believed that the brain is especially susceptible to further injury (Barkhoudarian, Hovda, & Giza, 2011).

Concussion results in impaired cognitive function (Giza & Hovda, 2014), which may present as headache, confusion, ataxia, loss of consciousness, vomiting, amnesia, dizziness and/or personality changes (Lau, Kontos, Collins, Mucha, & Lovell, 2011). Longer lasting symptoms over days to weeks may include persistent headaches, sleep disturbances, reduced concentration/awareness/attention, memory dysfunction and irritability (Barkhoudrian et al, 2011). However, most of these symptoms and deficits will resolve by a sequential course within days to weeks, with the majority of concussed individuals reaching clinical recovery within 14 days (Barkhoudrian et al, 2011; Giza & Hovda, 2001; McCrory et al, 2017).

Beyond clinical recovery from concussion, several negative short- and long-term implications to player welfare have been associated with the injury. A recent history of concussion has been shown to increase incidence of subsequent concussion (Abrahams, Mc Fie, Patricios, Posthumus, & September, 2014; Hollis et al, 2009; McGuine, Hetzel, McCrea, & Brooks, 2014) and any musculoskeletal injury (Cross, Kemp, Smith, Trewartha, & Stokes, 2016; Nordström, Nordström, & Ekstrand, 2014). Concussion injury during a playing career has also been linked with neurocognitive decline and common mental disorders in later life (de Beaumont, Brisson, Lassonde, & Jolicoeur, 2007; Decq et al, 2016; Gouttebarge, Aoki, Lambert, Stewart, & Kerkhoffs, 2017; Hume et al, 2016; Lewis, Hume, Stavric, Brown, & Taylor, 2017). There is also speculation that there may be a link between concussive injury and greater probability of developing Chronic Traumatic Encephalopathy (CTE) in older age (Bertrand, Stein, Alosco, &

McKee, 2016; Hay, Johnson, Smith, & Stewart, 2016). Characteristics of CTE include a progressive degeneration of memory and executive function, and mood and behavioural disturbances including depression, suicidal thoughts, anger and aggressiveness, and balance and walking issues (Daneshvar, et al, 2011).

There may also be negative implications to team performance as a result of concussion injury. Injury may impair players and their preparation for or participation in key events across a season, reducing the team's probability of success (Drew, Raysmith, & Charlton, 2017; Williams et al, 2016). Williams et al (2016) found that a reduction in match injury burden of 42 days/1000 player match hours was associated with the smallest worthwhile change in league points across a season (+3) in English Premiership rugby, illustrating how injury occurrence can affect chances of team success. It is therefore of interest to rugby national governing bodies to understand the true incidence of concussion, and to attempt to reduce that incidence to ensure greater player welfare and team success.

1.2: Thesis Rationale

Although subject to season-to-season variation, reported match concussion incidences have predominantly increased over the last 20 years in men's professional rugby (figures 1.1 and 1.2).

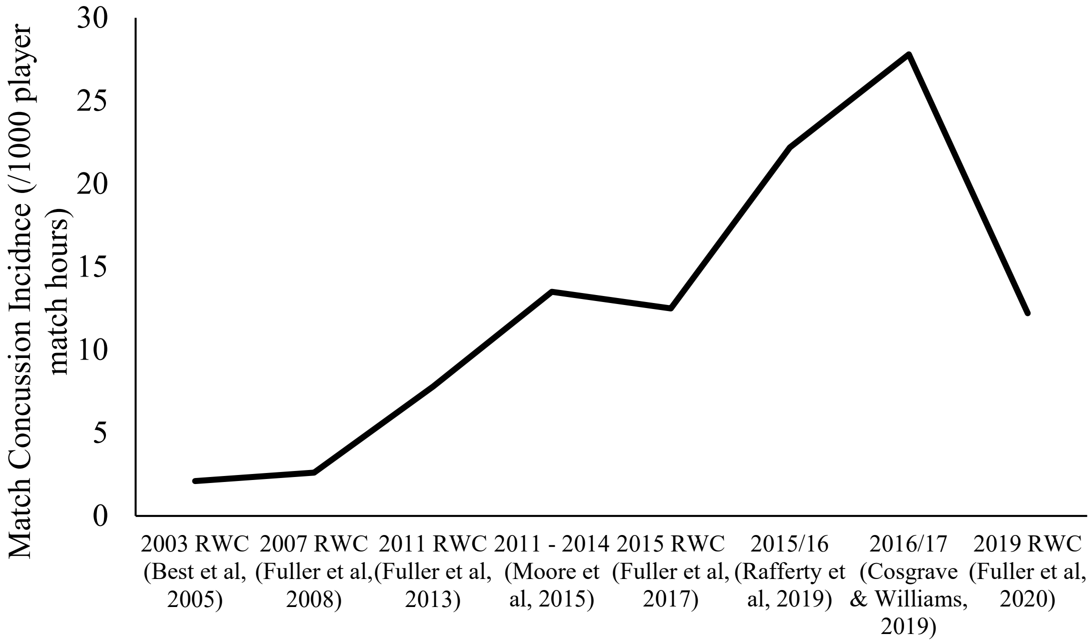

FIGURE 1.1: Match concussion incidence in men's international rugby.

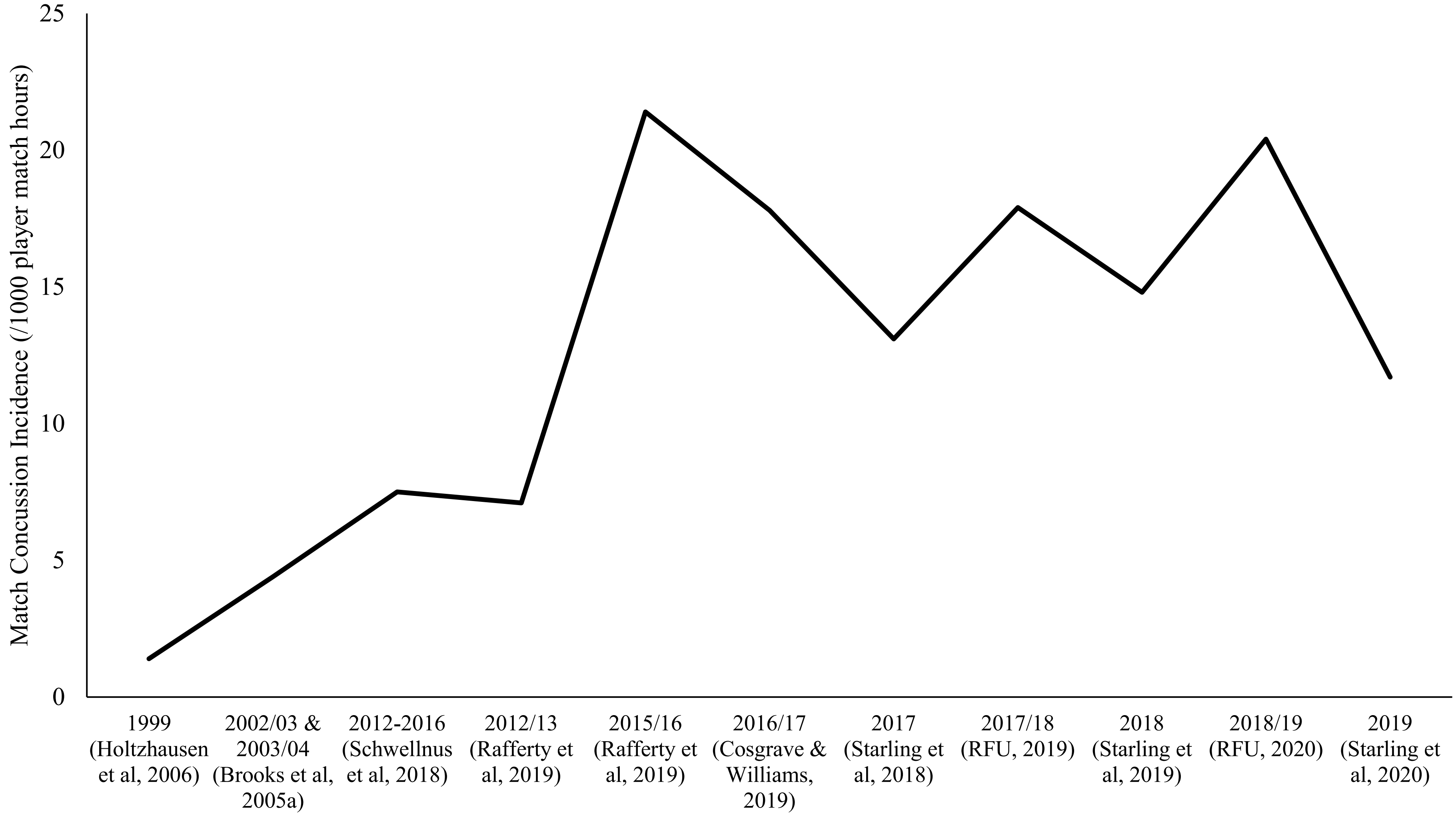

FIGURE 1.2: Match concussion incidence in men's professional club rugby

It is suspected the increasing concussion incidences illustrated in figures 1.1 and 1.2 are at least partly due to an increased awareness and improved ability to recognise and diagnose concussion (Emery et al, 2017; Lincoln et al, 2011), rather than a true increase. World Rugby have been one of the leading international governing bodies aiming to increase awareness and improve management of concussion (IRB, 2013; McCrory et al, 2013; Raftery & Falvey, 2021). World Rugby (then named the International Rugby Board: IRB) joined the International Conference on Concussion in Sport group for its second iteration in 2004 (McCrory et al, 2009), and was then a primary supporter of the quadrennial meetings in 2008 and 2012 (IRB, 2013). These meetings aim to provide recommendations to improve the safety of athletes who sustain a concussion in sport, resulting in a consensus statement aiming to improve current sport medicine practice and future research (McCrory et al, 2013). Sport medicine researchers/practitioners from World Rugby/IRB were selected to the expert panel to develop the consensus statement from the 2008 and 2012 meetings (McCrory et al, 2013; McCrory et al, 2009). Following the 2012 Concussion in Sport Consensus Statement, World Rugby/IRB introduced a new concussion assessment protocol (the Pitch Side Concussion Assessment tool) (Fuller, Kemp, & Decq, 2015; Raftery & Falvey, 2021), which has developed into the Head Injury Assessment (HIA) protocol, which is now used throughout all professional matches sanctioned by World Rugby to assess for the possibility of a concussion injury (Fuller, Fuller, Kemp, & Raftery, 2017a; Raftery et al, 2016; World Rugby, 2019b). Alongside this, World Rugby developed their own concussion working group to improve the awareness and recognition of concussion (Raftery & Falvey, 2021; World Rugby, 2017b), actions which were supported by the International Conference on Concussion in Sport group (McCrory et al, 2013). It is suspected that the work to improve the diagnosis and awareness of concussion has contributed to the increased rate of concussion reporting shown in figures 1.1 and 1.2, as has been reported in other settings (Emery et al, 2017; Lincoln et al, 2011).

The increasing match concussion incidence would suggest that true concussion incidence is unknown in men's international and professional club rugby. Minimal concussion epidemiology studies have been conducted in women's international rugby and men's and women's international rugby sevens, and therefore match concussion incidence in these cohorts is also relatively unknown across the world. Due to the negative implications of concussion around player welfare, an unknown concussion incidence is worrying.

Scotland are regarded as a tier one rugby nation. As of November 2019, the international teams are ranked 9th (men) and 11th (women) in the world (World Rugby, 2019d). The international rugby seven teams have a global ranking of 10th (men) and 12th (women) (World Rugby, 2019f). There are also two men's professional clubs who compete at the highest level of the men's professional club game. As the national governing body for rugby in Scotland, Scottish Rugby have a duty of care towards their professional players and should understand the possible hazards to health and welfare that are present in rugby (Fuller 1995; Fuller 2018a; Fuller & Drawer, 2004; Junge et al, 2008).

As the employer of players, Scottish Rugby's duty to protect player welfare falls under several United Kingdom health and safety legislations, including the "Health and Safety at Work etc. Act 1974" (HASAW), "The Management of Health and Safety at Work Regulation 1992" (MHSWR), and "The Reporting of Injuries, Diseases, & Dangerous Occurrences Regulations 1985" (RIDDOR; updated in 1995 and 2013). Section two of HASAW states: "It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety, and welfare at work of all his [*sic*] employees" (UK Public General Acts, 1974), demonstrating that Scottish Rugby has an obligation to protect welfare of professional players during time spent training and competing (Fuller 1995). Both HASAW and MHSWR also state that employers must undertake a sufficient assessment of the risks to employee welfare that exist whilst they are at work and communicate those risks to their employees (UK Public General Acts, 1974; UK Statutory Instruments, 1992). Regulation five of MHSWR states "Every employer shall ensure that his [*sic*] employees are provided with such health surveillance as is appropriate", whilst RIDDOR states that for any accident at work, the "responsible person" must "notify the enforcing authority", and "within 7 days, send a report to the enforcing authority on an approved form" (HSE, 2013; UK Statutory Instruments, 1992). As of the RIDDOR legislation updated in 2013, any accident/injury which results in the employee being unavailable for normal work tasks for three days must be recorded, whilst an absence from work for seven days must be reported to the relevant authority (HSE, 2013). These points of United Kingdom legislation illustrate the responsibility of Scottish Rugby to monitor the hazards to players whilst training and competing through injury surveillance records, communicate data on these hazards to the players, as well as other stakeholders, and to reduce said hazards to a level as low as reasonably practicable (Fuller, 1995; HSE, 2001).

Health surveillance in the form of injury epidemiology would fulfil Scottish Rugby's necessary role in undertaking an assessment of the various risks to player welfare (Fuller, 1995; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992), with risk being defined as "The expected loss in a particular situation within a stated period of time", calculated in injury epidemiology research as mean injury severity multiplied by injury incidence (Fuller, 2007). Scottish Rugby are also a business in the professional sports market, where financial growth is associated with their teams' competitive achievements (Morgan, 2002; Zhang, Lam, & Connaughton, 2003), yet competitive success can be inhibited by player unavailability through injury (Drew et al, 2017; Williams et al, 2016). Assessment of the incidence, severity, causative factors and aetiology of injury through injury epidemiology studies would allow an understanding of the risks to player welfare and performance potential which injury poses (Bahr et al, 2020; Fuller, 2018b; Fuller & Drawer, 2004; Junge et al, 2008; van Mechelen, Hlobil, & Kemper, 1992). This process of quantifying the injury risks which are present allows governing bodies such as Scottish Rugby to evaluate the magnitude of risk, and how it compares to what is deemed as acceptable (Fuller & Drawer, 2004; Fuller, 2007). With this risk assessment completed, the risks that are present should then be communicated to players and other key stakeholders (Fuller & Drawer, 2004). If the level of risk is perceived as unacceptable, particular high-risk injuries can then be targeted for risk reduction through mitigation strategies (Fuller, Junge & Dvorak, 2012). Armed with the knowledge of the aetiology of injuries from the epidemiology process, those risks which are deemed unacceptable can then be attempted to be reduced (Finch, 2006; Fuller, 2007; Meeuwisse, Tyreman, Hagel, & Emery, 2007; van Mechelen, 1997; van Mechelen et al, 1992). The methodology and efficacy of such interventions should then also be communicated to all stakeholders (Fuller & Drawer, 2004). This entire process of assessing risks through injury epidemiology, attempting risk reduction strategies where appropriate and communicating risks to players and key stakeholders would fulfil Scottish Rugby's duty as an employer as stated in United Kingdom health and safety legislature (Fuller, 1995; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992), as well as improving player availability for selection, potentially resulting in greater chances of team achievement and financial success (Drew et al, 2017; Morgan, 2002; Zhang et al, 2003; Williams et al, 2016).

The most recent injury epidemiology study in rugby in Scotland was completed early after the onset of professionalism for men's professional club rugby (Garraway, Lee, Hutton, Russell, & Macloed, 2000), yet this does not consider the increasing reported concussion incidences seen in the past 10-20 years (Best, McIntosh, & Savage, 2005; Brooks, Fuller, Kemp, & Reddin, 2005a; Cosgrave & Williams, 2019; Fuller, Laborde, Leather, & Molloy, 2008; Fuller, Sheerin, & Targett, 2013; Fuller et al, 2017b; Rafferty et al, 2019; RFU, 2019; RFU, 2020). Concussion epidemiology for other professional cohorts within Scottish Rugby has never been studied. As no contemporary study of concussion epidemiology specifically, or injury epidemiology generally in professional rugby in Scotland exists, Scottish Rugby cannot fulfil its legally bound duty of care towards players. Scottish Rugby therefore also has only a limited understanding of the risks to performance and competitive success which injury poses, and has no understanding of methods to mitigate injury risk (Fuller, 1995; Fuller & Drawer, 2007; Meeuwisse et al, 2007; van Mechelen et al, 1992). An investigation of concussion injury, containing epidemiology and considering potential methods to reduce concussion injury risk is therefore warranted. This will form the basis of the research conducted in this PhD thesis.

1.3: Injury Investigation and Intervention Frameworks

1.3.1: Proposed Models

Several models have been proposed to study injury/illness, presenting investigators/researchers/practitioners with an operationalised pathway to reducing injury/illness risk (Finch, 2006; Fuller & Drawer, 2004; O'Brien, Finch, Pruna, & McCall, 2019; Roe et al, 2017; Tugwell, Bennett, Sackett, & Haynes, 1985; van Mechelen et al, 1992; van Tiggelen, Wickes, Stevens, Roosen, & Witvrouw, 2008). By far the most frequently used of these has been the Sequence of Prevention model proposed by van Mechelen et al (1992) (Emery, Roy, Whittaker, Nettel-Aguirre, & van Mechelen, 2015; O'Brien et al, 2019; Roe et al, 2017). The Sequence of Prevention model is based upon the Measurement Loop model (Tugwell et al, 1985) and the World Health Organisation's Public Health approach to improve health and safety of all individuals (van Vulpen, 1989; WHO, 2002) and is presented in figure 1.3 below.

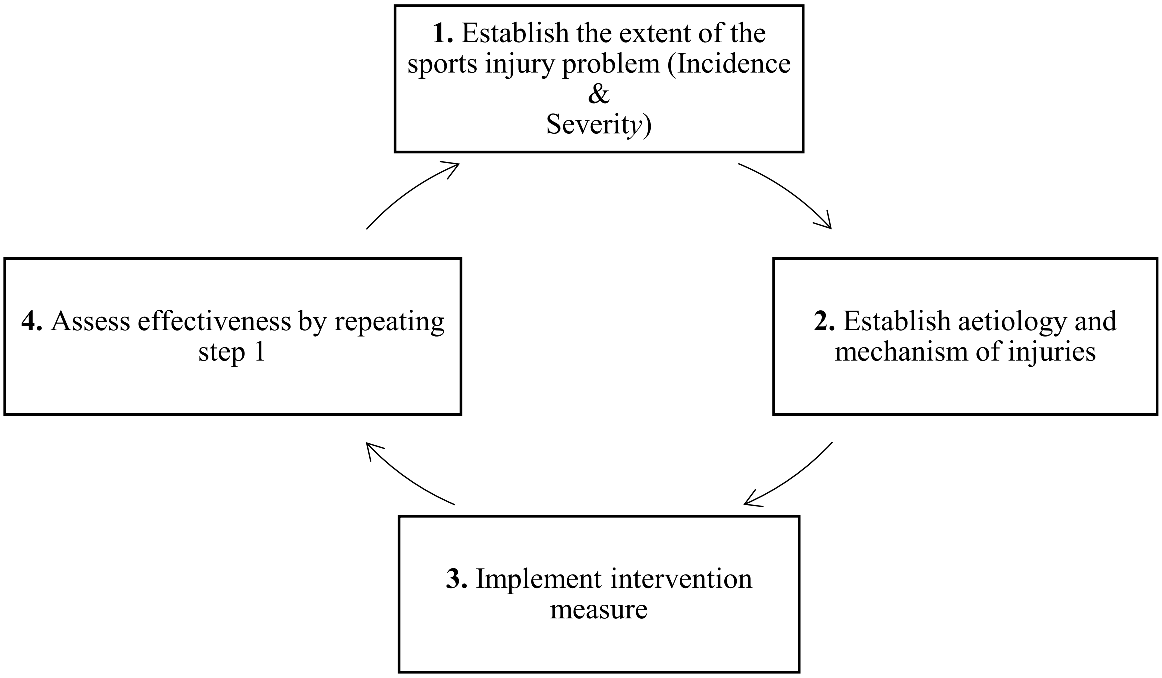

FIGURE 1.3: "The sequence of prevention of sports injuries" (edited from van Mechelen et al, 1992).

As illustrated in figure 1.3, the model states that the incidence and severity of the injury problem must first be identified (usually through prospective epidemiology studies), before the aetiology and/or mechanism of injury/injuries should be identified (van Mechelen et al, 1992). Based on aetiological information gathered in stage two, the third stage is to introduce a measure which is likely to reduce the incidence and/or severity of the injury being studied, with stage four repeating the epidemiological process from stage one to assess the efficacy or effectiveness of the intervention measure which was implemented (van Mechelen et al, 1992).

As recommended when attempting to reduce injury risk, the sequence of prevention model is grounded in and guided by injury epidemiology data (Bahr, Clarsen & Ekstrand, 2018; Bahr et al, 2020; Finch, 2006; Fuller & Drawer, 2004; Lett, Kobusingye & Sethi, 2002; Roe et al, 2017; van Mechelen, 1997) and recommends a continuous, cyclical process to ensure injury surveillance continues after intervention implementation (Tugwell et al, 1985). As a result, the sequence of prevention model has provided a constructive tool to operationalise injury prevention research (Finch, 2006; van Mechelen, 1997). However, despite its wide-spread use in controlled scientific studies, injury risk and/or incidence in sports such as rugby, rugby sevens and football has not decreased in recent years (Fuller, Taylor, & Molloy, 2010b; Fuller et al, 2017c; Fuller, 2018c; Fuller, 2018d; Fuller, 2019; RFU, 2020). Researchers have recently questioned the validity of the sequence of prevention model in ultimately reducing sports injury risk in "real-world" situations (Bekker & Clark, 2016; Bittencourt et al, 2016; Bolling, van Mechelen, Pasman, & Verhagen, 2018; Finch, 2006). Many of these criticisms have focused on the context and complexity of injury occurrence and aetiology, and the context in which resulting interventions are implemented in pragmatic real-world settings (Bahr & Krosshaug, 2005; Bittencourt et al, 2016; Bekker & Clark, 2016; Bolling et al 2018; Finch, 2006).

Injury occurrence and aetiology are complex and context specific, and it is argued that the first two stages of van Mechelen's model do not consider these issues (Bahr & Krosshaug, 2005; Bolling et al, 2018; Fuller & Vassie, 2004). Injury risk must always be placed in a specific context, considering each athlete's intrinsic risk factors (e.g., gender, physical fitness/strength, behaviours, injury history) and the extrinsic risk factors (e.g., specific game events/laws, weather, time of day/season) which are experienced during training/match play (Fuller & Drawer, 2004; Fuller, 2007; Fuller & Vassie, 2004; Meeuwisse, 1994; Meeuwisse et al, 2007). Injury aetiology is therefore likely extremely complex, dependent upon numerous interactions between intrinsic and extrinsic factors (Bolling et al, 2018). Aetiology models such as those proposed by Meeuwisse et al, (2007) and Bittencourt et al (2016) allow consideration for relationships of interaction and confounding between numerous risk factors, allowing for a more valid understanding of the contribution of risk factors to injury probability in specific contexts (Bolling et al, 2018; Bittencourt et al, 2016; Fuller & Drawer, 2004; Meeuwisse et al, 2007; Quatman, Quatman & Hewett, 2009). This increases the likelihood of eventual injury mitigation strategies to be contextualisd to meet the demands of the athlete(s)/injury in question, rather than assuming a generalised approach devoid of context would work for a multitude of scenarios (Bekker & Clarke, 2016; Bolling et al, 2018, Fuller, 2020).

Stages three and four of the sequence of prevention model also do not consider the context in which resulting interventions should be implemented (Bolling et al, 2018). Research into the sporting safety culture, behaviour, and perception of injury risk of the targeted athletes, coaches, support staff and governing bodies will likely provide greater context to how an intervention could best be implemented to achieve a reduction in injury risk (Finch, 2006; Fuller & Drawer, 2004; Fuller, 2007). These stages of the sequence of prevention model also do not consider implementation success beyond a reduction in injury incidence or severity, and do not consider other dimensions which may have impacted upon implementation effectiveness. Glasgow, Vogt, and Boles (1999) created the RE-AIM framework (Reach, Efficacy, Adoption, Implementation, Maintenance), suggesting the effectiveness of an intervention should be assessed by its impact on the five dimensions listed in table 1.1 below.

TABLE 1.1: RE-AIM factors advocated by Glasgow et al (1999) to assess intervention effectiveness.

Dimension	Definition
Reach	Proportion of the target population that participated in the intervention
Efficacy	Success rate of intervention when implemented as intended (positive outcomes minus unintended negative consequences)
Adoption	Proportion of settings that implement the programme as intended
Implementation	Extent to which the intervention is adhered to by individuals and settings once adopted (assessed over first 6-12 months)
Maintenance	Extent to which the intervention is sustained over time by individuals and settings (at least first two years)

Adapted from Glasgow et al (1999).

The dimensions assessed in the RE-AIM framework expand upon basic efficacy monitoring to multiple factors which can impact upon injury risk reduction (Gaglio, Shoup & Glasgow, 2013; Glasgow et al, 1999; Glasgow et al, 2019; O'Brien & Finch, 2014). This allows a more comprehensive evaluation of an intervention, providing explanations for the magnitude of success that the implementation achieves (Gaglio et al, 2013). This can aid in a continuous decision-making process, identifying which components of implementation require alteration to improve the overall impact of an intervention on injury risk (Gaglio et al, 2013; Glasgow et al, 1999; O'Brien & Finch, 2014).

Whilst van Mechelen's sequence of prevention framework provides a solid grounding in injury intervention research, it is clear that the issues of complexity and context need to be considered, as well as how implemented interventions are assessed for impact and effectiveness. The inclusion of these factors are not currently advised in the model in its current form.

Alternative injury models have been proposed to address the pitfalls discussed above in the Sequence of Prevention model. Finch (2006), van Tiggelen et al (2008), and O'Brien et al (2019) have all put forward updated models underpinned by the Sequence of Prevention process. Finch (2006) proposed an additional two stages to the sequence of prevention model to improve comprehension of issues which may provide resistance to intervention uptake in pragmatic real-world situations. The framework entitled "Translating Research into Injury Prevention Practice" (TRIPP) allows for research into potential implementation barriers once an intervention has been shown to be successful under ideal scientific conditions. How this compares with the original sequence of prevention model is shown in table 1.3 below.

TABLE 1.2: Comparison of TRIPP framework (Finch, 2006) with Sequence of Prevention (van Mechelen et al, 1992).

Stage	TRIPP (Finch, 2006)	Sequence of Prevention (van Mechelen et al, 1992)
1	Injury surveillance	Establish the extent of the problem (incidence and severity)
2	Establish aetiology and mechanisms of injury	Establish aetiology and mechanisms of injury
3	Develop preventative measures	Implement intervention measures
4	"Ideal conditions"/scientific evaluation	Assess effectiveness by repeating stage one
5	Describe intervention context to inform implementation strategies	-
6	Evaluate effectiveness of preventative measures in implementation context	-

Adapted from Finch (2006).

Stage five of the TRIPP model aims to improve comprehension of how results of efficacy research from stage four, which will have been carried out under controlled conditions, can be implemented into a real-world sporting context. Comprehension of potential barriers and how these impact motivation or resistance to intervention uptake will provide a greater context to the eventual wide-scale implementation of injury intervention programmes (Bekker & Clark, 2016; Bolling et al, 2018; Finch, 2006). Taking findings from stage four and five, stage six advocates intervention implementation and evaluation of its effectiveness in its intended real-world context (Finch, 2006). Correspondingly, Van Tiggelen et al (2008) suggested elongating the Sequence of Prevention model, incorporating stages which assess intervention efficiency and compliance/behaviours of participants before measuring intervention effectiveness. Similarly, O'Brien et al (2019) advocated a three-stage process of evaluation (understanding the injury situation and the current injury prevention methods), identification (comprehension of injury risk factors and potential barriers to intervention implementation), and intervention (planning and instigating mitigation strategies).

A further alternative model is the Risk Management framework (figure 1.4), which comprises the "Overall process of assessing and controlling risks within an organisational setting and includes the sub-processes of risk assessment and risk mitigation" (Fuller & Drawer, 2004). The framework centres around the concept of risk, defined as "The expected loss in a particular situation within a stated period of time", calculated in injury surveillance research as mean injury severity multiplied by injury incidence (Fuller, 2007). Risk assessment encapsulates stages one, two and three of the model, followed by risk communication in stage four (Fuller & Drawer, 2004).

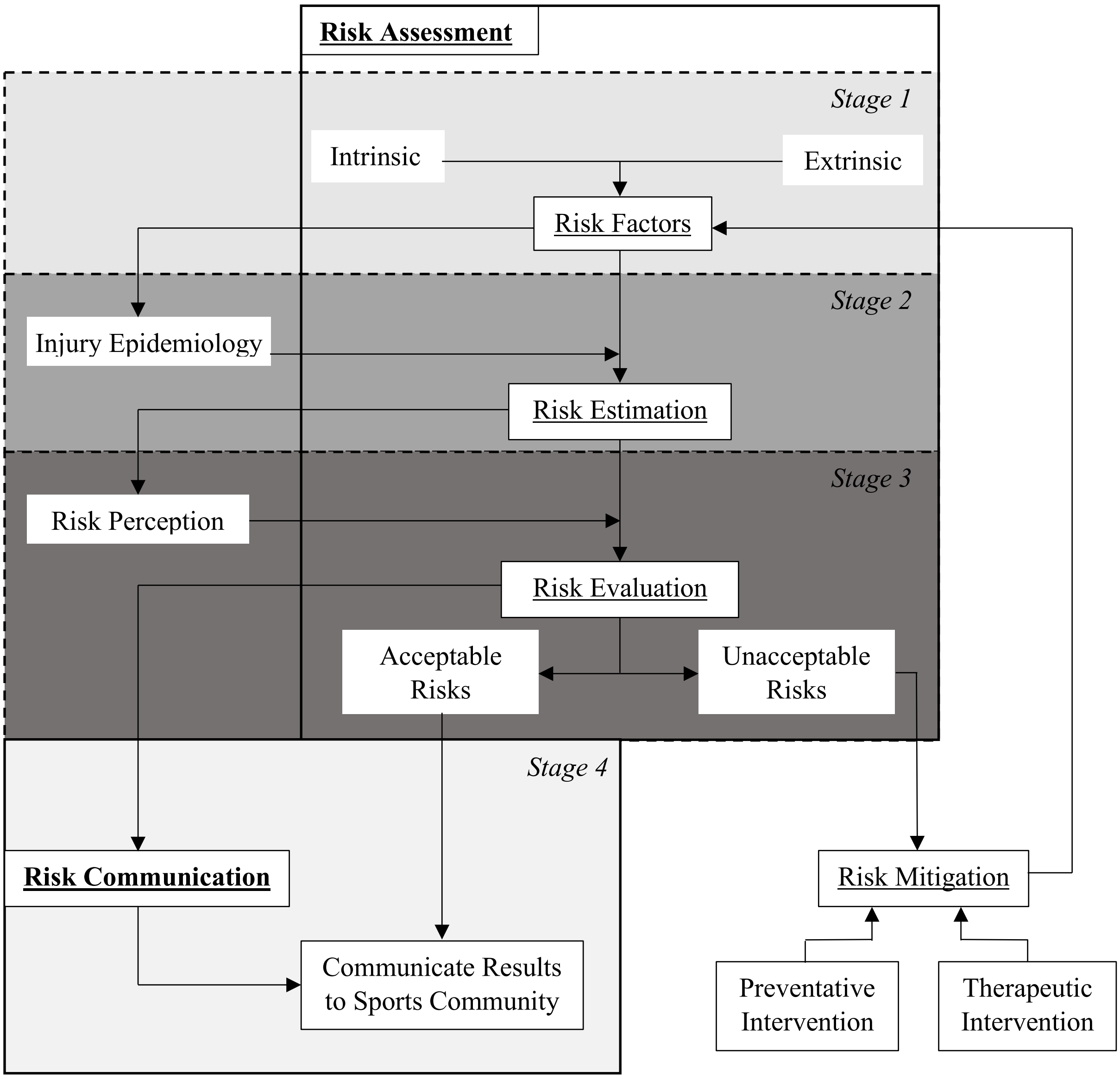

FIGURE 1.4: The Risk Management Framework (Adapted from Fuller & Drawer, 2004; Fuller, 2007; Fuller et al, 2012)

Stage one consists of identification of intrinsic and extrinsic risk factors likely to occur within a particular context, and the consideration of how relationships between risk factors may affect injury risk. No two athletes are ever likely to be placed at the same risk of injury, due to relationships/interactions/confounding between intrinsic risks and the extrinsic risks experienced in the training/competitive environment (Fuller, 2007). It is therefore necessary to consider which intrinsic risks may place particular athletes at a greater risk of injury when extrinsic factors are also considered (Fuller, 2007). Stage two ("risk estimation") assesses injury incidence and severity as a result of interaction of risk factors through injury epidemiology studies, notating injury cause through general biomedical terms (acute/chronic; contact/non-contact) as well as sport specific mechanisms (Fuller, 2007; Fuller, 2020). Stage three of the model ("risk evaluation") is the final stage of the risk assessment process, and determines the significance and acceptability of the quantified risks reported from stage two (Fuller & Drawer, 2004). Risk evaluation is influenced by risk perception and the levels of risk which are deemed acceptable by governing bodies/clubs/sport administrators/players and other stakeholders (Fuller & Drawer, 2004; Fuller, 2020). If risks are deemed acceptable, then the framework progresses to stage four and risk communication, whereby the results of the risk assessment process are shared with key stakeholders. If risks are deemed unacceptable during risk evaluation, then risk mitigation measures are implemented to reduce injury risk ("risk reduction") through either preventative or therapeutic interventions (Fuller et al, 2012). The effectiveness of mitigation strategies are assessed by repeating the risk management process from stage one, with results communicated to key stakeholders at stage four through risk communication (Fuller & Drawer, 2004).

1.3.2: Injury Investigation Framework for the Current PhD Thesis

This PhD research project has the overarching aim of increasing the understanding of concussion in elite rugby in Scotland. Due to the negative short- and long-term implications of concussion injury introduced earlier in this chapter, and the duty of care Scottish Rugby has towards its players, operating injury surveillance and attempting reduction of the incidence of concussion in professional rugby in Scotland are priorities to Scottish Rugby.

The sequence of prevention model has provided a reliable framework for many investigations into sports injury and sports injury prevention (Emery et al, 2015; Myklebust, Mæhlum, Holm & Bahr, 1998; Myklebust et al, 2003; O'Brien et al, 2019; Verhagen & van Mechelen, 2010; Verhagen, van Stralen & van Mechelen, 2010; Wedderkop, Kaltoft, Lundgaard, Rosendahl & Froberg 1997; Wedderkop, Kaltoft, Lundgaard, Rosendahl & Froberg 1999). Yet it is clear that elements of the model require updating to take into consideration the context and complexity of injury aetiology, the context in which injury interventions are implemented into pragmatic real world settings, and how the effectiveness of such interventions are assessed (Bahr & Krosshaug, 2005; Bekker & Clark, 2016; Bittencourt et al, 2016; Bolling et al 2018; Finch, 2006; Fuller, 2020; Fuller & Vassie, 2004; Glasgow et al, 1999). The current PhD research will aim to investigate concussion injury in elite Scottish Rugby by following the sequence of prevention model (van Mechelen et al, 1992), yet with adaptations to address the aforementioned concerns surrounding this model concerning the lack of consideration of context and complexity of injury aetiology, and the context in which interventions are implemented (Bolling et al, 2018; Fuller, 2019; Fuller, 2020; Meeuwisse et al, 2007). Modifications will also be followed due to time constraints placed on data collection throughout this PhD project.

Data collection for the current PhD research project will take place across two full Northern Hemisphere rugby union seasons (2017/18 and 2018/19). During this period, stage one of the Sequence of Prevention model will be followed, and an injury epidemiology study will be undertaken across all professional rugby cohorts in Scotland. Due to the pre-determined path of this research to investigate concussion, a study of concussion risk factors and concussion aetiology to follow stage two of the model will be completed simultaneously, opposed to aetiology investigations being informed by epidemiology results (van Mechelen et al, 1992). This will be a prospective cohort study investigating the effect of each individual's concussion history and the extrinsic risk factors experienced during different contact events on concussion propensity in each contact event type. To ensure the context and complexity of concussion aetiology is considered, the dynamic, recursive model of injury aetiology proposed by Meeuwisse et al (2007) will be followed to investigate concussion occurrence. This model allows consideration of how a predisposed athlete (defined by their intrinsic risk factors) interacts with extrinsic risk factors in the game environment to describe the probability of either injury or continued participation (see section 2.3) (Meeuwisse et al, 2007). In the case of injury, the model proposes either retirement, or rehabilitation followed by return to participation. This recursive model allows for injury history and previous participation to become intrinsic risk factors for future injury (Meeuwisse et al, 2007). Concussion aetiology can therefore be examined in the context of each individual's concussion history, and by extrinsic risk factors in different contact events. Previous research has reported that factors relating to each individual's concussion history may increase their susceptibility towards sustaining a future concussion (Abrahams et al, 2014;

Hollis et al, 2009; McCrory, 2004; Schneider, Meeuwisse, Hank, Schneider, & Emery, 2013), whilst certain extrinsic risks (e.g., speed into contact, body position, impact force, tackle type) have been shown to increase concussion incidence in rugby specific contact events (Cross et al, 2019; Sobue et al, 2017; Suzuki et al, 2019; Tucker et al, 2017a; Tucker et al, 2017b). However, no previous study in professional rugby has investigated the potential interaction of elements of individual concussion histories and extrinsic risks in contact events on concussion propensity in different contact event types. The study undertaken in stage two of the sequence of prevention model in this thesis will therefore attempt to illustrate whether this is the case, in a manner which considers the context and complexity of concussion occurrence (Bolling et al, 2018; Fuller & Vassie, 2004; Fuller, 2020; Meeuwisse et al, 2007).

The sequence of prevention model advocates that modifiable risk factors found from stage two inform potential intervention strategies developed during stage three (van Mechelen et al, 1992). However, due to the time constraints on data collection for this PhD thesis, it is considered impractical to wait on results from stage two to inform potential interventions for stage three. Therefore a pro-active decision has been made to identify a potential modifiable risk factor for concussion through a review of current literature (see section 2.4), and to plan and implement a concussion risk reduction strategy based on this risk factor to follow stages three and four of the sequence of prevention model. According to both the sequence of prevention model and risk management framework, two risk reduction methods are available: preventative interventions aiming to reduce the incidence of injury events; or therapeutic interventions aiming to reduce the severity of injury (Fuller et al, 2012; van Mechelen et al, 1992). Due to the negative short- and long-term implications of sustaining a concussion injury (Abrahams et al, 2014; Bertrand et al, 2016; Cross et al, 2016; de Beaumont, et al, 2007; Decq et al, 2016; Gouttebarge et al, 2017; Hay et al, 2016; Hollis et al, 2009; Hume et al, 2016; Lewis et al, 2017; McGuine, et al, 2014; Nordström et al, 2014), as well the fact that there is currently a standardised concussion rehabilitation protocol (McCrory et al, 2017; see section 2.2), altering which is beyond the realms of this PhD, a preventative measure aiming to reducing concussion incidence appears more practicable in this case.

Several strategies have been proposed to reduce concussion incidence in rugby, such as technique education and use of mouthguards or scrum caps (Emery et al, 2017; Kerr et al, 2018; Provvidenza et al, 2013). However, these have demonstrated no effect in professional rugby settings (Kemp, Hudson, Brooks, & Fuller, 2008; Kerr et al, 2018;

Marshall et al, 2005; McIntosh & McCrory, 2000). Recent studies have begun to investigate the association between enhanced neck strength and reduced concussion incidence. Muscles of the cervical spine are responsible for controlling the acceleration of the head during impulsive loading (Hrysomallis, 2016; Panjabi et al, 1998). In an anticipated collision, stronger neck muscles may stabilise the head and incorporate the torso as the effective mass, reducing head acceleration and concussion incidence (Broglio, Eckner, & Kutcher, 2012; Collins et al, 2014; Eckner, Oh, Joshi, Richardson, & Ashton-Miller, 2014; Mansell, Tierney, Sitler, Swanik, & Stearne, 2005). Neck strength was a statistical predictor of concussion incidence amongst high school athletes, with those that were concussed having 11-22% less neck strength than those who were non-concussed over a two-year period (Collins et al, 2014). Isometric resistance neck training exercises as part of a warm-up routine reduced risk of concussion in school aged (Hislop et al, 2017) and recreational male rugby players (Attwood, Roberts, Trewartha, England, & Stokes, 2017). However, changes in neck strength were not monitored. No study has recorded the effectiveness of a neck training programme aiming to enhance neck function and reduce concussion incidence in elite rugby players. This will form the aim of the study conducted across stages three and four of the sequence of prevention model.

This will be a controlled trial, aiming to provide proof of concept of whether the programme can enhance neck function, and in-turn whether those that complete the programme experience a reduction in concussion incidence. Although not implemented in a pragmatic, real-world setting, trials such as this still form an important step towards wide-scale implementation (Glasgow et al, 1999; Verhagen et al, 2010). To attempt to overcome barriers to implementation, recommendations to improve chances of the necessary behaviour change required for programme adoption by staff and players will be followed (DiClemente, Crosby & Kegler, 2002; Finch, 2006**;** McGlashan & Finch, 2010; Steffen et al, 2010; Verhagen et al, 2010). The rationale of the programme will be clearly explained to staff and players before implementation, with the potential benefits clearly identified (Finch, 2006). All players at each programme location will be participating in the programme, cue-sheets will be provided to be displayed at each programme location, and personal progress and compliance folders will be provided to each player. Staff instigating the programme will attend a workshop event prior to programme commencement to understand how to instruct exercises and the justification for their inclusion. The majority of equipment required will be available in all settings where the programme is to be implemented, whilst any remaining specialist equipment will be provided. These are all factors which are thought to aid in adoption and maintenance of an intervention (Finch, 2006), and it is hoped these considerations of the context in which the programme is to be instigated will aid in its reach, adoption and implementation (Bolling et al, 2018; Glasgow et al, 1999).

If shown to be efficacious, the eventual aim beyond this PhD will be to implement this programme across all professional squads in Scottish Rugby, with Scottish Rugby advised to follow stages five and six of the TRIPP framework to improve chances of a successful implementation (Finch, 2006). Post programme completion, feedback discussion groups will be arranged with medical and performance staff who implemented the programme, alongside other authorities within Scottish Rugby (O'Brien et al, 2019). Potential programme improvements, noted barriers to programme uptake and behaviour/attitude of players and coaching staff towards the programme will be discussed (Finch, 2006). However, it is recognised that this is not formal research, and Scottish Rugby will be recommended to follow its own research into stage five and stage six of the TRIPP framework, with final implementation in stage six monitored by RE-AIM principles (Finch, 2006; Glasgow et al, 1999). It is hoped this will result in an effective concussion injury intervention programme which has a high chance of being implemented and adopted on a wide scale throughout Scottish Rugby in the future.

1.4: Study-by-Study Research Aims

The studies in the current PhD project will be instigated as listed below.

Sequence of Prevention Stage One – Injury Epidemiology

The first step of van Mechelen's sequence of prevention model advises an injury epidemiology study to determine the magnitude of injury incidence and severity. Scottish Rugby also have a duty of care to perform health surveillance and to identify hazards to player welfare under several acts of United Kingdom legislation (Fuller, 1995; HSE, 2001; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992). A full injury epidemiology study and a specific concussion injury epidemiology study will be conducted. The first research aims of this thesis are therefore as follows:

i) Undertake a detailed epidemiological study of match and training injuries sustained by professional Scottish Rugby cohorts across the 2017/18 and 2018/19 seasons.

ii) Establish incidence, severity, and burden of concussion and undertake a detailed analysis of concussion injuries sustained during the 2017/18 and 2018/19 seasons.

Research objectives for this study are as follows:

a) Identify incidence, severity, burden, cause, mechanism, type and location of all injuries within professional rugby in Scotland.

b) Demonstrate the incidence, severity and burden of concussion in relation to other injuries.

c) Describe cause and mechanism of concussion within professional rugby in Scotland.

Sequence of Prevention Stage Two – Concussion Risk Factors and Aetiology

The second stage of the sequence of prevention model suggests that aetiology and mechanism of injury need to be understood (van Mechelen et al, 1992). In order to improve the validity of investigation, concussion aetiology must be examined in context, and by a method which considers the complexity of injury occurrence (Bolling et al, 2018; Bittencourt et al, 2016; Fuller & Vassie, 2004; Fuller & Drawer, 2004; Meeuwisse, 1994; Meeuwisse et al, 2007). A prospective cohort study will investigate risk factors for concussion in Scottish men's professional rugby during the 2017/18 and 2018/19 seasons. Concussion aetiology will be assumed to follow the dynamic, recursive model of injury aetiology proposed by Meeuwisse et al (2007), allowing the interaction of various intrinsic (elements of concussion history) and extrinsic risk factors around different contact events (e.g., speed into contact, body position, impact force). This study will therefore examine concussion occurrence in the context of the included risk factors, attempting to demonstrate any potential interaction of intrinsic and extrinsic risk factors on concussion propensity in different contact events, allowing for the complex aetiology of concussion to be considered.

The third research aim for this thesis is therefore as follows:

iii) Identify intrinsic (concussion history elements) and extrinsic (contact event specific) risk factors for concussion within professional Scottish rugby, and to demonstrate whether any interaction effect exists when intrinsic concussion history and extrinsic contact event specific risk factors are studied simultaneously.

Research objectives for this study are as follows:

a) Assess the effect intrinsic factors relating to concussion history have on concussion incidence.
b) Assess the effect extrinsic factors during match play have on concussion propensity in different contact types.
c) Demonstrate the effect on concussion outcome of any interaction between different intrinsic concussion history and extrinsic contact event specific risk factors in two contact event types.

Sequence of Prevention Stage Three and Four – Concussion Prevention

As described above, the study implemented here will not follow from modifiable risk factors identified from stage two of the sequence of prevention model. Based on a review of current concussion prevention literature, a pro-active decision has been taken to implement a neck training programme as a concussion prevention measure in Scottish Rugby academy players.

The fourth research aim for the current thesis is as follows:

iv) Assess the efficacy of a neck training programme aiming to enhance neck function and reduce match concussion incidence.

Research objectives for this study are as follows:

a) Investigate whether a neck training programme can improve neck function in elite rugby players.
b) Find whether those that complete the training programme reduce their match concussion incidence in comparison to a control group.

1.5: Chapter Layout:

Table 1.3 presents the layout of chapters in this thesis to meet the research aims listed above.

TABLE 1.3: Chapter layout for the current thesis

Chapter	Research Aim(s)	Objective(s)	Model Stage
Two	Review relevant literature		-
Three (A)	**i)** Undertake a detailed epidemiological study of match and training injuries sustained by professional Scottish Rugby cohorts across the 2017/18 and 2018/19 seasons.	*a)* Identify incidence, severity, burden, cause, mechanism, type and location of all injuries within professional rugby in Scotland *b)* Demonstrate the incidence, severity and burden of concussion in relation to other injuries	One
Three (B)	**ii)** Establish incidence, severity, and burden of concussion and undertake a detailed analysis of concussion injuries sustained during the 2017/18 and 2018/19 seasons.	*c)* Describe cause and mechanism of concussion within professional rugby in Scotland	
Four	**iii)** Identify intrinsic (concussion history elements) and extrinsic (contact event specific) risk factors for concussion within professional Scottish rugby, and to demonstrate whether any interaction effect exists when intrinsic concussion history and extrinsic contact event specific risk factors are studied simultaneously.	*a)* Assess the effect intrinsic factors relating to concussion history have on concussion incidence. *b)* Assess the effect extrinsic factors during match play have on concussion propensity in different contact types . *c)* Demonstrate the effect on concussion outcome of any interaction between different intrinsic concussion history and extrinsic contact event specific risk factors in two contact event types.	Two
Five	**iv)** Assess the efficacy of a neck training programme aiming to enhance neck function and reduce match concussion incidence.	*a)* Investigate whether a neck training programme can improve neck function in elite rugby players *b)* Find whether those that complete the training programme reduce their match concussion incidence in comparison to a control group	Three and Four
Six	Conclude thesis findings		-

1.6: Summary

Concussion epidemiology is unknown for professional rugby in Scotland. Due to the negative short- and long-term implications of concussion injury and the duty of care Scottish Rugby has towards its players, identifying and quantifying the concussion risk, and reducing the incidence of concussion in professional rugby in Scotland is of a priority to Scottish Rugby. The current thesis will apply van Mechelen's framework "The sequence of prevention of sports injuries" (van Mechelen et al, 1992) to investigate concussion in professional rugby in Scotland. In order to ensure pitfalls in the model around context and complexity of injury aetiology and intervention implementation are addressed, a multifactorial model of injury aetiology will be used to assess concussion risk factors (Meeuwisse et al, 2007), and strategies to improve probability of intervention uptake will be integrated as necessary (Finch, 2006; DiClemente et al, 2004; McGlashan & Finch, 2010; Steffen et al, 2010; Verhagen et al, 2010). Studies will report the magnitude of concussion incidence, severity and burden in comparison to all other injuries, causative factors of concussion, investigate the effect of intrinsic (concussion history) and extrinsic (game events) concussion risk factors on concussion aetiology, and establish the effectiveness of a preventative measure to reduce concussion incidence by enhancing neck function.

END OF CHAPTER ONE

CHAPTER TWO: LITERATURE REVIEW

2.1: Introduction

The model "The sequence of prevention of sports injuries" (van Mechelen et al, 1992) provides a framework for this thesis. Research aims were laid out in chapter one in-line with steps in the framework model. The current chapter will review the pertinent literature around each research aim and follow three sections:

- Injury and concussion epidemiology in professional rugby (step one of model)
- Concussion risk factors (step two of model)
- Concussion prevention methods (step three of model)

Online academic databases (e.g., Google Scholar, PubMed) were searched with relevant terms, and reference lists of pertinent papers found were examined for additional articles which were not highlighted during the initial search.

2.2: Injury and Concussion Epidemiology in Professional Rugby (Stage One of Model)

2.2.1: Sports Injury Surveillance

Injuries occur when mechanical energy is transferred to body tissues at a greater rate or magnitude than the accepted threshold for body tissue damage (Meeuwisse et al, 2007). In order to be able to compare injury rates across different research studies, a universally accepted definition for injury is required (Bahr et al, 2020; Finch, 1997). Previous injury epidemiology studies have used definitions such as admissions to medical facilities, insurance claims, or time-loss from planned training or competition (Brooks et al, 2005a; Cumps, Verhagen, Annemans, & Meeusen, 2003; Fuller & Drawer, 2004; Maehlum & Daljord, 1984). Different definitions can result in differing conclusions drawn on the magnitude of the injury situation between studies (Kluitenberg et al, 2016). Van Mechelen et al (1992) stated an athlete remains injured if they cannot participate in training/competition that is scheduled, referring to a "time-loss" definition of injury (Bahr et al 2020). This is similar to the definition advised by research consensus statements for both rugby and soccer (Fuller et al, 2006; Fuller et al, 2007d).

There are numerous ways injury data may be reported. It is possible to report injury data as an absolute number, or as a statement of number of injuries per participants (de Loës, 1997). However, these methods do not take into account an element of rate, preventing full explanation of injury incidence (Bahr et al, 2020). In order to provide an accurate epidemiological study and fully describe the incidence of injury, exposure data to the activity in question must be included (Bahr et al, 2020; de Loës, 1997; Junge et al, 2008). Exposure data may be recorded as athlete-exposures or per unit of time (Junge et. al, 2008). Exposure expressed as a unit of time (often 1000 hours for match or training), especially in team sports where the duration of an event and the number of participants is constant, is often preferred (Bahr et al, 2020; Junge et al, 2008).

2.2.2: Injury and Concussion Epidemiology in Contact Sport

Contact sports have previously reported a greater incidence of match injury than non-contact sport (Hootman et al, 2007). Using an injury definition of time-loss from training activities and/or competition, non-contact sports have reported low injury incidences of 7.1 (men's international cricket) and 3.8/1000 player match hours (men's, women's, and junior international volleyball) (Bere et al, 2015; Ranson et al, 2013), whilst semi-contact sports such as soccer have reported an injury incidence of 29.3/1000 player match hours (men's international) (Junge & Dvořák, 2015). Using identical injury definitions, contact sports have reported match injury incidences of 52.1 (men's international ice hockey) and 78/1000 player match hours (men's professional rugby league) (Fitzpatrick, Naylor, Myler, & Robertson, 2018; Tuominen et al, 2015). Recent studies have found match injury incidences of 79.4 - 109.7/1000 player match hours for men's international, men's professional club rugby, and men's and women's international rugby sevens (Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller, Taylor, Douglas, & Raftery, 2020; RFU, 2019). It appears even amongst other full contact sports rugby presents with a greater incidence of injury.

It has been reported that rugby also has one of the highest incidences of match concussion when compared to other team sports. Recent studies in rugby have reported concussion incidences of 17.8-27.8/1000 player match hours across men's international rugby, men's professional club rugby, and men's and women's international rugby sevens (Cosgrave & Williams, 2019; Fuller et al, 2017c; Rafferty et al, 2019; RFU, 2019; RFU, 2020). Previous literature has found concussion incidences of 0.4 - 2.0 (men's and women's elite soccer), 3.4 - 5.2 (men's and women's professional ice hockey) and 6.1 - 7.1/1000 player match hours (men's and women's professional rugby league) (Junge &

Dvořák, 2007; Junge & Dvořák, 2015; King, Hume, Gissane, & Clark, 2017; King & Gabbett, 2007; Nilsson, Hägglund, Ekstrand, & Waldén, 2013; Tuominen et al, 2015; Tuominen et al, 2016). Frequent, open skilled contact events with large impact forces may contribute to a greater concussion incidence in rugby compared with other sports (Burger et al, 2016; Davidow et al, 2018; Fuller, Brooks, Cancea, Hall, & Kemp, 2007b; Hendricks, Karpul, & Lambert, 2014a; Seminati, Cazzola, Preatoni, & Trewartha, 2017). The larger concussion incidences reported in rugby reaffirm the need for accurate understanding of the probability of concussion occurrence, and implementation of methods to attempt to reduce concussion incidence.

2.2.3: Concussion Physiology

Concussion is caused by a biomechanical force which results in rapid acceleration or deceleration of the head and brain (McCrory et al, 2017; Zhang et al, 2004). A 66, 82, and 106 *g* resultant linear acceleration of the centre of mass of the head, or a 4.6×10^3, 5.9×10^3, and 7.9×10^3 rad·s^2 rotational acceleration would result in a 25, 50, or 80% chance respectively of sustaining a concussion (Zhang et al, 2004). However, there is substantial interindividual variability in the acceleration required to sustain a concussion (Kutcher & Eckner, 2010), likely dependent upon different intrinsic risk factors such as history of recent concussion, gender and genetic polymorphisms altering the threshold for concussion injury (Hollis et al, 2009; Mc Fie & September, 2019; Tierney et al, 2005) (see section 2.3 for greater discussion).

The energy transferred to the brain causes both focal lesions (either at the *coup* or collateral *contrecoup* site) due to linear acceleration of the brain, and diffuse lesions throughout the brain due to rotational acceleration (Hardy et al, 1994; King et al, 2003). Resulting structural damage to cellular membranes of axons results in microtubule disruption and neuronal apoptosis, whilst microglial cells respond to axonal damage by causing substantial inflammation, risking further damage to other cellular structures (Dashnaw et al, 2012; Giza & Hovda, 2014; King et al, 2003; Pabian et al, 2016). Axonal damage may result in a reduced ability to regulate $Na^+/K^+/Ca^{2+}$ flux, leading to glutamate release and membrane depolarisation (Barret, McBurney, & Ciappio, 2014). To mitigate this, Na^+/K^+ pumps are activated which requires a substantial provision of ATP (Barkhoudarian et al, 2011). Under normal conditions ATP can comfortably be resynthesised by aerobic means (Barkhoudarian et al, 2011). However, concussive impacts also result in a reduction in cerebral oxygenation, due to impaired cerebral blood flow and disrupted oxidative metabolism due to influx of Ca^{2+} into the mitochondria

(Maugans, Farley, Altaye, Leach, & Cecil, 2012; Pabian et al, 2016). Resynthesis of ATP for Na^+/K^+ pumps must therefore rely on glycolytic pathways, resulting in increased oxidative stress and excessive accumulation of hydrogen ions and inorganic phosphate (Barrett et al, 2014; Sikoglu et al, 2015). Once all available glycogen has been used, the brain enters into a hypometabolic state, during which time it is believed it is especially susceptible to further injury (Barkhoudrian et al, 2011).

The damage caused to the brain during a concussion injury may result in reduced neural transmission and impaired cognitive function (Giza & Hovda, 2014). This may cause symptoms which evolve immediately and/or across the next few hours such as headache, confusion, ataxia, loss of consciousness, vomiting, amnesia, dizziness and/or personality changes (Lau et al, 2011). Effects lasting from days to weeks may include persistent headaches, sleep disturbances, reduced concentration/awareness/attention, memory dysfunction and irritability (Barkhoudrian et al, 2011). Presence of these symptoms are used to diagnose concussion in professional rugby (see information on the head injury assessment below).

2.2.4: Concussion Diagnosis and Management in Professional Rugby

The head injury assessment (HIA) protocol was introduced by World Rugby in 2011/12, and is now used throughout all professional matches sanctioned by World Rugby (Fuller et al, 2017a; Fuller et al, 2015b; Raftery et al, 2016; World Rugby, 2019b). It is a three-stage process, with assessments conducted pitch-side immediately after the suspected concussive incident (HIA 1), 2-3 hours post incident (HIA 2), and 48 hours post incident (HIA 3) (Raftery et al, 2016; World Rugby, 2019b). The HIA protocol is based upon the Sports Concussion Assessment Tool, allowing assessments to be compared to a baseline assessment performed on each player during the off-season (Raftery et al, 2016; World Rugby, 2019b). Concussion is diagnosed if a player is identified to have demonstrated criteria for immediate removal from play (HIA 1; see table 2.1), or a clinical diagnosis is made during HIA 2 or HIA 3 (World Rugby. 2019b). Pitch-side evaluation and the video review system of HIA 1 for identifying concussion presents sensitivity and specificity values of 77.5-84.6% and 74% respectively (Fuller et al, 2015b; Fuller, Kemp, & Raftery, 2017d). Examples of blank HIA 1, 2, and 3 assessment forms are provided in appendix one.

TABLE 2.1: Criteria for immediate and permanent removal from play (HIA 1)

Concussion Signs and Symptoms	
Confirmed loss of consciousness	Suspected loss of consciousness
Convulsion	Tonic posturing
Ataxia	Clearly dazed
Not orientated in time, place, or person	Definite confusion
Definite behavioural change	Oculomotor signs

Adapted from Raftery et al (2016)

Since the first concussion consensus group meeting in 2001, a six-stage stepwise return to play protocol has been advised following concussion injury, with 24 hours designated for each stage (Aubry et al, 2002). This advice has been continued through to the most recent concussion consensus meeting and is endorsed by World Rugby (McCrory et al, 2017; World Rugby, 2017b). Players must initially experience 24 hours at rest with no concussion symptoms. They may then progress to non-exercise daily activity, followed by light aerobic exercise, sport specific exercise, non-contact training drills, and full contact training before return to full competition and training (table 2.2) (McCrory et al, 2017; World Rugby, 2017b). Each step should take 24 hours. If a player experiences recurrence of concussion symptoms at any stage, they should rest for 24 hours, before returning to their previous asymptomatic level, and attempt to progress again (McCrory et al, 2017; World Rugby, 2017b). As a result, minimum concussion severity in rugby should be six days.

TABLE 2.2: Stepwise return to sport progression

Stage	Aim	Activity	Goal
1	Symptom-limited activity	Daily activities	Reintroduction of daily activity
2	Light aerobic exercise	Walking or stationary cycling	Increase heart rate
3	Sport-specific exercise	Running drills	Add movement
4	Non-contact training drills	Skill drills and resistance training	Exercise and co-ordination
5	Full contact practice	A full contact training session/drill	Restore confidence
6	Return to competition/full training	Normal game play/training	

Adapted from McCrory et al (2017).

2.2.5: Match Play Injury & Concussion Epidemiology in Professional Rugby

The first two research aims of this thesis are concerned with injury and concussion epidemiology in male and female professional rugby and rugby sevens in Scotland. The cohorts which are under observation for epidemiology are demonstrated in table 2.3 below.

TABLE 2.3: Professional cohorts in Scotland participating in epidemiology research

Professional Cohorts in Scotland	
Men's International Rugby	Men's International Rugby Sevens
Women's International Rugby	Women's International Rugby Sevens
Men's Professional Club Rugby (Edinburgh Rugby and Glasgow Warriors)	

When reviewing previous literature, only studies involving professional cohorts will be considered. Where professionalism is ambiguous (for women's rugby and women's rugby sevens) only previous studies investigating international cohorts will be reviewed. Match and training injuries will be treated separately. Studies where match and training injuries are analysed collectively (i.e. Doyle & George, 2004) are not included in this review.

Injury Incidence, Severity, and Burden

Injury incidences from all teams at the Men's Rugby World Cups in 2007, 2011, 2015 and 2019 have been reported between 79.4 - 90.1/1000 player match hours (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller, et al, 2020). By comparison, injury incidences from the Women's Rugby World Cups of 2006, 2010, 2014 and 2017 are greatly reduced compared with the men's tournaments, with values of 35.5 - 53.3/1000 player match hours (Fuller & Taylor, 2014; Fuller & Taylor, 2017; Schick, Molloy, & Wiley, 2008; Taylor, Fuller, & Molloy, 2011). In comparison with men's international rugby, women's international rugby has taken longer to embrace professionalism, with the game essentially remaining amateur until an increase in professional programmes in some countries the past decade (Donnelly, 2018; Kessel, 2015). Men's rugby reported a large increase in reported injury incidence as professionalism was introduced (Bathgate, Best, Craig, & Jamieson, 2002; Garraway et al, 2000). It is possible that as professionalism in women's international rugby has increased the past ten years, an increase in reported injury incidence will also have occurred. Contemporary injury surveillance studies in women's international rugby are required to confirm this.

Previous injury surveillance studies in men's professional club rugby across multiple cohorts have found injury incidences ranging from 62 - 103/1000 hours (Brooks et al, 2005a; Fuller, Raftery, Readhead, Targett, & Molloy, 2009; RFU, 2019; RFU, 2020; Schwellnus et al, 2018; Starling et al, 2018; Starling et al, 2019; Starling, et al, 2020; Whitehouse, Orr, Fitzgerald, Harries, & McLellan, 2016; West et al, 2020). Across all teams in the Men's Sevens World Series in 2008/09 and 2010/11-2018/19, the men's 2009 World Cup Sevens, and men's international rugby sevens at the 2016 Rio Olympic Games, injury incidences of 106.2 - 124.5/1000 hours were reported (Fuller et al, 2010b; Fuller et al, 2017c; Fuller & Taylor, 2020b). All countries participating in the Women's Sevens World Series from 2012/13-2019/20 and women's international rugby sevens at the Rio 2016 Olympic Games reported injury incidences of 71.1 - 109.4/1000 hours (Fuller et al, 2017c; Fuller & Taylor, 2020a). When comparing international rugby sevens to international rugby, injury incidences for both men and women appear greater in rugby sevens. Greater volumes of high intensity running have been reported in rugby sevens compared with rugby (Higham et al, 2012; Ross et al, 2014), as well as greater proportion of match time with the ball in play (Quarrie et al, 2013; Read et al, 2018; Williams et al, 2005; World Rugby, 2015a). Greater proportion of ball in play time in rugby sevens may provide greater opportunity for injury, as well as potentially resulting in greater player fatigue, which may be a risk factor for increased injury incidence (Fuller, Taylor, Raftery, 2016).

All of the injury surveillance studies referenced in the previous two paragraphs utilise a multiple cohort methodology, requiring numerous medical teams to collate their respective injury data and transfer it to researchers for analysis. Reliable and valid data from these studies rely on two main factors: all medical staff from each team/nation are equally diligent at diagnosing injuries; and that all medical staff across the different teams are equally assiduous at reporting injury. Moore, Ranson and Mathema (2015) suggested that single cohort studies, where injury recognition, diagnosis and reporting is performed by a single medical team may provide a more accurate assessment of injury incidence. Brooks, Fuller, Kemp and Reddin (2005c) undertook an injury surveillance study of the England men's national team during the 2002/03 season and the 2003 Rugby World Cup, with injury incidence reported as 218/1000 hours. Injury incidence was found as

180/1000 hours for the Welsh men's international team from 2011 - 2014 (Moore et al, 2015). Injury incidence amongst the English women's national team in 2017/18 and 2018/19 seasons was found at 146 and 92/1000 player match hours (Rugby Safe, 2019; Rugby Safe, 2020). Gabb, Trewartha, Kemp and Stokes (2014) reported an injury incidence of 187/1000 hours for the English women's international rugby sevens squad in 2013. Single cohort studies appear to find greater injury incidences when compared with multiple cohort studies. Due to more consistent recognition, diagnosis and reporting of injury, single cohort studies may provide a greater validity to injury surveillance data.

However, it is also important to consider the variation possible in injury incidence from season-to-season or team-to-team. The injury incidence recorded in the England men's international team from the 2002/03 to 2017/18 season has a mean injury incidence of 127/1000 player match hours, yet with a range of 62 – 221/1000 player match hours (RFU, 2019). Moore et al (2015) reported an injury incidence of 180/1000 player match hours, yet this ranged from 178.6 – 262.5/1000 player match hours depending on the different tournaments where data was collected. Results from single cohort studies are also likely to be accompanied by wider confidence intervals when compared with multiple cohort studies, due to the smaller sample size of injuries available for analysis. It is also necessary to consider the purpose of single compared with multiple cohort studies. Single cohort studies will reflect the probability of injury from the way a particular team plays. Whilst this offers useful assessment of the resultant hazards present to that team and is therefore important for national governing bodies, it does not necessarily reflect the sport as a whole, or provide useful data for international governing bodies. Multiple cohort studies tend to reflect injury incidence across the game as a whole, taking into consideration different playing styles and team-to-team variation in injury incidence, allowing international governing bodies to assess the probability of injury across the sport as a whole. This is an important point to consider for the current thesis, as research will be conducted on a single cohort basis and will reflect the injury incidence for Scottish Rugby professional teams only.

Injury severity is quantified as "The number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection" (Fuller et al, 2007d). Previous studies have found men's international rugby to report injury severities of 14.7 - 30.0 (mean) and 6.0 - 8.0 days (median) (Brooks et al, 2005c; Fuller et al, 2008; Fuller et al, 2009; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Moore et al, 2015; RFU, 2020). Men's professional club rugby has reported injury severities of 13.0 - 37.5 (mean) and 4.0 - 14.0 days (median) (Brooks et al, 2005a; RFU, 2019; RFU, 2020; Starling et al, 2018; Starling et al, 2019; Starling et al, 2020; West et al, 2020; Whitehouse et al, 2016). Injury severity from the last three Women's Rugby World Cups has been reported at 40.9 – 55.0 (mean) and 7.0 – 9.0 (median) (Fuller & Taylor, 2014; Fuller & Taylor 2017; Taylor et al, 2011), whilst lower mean (14 – 31 days) and greater median (11 – 20 days) severities have been reported from the English women's national team for the 2017/18 and 2018/19 seasons (Rugby Safe 2019; Rugby Safe 2020). Although important to consider the likely smaller sample size from the English women's national team compared to World Cup studies, these differences may be explained by differences in reporting methods between single and multiple cohort studies.

Previous literature has suggested that injury severity for men's and women's international rugby sevens is greater than that reported for men's and women's international rugby. Mean injury severity has been reported as 39.0 - 86.0 (men) and 34.0 - 92.0 days (women) for international rugby sevens (Fuller et al, 2010b; Fuller et al, 2017c; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Gabb et al, 2014). Median severity has been reported as 21.0 - 40.0 (men) and 30.0 - 42.0 days (women) (Fuller et al, 2010b; Fuller et al, 2017c; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b). Greater relative intensity and running speed experienced by rugby sevens players (Higham et al, 2012), resulting in higher impact contact situations may cause injuries of a greater severity, requiring longer rehabilitation. There may also be an element of type I error – international rugby sevens tournaments are not played every week, and there may be a two–three week break between tournaments. There is therefore less pressure to rush players through rehabilitation protocols, allowing medical staff to conduct a longer rehabilitation phase on some injuries (Fuller et al, 2010b). This would artificially increase injury severity.

Mean injury severity appears to be increasing over time in both men's international and men's professional club rugby, yet this does not appear to be occurring in other formats (Fuller et al, 2020a; Fuller & Taylor, 2014; Fuller & Taylor, 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Taylor et al, 2011; West et al, 2020). This rise in severity appears to be accounted for by an increase in the number of more severe injuries in men's professional rugby (Fuller et al, 2020a; West et al, 2020), yet it is unclear whether this is due to more conservative rehabilitation protocols or a true increase in the severity of injury (West et al, 2020).

Injury burden is the term used in epidemiological studies to express risk, defined (as discussed in chapter one) as the expected loss within a period of time, and is quantified in epidemiological studies as incidence multiplied by severity, and expressed as days absence per 1000 hours (Fuller, 2007; Fuller, 2018b). Injury burden can provide governing bodies with a greater understanding of the injury situation and risk to player welfare and availability (Fuller, 2018b; Fuller, 2019; Fuller, 2020).

Injury burden reported from the previous four Men's Rugby World Cups have ranged from 1,233.3 – 2,685.0 days absence/1000 player match hours (Fuller et al, 2008; Fuller et al, 2009; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a), whilst Moore et al (2015) reported an injury burden of 3,240 days absence/1000 player match hours from the Welsh men's international squad from 2011-2014. From 2002/03 to 2018/19 seasons, the injury burden reported for the English men's international team has ranged from 813 – 4,264 days absence/1000 player match hours with a mean of 2,408 (RFU, 2020). The previous three Women's Rugby World Cups have resulted in burdens of 1,864.8 – 2,180.0 days absence/1000 player match hours (Fuller & Taylor, 2014; Fuller & Taylor 2017; Taylor et al, 2011), whilst the England women's international squad have reported injury burdens of 2,046 and 2,842 days absence/1000 player match hours from the 2017/18 and 2018/19 seasons (Rugby Safe, 2019; Rugby Safe, 2020).

Injury burden from English Premiership clubs from the 2002/03 to 2018/19 season has ranged from 1,556 – 3,479 days absence/1000 player match hours (Brooks et al, 2005a; RFU, 2020), with a mean of 2,178 days absence/1000 hours over the whole duration (West et al, 2020). Injury burden has statistically increased over this time frame, potentially due to the simultaneous increase in injury severity (West et al, 2020). Injury burden in other men's professional club rugby cohorts has been found to range from 1,222 – 2,629 days absence/1000 player match hours (Fuller et al, 2009; Starling et al, 2018; Starling et al, 2019; Starling et al, 2020; Whitehouse et al, 2016).

Across all teams in the Men's Sevens World Series in 2008/09 and 2010/11-2018/19, mean injury burden was reported as 5,263 days absence/1000 player match hours (Fuller & Taylor, 2020b). Similarly high values have been reported for teams in the Women's Sevens World Series, with a mean injury burden reported as 5,640/1000 player match hours from the 2012/13-2019/20 seasons (Fuller & Taylor, 2020a). Injury burden for the English women's international rugby sevens squad during the 2013 World Cup season was reported as 6,171 days absence/1000 player match hours (Gabb et al, 2014). Reported match injury burden values for men's and women's international rugby sevens are substantially greater than that recorded in men's and women's international rugby, as would be expected due to the greater injury incidence and severity reported (Fuller et al, 2008; Fuller et al, 2009; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a).

Injury Location and Type

Previous studies across professional rugby and rugby sevens cohorts have reported that injuries to the lower limb are the most common, with proportions of 38 - 70% of all match injuries (Brooks et al, 2005a; Fuller et al, 2008; Fuller et al, 2010b; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2014; Fuller & Taylor 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a; Gabb, Trewartha, & Stokes, 2017; Holtzhausen, Schwellnus, Jakoet, & Pretorius, 2006; Moore et al, 2015; RFU, 2019; Rugby Safe, 2019; Rugby Safe 2020; Schwellnus et al, 2018; Starling et al, 2018; Starling et al, 2019; Starling et al, 2020; Taylor et al, 2011; West et al, 2020). Muscle and tendon injuries (24.8 - 50.0%), or joint (non-bone) and ligament injuries (24.8 - 62.4%) appear the most common across professional rugby and rugby sevens cohorts (Brooks et al, 2005a; Fuller et al, 2008; Fuller et al, 2010b; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2014; Fuller & Taylor 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a; Gabb et al, 2017; Holtzhausen et al, 2006; Moore et al, 2015; RFU, 2019; Schwellnus et al, 2018; Taylor et al, 2011).

Injury Cause and Mechanism

Previous literature across all professional rugby and rugby sevens cohorts have identified contact with another player as the primary cause of match injury (66.6 - 96.2% of all injuries) (Brooks et al, 2005a; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2014; Fuller & Taylor 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a; RFU, 2019; Taylor et al, 2011). Within contact mechanisms, the tackle situation (being tackled and tackling) appears responsible for the greatest proportion of injuries (5.1 – 49.0% of all injuries) (Brooks et al, 2005a; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2014; Fuller & Taylor 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a; RFU, 2019; Rugby Safe, 2019; Rugby Safe 2020; Schick et al, 2008; Starling et al, 2018; Starling et al, 2019; Starling et al, 2020; Taylor et al, 2011; West et al, 2020). Being tackled and tackling are open skills and their unpredictability may contribute to the probability of injury (Burger et al, 2016), alongside the large impact forces which may occur between players (Hendricks et al, 2014a; Seminati et al, 2017). Although collisions and scrums appear to have a greater injury propensity, the tackle is the contact event which happens most frequently within matches (Fuller et al, 2007b). This may contribute to the large proportion of injuries sustained whilst tackling or being tackled.

Concussion Incidence, Severity, and Burden

The past 10-15 years have seen a changing profile in the most common pathologies diagnosed in professional rugby, in particular a change in frequency of concussion diagnosis. Figure 2.1 presents rising concussion incidences reported in previous literature from 1999 to 2019. A maximum concussion incidence of 27.8/1000 player match hours was found in Irish men's international rugby in 2016/17 (Cosgrave & Williams, 2019). This is in comparison with concussion incidence in three teams in the 1999 Super 12 competition, where reported concussion incidence was 1.4/1000 hours (Holtzhausen et al, 2006).

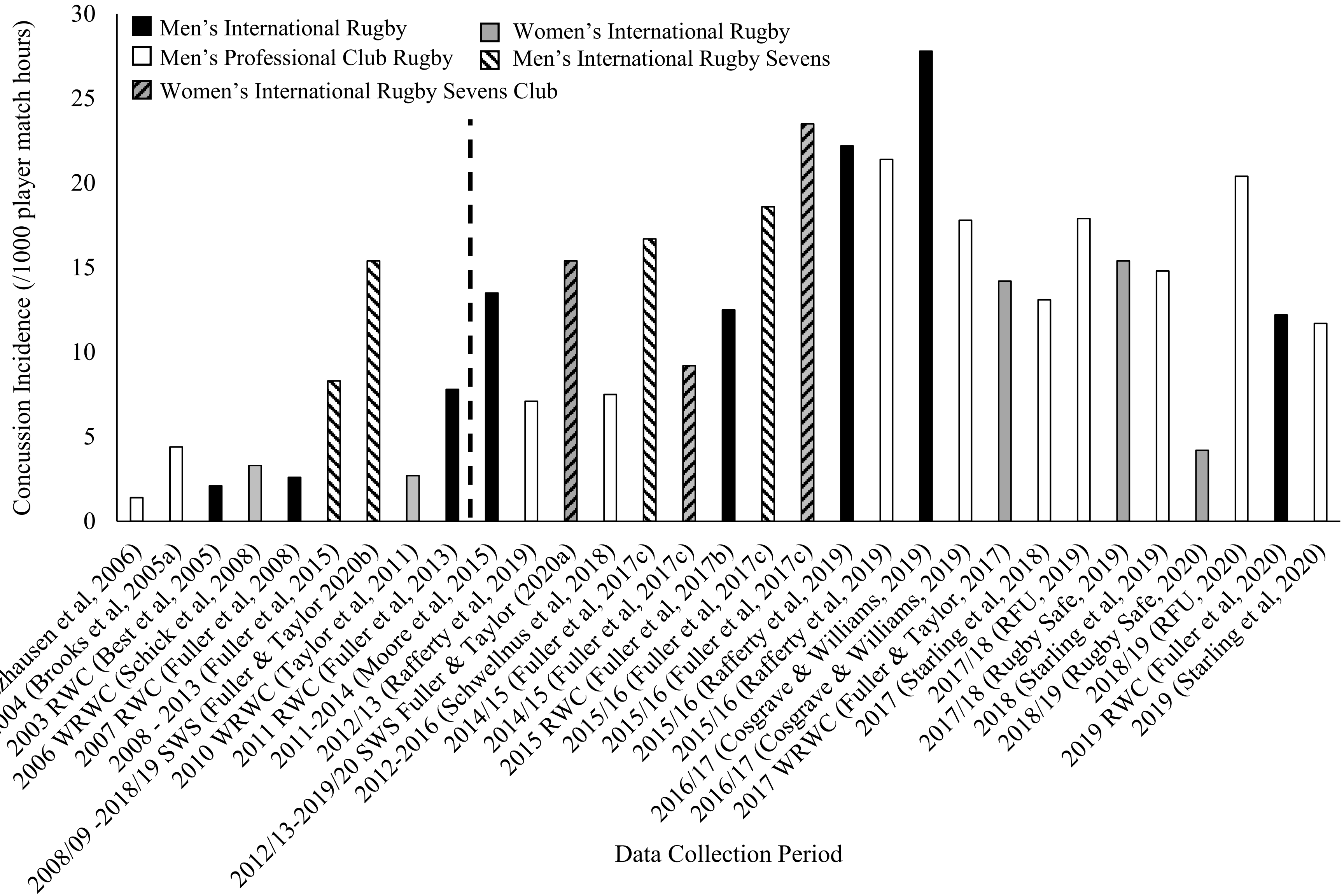

FIGURE 2.1: Match concussion incidence over time in men and women's international rugby, men's professional club rugby, and men's and women's international rugby sevens. Studies are listed from the start date of data collection period. Dashed line marks introduction of head injury assessment and increased drive from World Rugby on concussion recognition. RWC = Rugby World Cup, WRWC = Women's Rugby World Cup.

Prior to 2011, concussion tended to occupy less than 5% of all injuries across men's and women's international rugby, men's professional club rugby and men's international rugby sevens (Best et al, 2005; Brooks et al, 2005a; Fuller et al, 2010b; RFU, 2019; Taylor et al, 2011). Since 2011, the frequency of concussion diagnosis has steadily risen. Fuller et al (2013) reported that concussion was the second most frequent diagnosed injury, occupying 8.8% of all injuries at the 2011 Rugby World Cup (7.8/1000 player match hours). Concussion rose to the most common injury at the 2015 and 2019 tournament, occupying 14.0% and 15.4% of all injuries (12.5 and 12.2/1000 player match hours respectively), and was the most common injury amongst the Welsh men's international team during the 2015/16 season (12.5% of all injuries; 22.2/1000 player match hours (Fuller et al, 2017b; Fuller et al, 2020a; Rafferty et al, 2019). Concussion incidence has risen from 10% of all injuries (3.6/1000 player match hours) at the 2010 Women's Rugby World Cup, to 26.6% of all injuries at the 2017 tournament (14.2/1000 player match hours) (Fuller & Taylor, 2017). Concussion was the most common match injury reported amongst England women's international squad during the 2017/18 season, at 10.5% of all injuries (15.4/1000 player match hours) (Rugby Safe, 2019). From 2002/03 to 2017/18, concussion incidence has risen significantly amongst English men's Premiership clubs, with a dramatic increase from 2011 onwards (West et al, 2020). Since the 2012/13 season, concussion has been demonstrated as the most common injury in English Premiership rugby each season, peaking at 20.9/1000 player match hours in 2016/17 (21.8% of all injuries) (RFU, 2020). Concussion has also been the most common injury in men's professional club rugby in South Africa in 2014 and 2016 – 2019, with a peak incidence of 14.8/1000 player match hours in 2018 (18.2% of all injuries that season) (Starling et al, 2020). Concussion incidence was shown to significantly increase from 2008/09 to 2018/19 in Men's Sevens World Series, and was the most common injury recorded during that time frame (12.6% of all injuries; 15.4/1000 player match hours) (Fuller & Taylor, 2020b). Concussion was also the most frequently diagnosed injury from 2012/13 – 2019/20 in the Women's Sevens World Series (15.6% of all injuries; 16.5/1000 player match hours) (Fuller & Taylor, 2020a), peaking in the 2015/16 series with an incidence of 23.4/1000 player match hours (21.4% of all injuries) (Fuller et al, 2017c). Although as categories of injury location or type, lower limb injuries and muscle and tendon or joint (non-bone) and ligament injuries may occur most often, it appears that concussion has now become the most frequently diagnosed specific match injury in professional rugby and rugby sevens.

It is conceivable that the rise in match concussion incidence is a due to increased reporting (Cross et al, 2017). The rise in reported incidence coincides with the introduction of the head injury assessment (HIA) concussion diagnosis protocol (Cosgrave & Williams, 2019; Cross et al, 2017; Moore et al, 2015; Rafferty et al, 2019; RFU, 2017). This was first piloted in elite rugby in 2012, alongside an increased drive from World Rugby on concussion awareness, recognition, diagnosis and reporting (Fuller et al, 2015b; Raftery et al, 2016; RFU, 2017; World Rugby, 2017b). Programmes designed to increase concussion recognition and improve management have previously been found to increase reported concussion incidence in other sports (Emery et al, 2017; Lincoln et al, 2011). A similar phenomenon may have occurred in professional rugby since the introduction of the HIA protocol (Cross et al, 2017). Since 2012 however, there have also been evolutions to the original HIA process, which may have affected the concussion incidence being reported during this time (West et al, 2020). In its first iteration, there were only three criteria for immediate and permanent removal from play during the pitch side concussion assessment (early version of HIA 1), which was increased to five in 2014, and eleven in 2016 (Raftery et al, 2016; Raftery & Tucker, 2016; World Rugby, 2019b). Medical staff were only provided with 5 minutes to undertake the pitch side assessment up until 2014, when this was elongated to 10 minutes (Raftery et al, 2016; Raftery & Tucker, 2016). This change allowed a greater number of diagnostic tests to be included, increasing from Maddock's questions, and symptom and balance assessment, to include elements of the Standard Assessment of Concussion (Fuller et al, 2020b; Raftery & Tucker, 2016; World Rugby, 2015b). From 2014 onwards, a standardised post-game procedure was introduced, with compulsory concussion assessments within 3 hours of the suspected injury (HIA 2); and 36 – 48 hours post-game (HIA 3), recognising that concussion may be a transient condition with delayed onset of symptoms (Raftery et al, 2016; Raftery & Tucker, 2016). Finally, a video review system to improve identification and decision making around potential concussive incidents was trialled at the 2015 Rugby World Cup and introduced to the HIA process soon after (Fuller et al, 2017b; Fuller et al, 2017d). It is likely these changes to the HIA protocol have lowered the diagnostic threshold for concussion, potentially explaining further the increased incidence of concussion reported during this time frame (Fuller et al, 2020b). From data reported in figure 2.1, recent studies have begun to illustrate a decline in match concussion incidence. This may suggest that ongoing work from World Rugby of education around concussion injury and concussion injury management may be beginning to have a positive effect on concussion injury prevention (Fuller & Taylor, 2020b; World Rugby, 2017a; World Rugby, 2019a; World Rugby, 2019e).

Due to the stepwise return to play protocol outlined by the concussion consensus group and World Rugby, the majority of previous research reports concussion severity greater than six days across all formats: 7.7 – 22 days (mean); and 9.0 - 11.0 days (median) (Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2013; Fuller et al, 2015; Fuller et al, 2017b; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a; Moore et al, 2015; Rafferty et al, 2019; RFU, 2020; Rugby Safe, 2019; Rugby Safe, 2020; Starling et al, 2020). Previous literature has reported 53 - 72% of concussions sustained in men's professional rugby and international rugby sevens returned to play within 10 days (Cosgrave & Williams, 2019; Fuller, Taylor, & Raftery, 2015a). Only one study has recorded a mean concussion severity of less than six days (4.8 days) (Fuller et al, 2008). Returning a player to full competition within six days has been associated with increased chances of neuropsychological deficits and further injury, and should be avoided (Barkhoudrian et al, 2011; McCrory et al, 2013; McCrory et al, 2017). From 2002/03 to 2017/18, statistical increases in magnitude of both mean (0.5 days/season) and median (0.1 days/season) concussion severity have been illustrated in English men's Premiership rugby (West et al, 2020). However, it is impossible to ascertain whether this is due to a true increase in more severe concussion injuries, or more conservative rehabilitation practices by medical staff. Fuller et al (2015a) recorded greater concussion severities for international rugby sevens (mean: 19.3 days, median: 20.0 days) compared with rugby (mean: 10.1 days, median: 7.0 days). This may be a result of two-to-three week breaks between international tournaments in rugby sevens and a therefore more conservative approach to concussive rehabilitation.

Likely as a result of increasing incidence of concussion, match concussion injury burden has increased in recent years in men's international and professional club rugby. Concussion injury burden was found at 78.8 days absence/1000 player match hours (3.7% of total injury burden) and 95.8 days absence/1000 player match hours (3.6% of total injury burden) at the men's 2011 and 2015 Rugby World Cups respectively (Fuller et al, 2013; Fuller et al, 2017b). This increased to 201.3 days absence/1000 player match hours at the 2019 tournament (8.8% of total injury burden) (Fuller et al, 2020a), whilst Cosgrave and Williams (2019) reported concussion injury burden of 228.2 days absence/1000 player match hours in Irish men's international and professional club rugby in the 2016/17 season. From the 2002/03 to 2017/18 season in the men's English Premiership, concussion injury burden has increased at an average of 23.8 days absence/1000 player match hours/season (West et al, 2020), increasing up to a value of 338 days absence/1000 player match hours in the 2017/18 season (9.9% of total season burden) and 455/1000 player match hours for the 2018/19 season (15% of total injury burden) (RFU, 2020). In comparison, concussion injury burden in men's professional club rugby in South Africa appears slightly reduced, with values of 109-210 days absence/1000 player match hours (5.0-8.9% of total injury burden) over the 2017, 2018, and 2019 seasons (Starling et al, 2020).

Limited values are present in research for women's international rugby, and men's and women's international rugby sevens. The England women's international squad reported a concussion injury burden of 285 days absence/1000 player match hours (13.9% of total burden) for the 2017/18 season, yet this had reduced to 88 days absence/1000 player match hours (3.1% of total burden) for the 2018/19 season (Rugby Safe, 2019; Rugby Safe 2020). However, the small sample sizes in these data sets means this data should be interpreted with caution. Concussion injury burden was reported as 238.7 days absence/1000 player match hours (4.5% of total injury burden) for Men's Sevens World Series from 2008/09 – 2017/18 (Fuller & Taylor, 2020b) and 321.8 days absence/1000 player match hours (5.7% of total injury burden) for the Women's Sevens World Series from 2012/13 – 2019/20 (Fuller & Taylor, 2020a).

Concussion Cause & Mechanism

As a result of the biomechanical forces required to induce concussion (McCrory et al, 2017; Zhang et al, 2004), the vast majority of concussions are caused by contact with other players (Tucker et al, 2017a). The tackle situation (tackling and being tackled) and collisions appear contact mechanisms which cause the majority of concussions across rugby and rugby sevens (Cosgrave & Williams, 2019; Fuller et al, 2015a; Fuller & Taylor, 2020b; Tucker et al, 2017a).

Within the tackle situation, the tackler appears to have a greater chance of concussion (Fuller et al, 2015a; RFU, 2019; Tierney, Lawler, Denvir, McQuilkin, & Simms, 2016; Tucker et al, 2017a). Tackling is an open skill, where the tackler is often reacting to the movement of the ball carrier (Burger et al, 2016; Hendricks, Matthews, Roode, & Lambert, 2014b). For the majority of tackles, the tackler should be aiming to make contact with the ball carrier with their shoulder (Rugby AU, 2017; Rugby Smart, 2018). A failure to react to the ball carrier or an element of technical deficiency may increase the likelihood for the head of the tackler to be impacted (Burger et al, 2016; Davidow et al, 2018). This may increase the propensity of tackler concussion (Tucker et al, 2017a).

As a contact mechanism, collisions may be intentional or accidental. An intentional collision (attempting to "charge or knock down an opponent carrying the ball without attempting to grasp that player") are against the laws of the game (World Rugby, 2019c). These have been shown to statistically increase concussion propensity compared with legal tackles (Suzuki et al, 2019). Accidental collisions may involve contact whilst contesting to receive a kick, or off-the-ball collisions. Kick contest collisions have been shown to possess a high incidence of concussion (Tucker et al, 2017a). However, their relative infrequent appearance in matches suggests they do not contribute to a large number of concussions (Tucker et al, 2017a). The number of concussions caused by accidental off-the-ball collisions has yet to be monitored.

2.2.6: Training Injury & Concussion Epidemiology in Professional Rugby

Injury Incidence, Severity, and Burden

Across all cohorts, training injury incidence is substantially reduced compared to match injuries. However, as with match injuries, there appears a difference in incidence based on the methodology of single versus multiple cohort studies. Training injury incidences across all teams at the 2007, 2011, 2015 and 2020 men's Rugby World Cups ranged from 1.0-3.5 injuries/1000 player training hours (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a). Injuries sustained in training amongst all teams at the 2006, 2010, 2014 and 2017 Women's Rugby World Cup ranged from 0.8-3.0/1000 hours (Schick et al, 2008; Fuller & Taylor, 2014; Fuller & Taylor 2017). Training injury incidences from all English Premiership, and all Australian and South African Super Rugby teams ranged from 1.6 - 2.9/1000 hours (Brooks, Fuller, Kemp & Reddin, 2005b; RFU, 2019; RFU, 2020; Schwellnus et al, 2018; West et al, 2019; Whitehouse et al, 2016). Fuller (2018c) recorded training exposure and injuries amongst men's international rugby sevens squads participating in the Sevens World Series from 2008/09 to 2015/16 and found a training injury incidence of 0.91/1000 hours. Amongst all teams participating in the Women's Sevens World Series in 2014/15, 2015/16 and women's international rugby sevens at the 2016 Rio Olympic Games, training injury incidence ranged from 1.0 - 2.2/1000 hours (Fuller et al, 2017c).

Previous studies which have used a single cohort methodology have tended to report higher training injury incidences. Training injury incidence in men's international rugby has been recorded between 4.3 - 6.1/1000 hours (Brooks et al, 2005c; Moore et al, 2015; RFU, 2019; RFU, 2020). Training injury incidence for the English women's international rugby squad has been reported at 4.5 and 13.0/1000 player training hours for the 2017/18 and 2018/19 seasons respectively (Rugby Safe, 2019; Rugby Safe, 2020). Gabb et al (2014) monitored training exposure and injuries for England women's international rugby sevens in 2013, and reported a training injury incidence of 10/1000 player training hours. Single cohort studies appear to find greater injury incidences when compared with multiple cohort studies. As discussed with match injuries, this may be due to more consistent injury recognition, diagnosis and reporting by single medical teams in single cohort studies, potentially resulting in a more accurate assessment of injury incidence (Moore et al, 2015). However as with match injuries, single cohort studies report an incidence of injury which reflects the training practices of the team in question, and results will likely be accompanied by wider confidence intervals due to smaller sample sizes. There are also wide variations in training injury incidence reported in different training activities, dependent upon the content of the activity (e.g., contact versus non-contact) (Brookes et al, 2005b; RFU, 2020). Training injury incidences are therefore likely to vary from team to team based on their time spent in different training activities, and also likely season-by-season within-teams if training philosophies are altered over time (West et al, 2019). Single cohort studies are therefore useful in providing national governing bodies with an assessment of injury probability for that team/cohort that has been studied. Yet this does not necessarily reflect the sport as a whole, or provide valid data for international governing bodies to understand the probability of injury when wide variations in training methodology/training activity choice across multiple teams are taken into consideration. This is an important point to consider for the current thesis, as research will be conducted using a single cohort methodology, and will reflect the training injury incidence for Scottish Rugby professional teams only.

Despite potential difference between single and multiple cohort methodologies, training injury incidence is greatly reduced compared with match injuries in all cases. Training is an environment under the control of coaches and sport science staff. Most match injuries occur in contact situations, such as being tackled, tackling and rucks (Brooks et al, 2005a; Fuller et al, 2007b; RFU, 2019; Schick et al, 2008). These contact aspects are integral to the game of rugby. However, training can be adapted and therefore time spent in full contact or high injury incidence activities can be limited, reducing the probability of injury (Brooks et al, 2005b).

Training injury severity for men's international rugby has been reported at 12.0 - 26.9 (mean) and 6.0 - 9.0 days (median) (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Moore et al, 2015; RFU, 2019; RFU, 2020). Mean training injury severity for England women's international rugby has been reported as 44 and 36 for the 2017/18 and 2018/19 season respectively, with a median of 10 days for the 2017/18 season (Rugby Safe, 2019; Rugby Safe, 2020). Mean (24.0 - 37.5 days) and median (9.0 -17.0) training injury severity for men's professional club rugby appears greater than men's international rugby (Brooks et al, 2005b; RFU, 2019; RFU, 2020; West et al, 2019; Whitehouse et al, 2016). From the 2007/08 to the 2017/18 season, mean injury severity rose by 1.7 days/season, and median injury severity rose by 0.8 days/season in English men's Premiership rugby, similar to the trend observed for match injuries amongst this population (West et al, 2020; West et al, 2019). This rise may reflect a true increase in injury severity, or more conservative approach to injury rehabilitation, or changes in training intensity or time spent (and therefore injuries accrued) in different training activities (West et al, 2019).

Previous literature in rugby sevens shows greater training injury severity than men's international or professional club rugby. Mean training injury severity has been reported as 31.5 - 43.5 (men) and 27.0-67.1 days (women) for international rugby sevens (Fuller et al, 2017c; Fuller, 2018c; Gabb et al, 2014). Median severity has been reported as 27.0 - 33.0 (men) and 9.0 - 19.0 days (women) (Fuller et al, 2017c; Fuller, 2018c; Gabb et al, 2014). As with match injuries, greater training injury severity compared with rugby cohorts may be due to greater relative intensity of rugby sevens (Higham et al, 2012), resulting in injuries of a greater severity. However, due to international rugby sevens tournaments occurring every two–three weeks, there may be an element of type I error as medical staff can implement more conservative rehabilitation protocols, inflating injury severity (Fuller et al, 2010b).

There appears large variation in training injury burden reported in previous literature. From teams training at the past four men's Rugby World Cups, training injury burden has ranged from 14.4 – 62.3 days absence/1000 player training hours (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a). Moore et al (2015) reported a value of 89.3 days absence/1000 player training hours for the Welsh men's international team from 2011-2014. From 2002/03 to 2018/19, the English men's international team has a mean training injury burden of 62 and 128 days absence for strength & conditioning and rugby skills training activities respectively (RFU 2020). However, over this time, strength & conditioning (2 – 579 days absence/1000 player training hours) and rugby skills (3 – 233 days absence/1000 player training hours) training activities have demonstrated wide variations on a season-by-season basis (RFU, 2020). The English women's international team have reported training injury burden values of 208 and 465 days absence/1000 player training hours from the 2017/18 and 2018/19 seasons respectively (Rugby Safe, 2019; Rugby Safe, 2020). Values ranging from 48 – 106 days absence/1000 player training hours has been recorded in men's professional club rugby in England and Australia (Brooks et al, 2005; RFU, 2019; RFU, 2020; Whitehouse et al, 2016). Training injury burden significantly increased in English Premiership clubs from 2007/08 – 2017/18 at a rate of 4.4 days absence/1000 player training hours/season, likely due to an increase in mean training injury severity reported over this time (West et al, 2019). Previous studies report training injury burden from the Sevens World Series at 25.2 – 47.4 days absence/1000 player training hours (men) and 25.7 – 147.6 days absence/1000 player training hours (women) (Fuller et al, 2017c; Fuller, 2018c). Training injury burden for the English women's international rugby sevens squad during the 2013 World Cup season was reported as 400 days absence/1000 player match hours (Gabb et al, 2014).

Wide variation in training injury burden is likely due to aforementioned differences in training injury incidence between different teams, reflecting differing training activities and training philosophies, combined with potential differences in diagnosing and recording injuries between single and multiple cohort methodologies (Moore et al, 2015). Increasing training injury severity in some cohorts may also suggest reasons for training injury burden increasing over time (West et al, 2019).

Injury Location and Type

Across all cohorts, lower limb appears the most injured body region, occupying 63.7 - 89.0% of all training injuries (Brooks et al, 2005b; Gabb et al, 2017; Holtzhausen et al, 2006; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Rugby Safe, 2019; Rugby Safe 2020). Muscle and tendon injuries are the most common injury types for men's international and men's professional club rugby, representing 42.9 - 70.0% of all injuries (Brooks et al, 2005b; Holtzhausen et al, 2006; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a). From a single study, Gabb et al (2017) showed joint (non-bone) and ligament injuries were the most common in women's international rugby sevens (31% of all injuries). Differences in most common training injury type between men's international/professional club rugby and women's international rugby sevens may be due to hormonal and Q-angle differences, and their effects on the probability of lower body ligament injury (Balachandar, Marciniak, Wall, & Balachandar, 2017; Heitz, Eisenmann, Beck, & Walker, 1999; Hewett, Zazulak, Myer, & Ford, 2005). No previous studies have detailed common training injury location or type for men's international rugby sevens.

Injury Cause, Mechanism and Training Activity

Limited studies have recorded training injuries by cause and mechanism. Both Moore et al (2015) (74%) and Brooks et al (2005b) (57%) reported that the majority of training injuries were caused in non-contact situations in men's international and men's professional club rugby respectively. However, Fuller et al (2020) reported that 70% were caused by contact in teams training at the 2020 men's Rugby World Cup. This difference is likely attributable to the differences in training structure and training activities across different teams. Brooks et al (2005b) and West et al (2019) found running as the most common training injury mechanism in men's professional club rugby.

By different training activities, rugby skills training (6.5 and 2.9/1000 player training hours) has been shown to have greater injury incidence than strength & conditioning training (4.1 and 2.0/1000 player training hours) for the English men's international and English men's Premiership clubs respectively (RFU, 2020). In rugby skills training, full-contact activities have been found to have the largest injury incidence (5.9-20.0/1000 player training hours), followed by semi-contact (4.7 - 4.8/1000 hours) and non-contact (0.4 - 4.2/1000 hours) (Brooks et al, 2005b; Brooks et al, 2005c; Fuller et al, 2008; Fuller et al, 2013; West et al, 2019). Within strength & conditioning training activities, non-gym/on-feet conditioning (1.4 – 24/1000 player training hours) appears to have a greater incidence compared with gym-based training activities (0.4 – 0.9/1000 player training hours) in English men's international and English men's Premiership club rugby (Brooks et al 2005b; Brooks et al, 2005c; RFU, 2020; West et al, 2019).

Training Concussion Incidence, Severity and Burden

Concussion incidence in training is greatly reduced compared to match play. At the 2007, 2015 and 2019 men's Rugby World Cups, concussion incidence ranged from 0.06 - 0.1/1000 player training hours (2.9 – 5.7% of all training injuries) (Fuller et al, 2008; Fuller et al, 2017b; Fuller et al, 2020a). Similar incidences have been found in men's professional club rugby, ranging from 0.01 - 0.21 concussions/1000 hours (Brooks et al, 2005b; RFU, 2019; RFU 2020; West et al, 2019). From the 2007/08 English Premiership season to 2017/18, the mean training concussion incidence was reported at 0.09/1000 player training hours (5.4% of all training injuries) (West et al, 2019). However, this has seen an increase from 0.01/1000 player training hours (0.3 – 0.4% of all training injuries) in 2007/08-2009/10 to 0.21/1000 player training hours in 2017/18 and 2018/19, becoming the 3rd most common training injury for English Premiership clubs for the 2016/17 – 2018/19 seasons (4.8 – 7.2% of all injuries) (RFU, 2020; West et al, 2019) Slightly greater concussion incidences were reported from the English women's international squad in training over the 2017/18 (0.84/1000 player training hours; 18.7% of all injuries) and 2018/19 (0.6/1000 player training hours; 4.6% of all injuries) seasons (Rugby Safe, 2019; Rugby Safe 2020). No previous studies have detailed concussion incidence in training for men's or women's international rugby sevens.

There appears some evidence, particularly in men's professional club rugby in England, of concussion incidence increasing over time, particularly since the introduction of the HIA protocol and increased concussion education and management from World Rugby (Cross et al, 2017; RFU, 2020; West et al, 2019). However, concussion frequency, both expressed as incidence and as a proportion of all injuries appears reduced in the cohorts listed above when compared with matches.

Concussion severity in training has been reported as 9.0 - 14.0 (mean) and 9.0 - 11.0 days (median) (Brooks et al, 2005b; Cosgrave & Williams, 2019; Fuller et al, 2008; Rugby Safe, 2019; Rugby Safe, 2020; West et al, 2019). However, recent data from English men's Premiership club rugby suggests a large increase in mean concussion severity in recent years, with reported values of 17.1 days (2016/17 season) and 35.2 days (2018/19 season) (RFU, 2020). These represent significant outliers from the mean value of 14 days in this population from 2007/08 – 2017/18 (West et al, 2019), suggesting a valid reflection of more severe concussion injuries, or a more conservative approach to concussion rehabilitation in recent years. Concussion severity in training has not been reported amongst other professional rugby cohorts.

Concussion training injury burden has been reported to range from 0.28 – 8.4 days absence/1000 player training hours (0.58 – 4.0% of total training injury burden) in men's and women's international rugby, and men's professional club rugby from 2002/03 to 2017/18 (Brooks et al, 2005b; Fuller et al, 2008; RFU, 2018; Rugby Safe, 2019; Rugby Safe, 2020; West et al, 2019). Reflecting recent rises in concussion incidence and severity in training in English men's Premiership rugby, concussion injury burden in training for the 2018/19 season represented 8.0% of the total training injury burden (7.4 days absence/1000 player training hours) (RFU, 2020). No previous studies have reported concussion injury burden in training in men's or women's international rugby sevens.

Training Concussion Cause and Mechanism

Limited research has reported concussion cause and mechanism in training. As with match concussions, common cause appears to be contact with other players, with tackling, being tackled, and collisions common mechanisms (Cosgrave & Williams, 2019).

2.2.7: Summary

Overall injury incidences appear to vary by methodology in professional rugby and rugby sevens. Multiple cohort studies tend to report match injury incidences between 62.0 - 103.0/1000 player match hours for men's international and professional club rugby, and up to 124.5 (men) and 109.4/1000 hours (women) for international rugby sevens. Multiple cohort studies for women's international rugby report low injury incidences (35.5-53.3/1000 player match hours) by comparison with other cohorts, yet this may be representative of injury reporting from multiple cohort studies with a number of non-professional teams. Single cohort studies report greater match injury incidences, with values of 92-218/1000 hours for men's and women's international rugby and women's international rugby sevens. This may be due to more assiduous/consistent injury reporting, yet also likely reflects the manner in which these specific teams play and illustrates the wide variations possible in injury incidences between teams and on a season-by-season basis. Single cohort studies are likely to offer greater interest to the responsible national governing body as an indication of injury occurrence within their team, yet the smaller sample size of injuries analysed will likely result in wider confidence intervals (and therefore potentially less precise results) within the data. Match injury burden appears to range between approximately 1,000 - 4,000 days absence/1000 player match hours for professional rugby cohorts, and between approximately 5,000 - 6,000 days absence/1000 player match hours for men's and women's international rugby sevens.

Training injury incidence tends to be greatly reduced compared to matches, with values of 0.8 – 13.0/1000 player training hours for all professional cohorts. Single cohort studies tend to report higher incidences of training injury, yet training injury incidences are likely also influenced by time spent in different training activities by different teams. Training injury burden appears to vary, with reported values ranging from 14.4 – 400 days absence/1000 player training hours, yet this is also likely influenced by training philosophies and time spent in different training activities.

Concussion injuries appear to occur far more frequently in match play compared with training. Match concussion incidences have risen in recent years since the introduction of the HIA protocol and an increased drive from World Rugby on improving concussion recognition and awareness. Concussion is now the most frequent match injury reported in most cohorts (approximately 15-20% of all match injuries), with incidences reaching over 20/1000 player match hours around 2015. However, recent studies have suggested a slight decline in concussion incidence, suggesting that ongoing work from World Rugby around concussion education, management, and prevention may be beginning to have a beneficial effect. Match concussion injury burden has increased since the introduction of the HIA protocol, with maximum values of 455 days absence/1000 player match hours (15% of total match injury burden) reported amongst English men's Premiership clubs in the 2018/19 season.

Concussion is caused primarily by contact with other players, with tackling, being tackled, and collision the most common mechanisms across matches and training. Most concussion cases across matches and training appear to resolve in 10-14 days by following the six stage stepwise graduated return to play protocol, yet evidence from recent studies from men's professional club rugby suggest concussion severity may be increasing. However, it is not possible to determine whether this is due to more severe concussion injuries, or a more conservative approach being taken towards concussion rehabilitation.

Match and training concussion incidence remains unknown for professional rugby and rugby sevens in Scotland. Scottish Rugby therefore cannot fulfil its legally bound duty of care towards players of injury surveillance and assessment of risks, as stipulated within United Kingdom health and safety legislature. Chapter 3A and 3B of the current thesis will aim to find the incidence, severity, and burden of concussion amongst all match and training injuries, and describe concussion cause and mechanism. This conforms to the first step of van Mechelen's research model "The sequence of prevention of sports injuries". This will fulfil Scottish Rugby's duty of care and aim to improve Scottish Rugby's understanding of the risks to player welfare and player availability/team performance due to concussion injury. Studies completed in this stage of the model will offer a contemporary statement on injury and concussion in rugby and rugby sevens for different professional cohorts, to be compared with those referenced from previous literature in this section.

2.3: Concussion Risk Factors (Stage Two of Model)

2.3.1: Injury Aetiology

The second step of van Mechelen's research model "The sequence of prevention of sports injuries" states that aetiology and mechanism of injury need to be understood (van Mechelen et al, 1992). Injury occurrence in sport can be described by the exposure to and interaction of risk factors from two distinct categories: "Intrinsic" and "Extrinsic" (Fuller, 2007; Meeuwisse 1994; Meeuwisse et al, 2007, van Mechelen et al, 1992). Intrinsic factors are particular to each individual, and may include physical and psychological fitness/strength, skill level/ability, and prior injury history (Hollis et al, 2009; van Mechelen et al, 1992; Witchalls, Blanch, Waddington, & Adams, 2012). Extrinsic factors are those which are experienced by individuals during competition or training such as equipment, sporting rules/laws, actions of opponents/team-mates, and weather conditions (Lawrence, Comper & Hutchison, 2016; van Mechelen et al, 1992). Examples of extrinsic and intrinsic risk factors are shown in table 2.4.

TABLE 2.4: Examples of intrinsic and extrinsic risk factors

Intrinsic Factors	Extrinsic Factors
Physical Fitness: Aerobic endurance, strength, speed, sporting skill/co-ordination, flexibility	Sport-Related Factors: Type of sport, exposure, nature of event, role of opponents and team-mates
Previous injury	Venue: State of floor or ground, Lighting, Safety Measures
Psychological Factors: Self-concept, risk acceptance, type A or C behaviour, personality, locus of control	Equipment: Tools (stick/racquet etc.), risk acceptance, protective equipment, other equipment (shoes, clothes etc.)
Physical Build: Height, mass, joint stability, body fat	Weather conditions: Temperature, relative humidity, wind
Age	Trainer: Conduct of match, rules, referee's application of the rules
Biological Sex	

Adapted from van Mechelen et al (1992)

Injury epidemiology studies such as that which will be performed in Chapters 3A and 3B will list cause and mechanism of each sustained concussion from the inciting event. Whilst this is beneficial as it provides information on events which are associated with concussion injury, there are likely multiple intrinsic and extrinsic risk factors which interplay and effect the overall chance of concussion (Cross et al, 2019; Hollis et al, 2009). Due to the intrinsic risk factors particular to each individual, and how these factors develop relationships/interactions/confounding with extrinsic risks experienced during training/competing it is highly unlikely that two athletes will ever experience the same level of injury risk. It is therefore necessary to consider which intrinsic risks may place particular athletes at a greater risk of injury when extrinsic factors are also considered (Fuller, 2007). Meeuwisse (1994) established a multifactorial injury model to investigate sport injury aetiology in this context (figure 2.2).

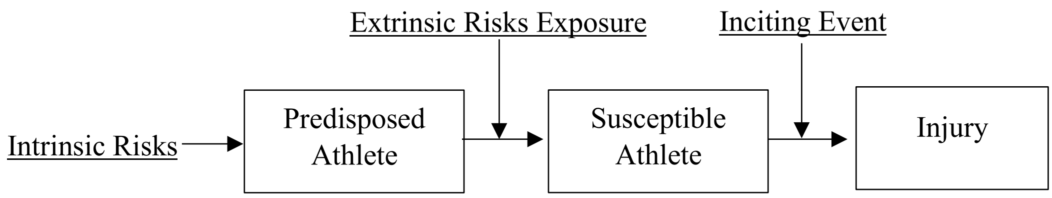

FIGURE 2.2: "A Model of Multifactorial Aetiology in Athletic Injury". Adapted from Meeuwisse (1994).

The interaction of intrinsic and extrinsic risks describes the probability for injury to occur from a single inciting event (Fuller, 2007; Meeuwisse, 1994; Meeuwisse et al, 2007). Previous research suggests that both intrinsic and extrinsic factors can influence the probability of concussion, yet there is limited knowledge on how intrinsic and extrinsic risks interact to affect total concussion aetiology.

2.3.2: Intrinsic Risk Factors for Concussion

Concussive History

Prior concussion injury may increase the probability for sustaining a subsequent concussion. In their systematic review, Abrahams et al (2014) stated that "a history of previous concussion increases concussion risk with a high level of certainty". Athletes who have been concussed in the previous 12 months have been demonstrated to be almost twice as likely to sustain a future concussion compared with players who had not been concussed in both American football and rugby (Hollis et al, 2009; McGuine, et al, 2014). A study of collegiate American football players demonstrated that players reporting a history of three or more previous concussions in the past seven years were three times more likely to suffer from a subsequent concussion than those who did not report previous concussions (Guskiewicz et al, 2003). Certain symptoms at diagnosis of previous concussion have also been reported to influence chance of future concussion (Delaney, Lacroix, Leclerc, & Johnston, 2000; Delaney, Lacroix, Leclerc, & Johnston, 2002; McCrory 2004; Schneider et al, 2013).

Reasons why elements of concussion history have an effect on future concussion incidence has been hypothesised to be due to inadequate recovery from previous concussion. This may result in heightened neuronal vulnerability, leaving cells at greater chance of re-injury (Barrett et al, 2014; Hollis et al, 2009; Howell, Lynall, Buckley, & Herman, 2018). Neuromuscular control deficits as a result of previous concussive injury may also remain beyond clinical recovery, reducing co-ordination and contact skill proficiency (Bussey et al, 2019; Di Virgilio, Ietswaart, Wilson, Donaldson, & Hunter, 2019; Hides et al, 2016). Bussey et al (2019) reported diminished feed-forward control of neck muscles in those who had been concussed in the previous 12 months. Neck musculature appears to play a role in reducing concussion incidence through limiting cranial acceleration (Broglio et al, 2012; Collins et al, 2014; Viano, Casson, & Pellman, 2007) and impaired feed-forward control may increase probability of future concussion.

Neck Strength

Neck musculature is responsible for controlling the acceleration of the head during impulsive loading (Dempsey, Fairchild, & Appleby, 2015; Gutierrez, Conte, & Lightbourne, 2014; Panjabi et al, 1998; Tierney et al, 2005). Therefore, strength of each individual's cervical spine musculature may influence their probability of sustaining a concussion (Hrysomallis, 2016). After correcting for gender and sport, neck strength remained a statistical predictor of concussion amongst 6,662 high school athletes (Collins et al, 2014). Athletes who were concussed were shown to have 11-22% less overall neck strength than those who were non-concussed (Collins et al, 2014). Using a Hybrid III dummy, increases in neck stiffness were shown to reduce peak head acceleration in reconstructed head impacts (Viano et al, 2007). The dynamic restraint system of neck muscles may be able to stabilise the head and incorporate the torso as the effective mass in an anticipated collision and therefore reduce head acceleration and concussion incidence (Broglio et al, 2012; Eckner et al, 2014; Mansell et al, 2005). In a situation where weak neck muscles are unable to provide a stable link between head and torso, the head becomes the sole mass to be accelerated in a collision. By Newton's second law of motion, or the law of conservation of energy, the small mass of the head would see a large change in velocity pre- to post-collision, increasing probability of concussion (Broglio et al, 2012; Rowson & Duma, 2013; Viano et al, 2007; Zhang et al, 2004).

Biological Sex

Concussion incidence has been found to be statistically greater for women's basketball, soccer and baseball compared with men of similar age and playing level (Covassin, Swanik, & Sachs, 2003; Delaney, Al-Kashmiri, Drummond, & Correa, 2008; Lincoln et al, 2011). A recent systematic review found 10 studies which suggested women had a greater incidence of concussion in sport where rules were identical between men and women (Abrahams et al, 2014). Greater incidence of concussion in women's sport may be due to weaker cervical musculature in women compared with men (Mansell et al, 2005), allowing for more substantial head acceleration during head impacts (Gutierrez et al, 2014; Tierney et al, 2005).

However, no statistical difference was found in concussion incidence between the 2007 men's Rugby World Cup and 2006 Women's Rugby World Cup (2.6 and 3.3/1000 player match hours respectively) (Fuller et al, 2008; Schick et al, 2008). Poor recognition and diagnosis of concussion injury prior to the introduction of the head injury assessment protocol may confound any differences between men's and women's professional rugby. A contemporary analysis would be required to ascertain differences between men's and women's concussion incidence in professional rugby.

Fatigue

There is debate in previous literature on the effect fatigue may have on concussive incidence. In schoolboy rugby, statistically higher incidences of concussion in the final quarter of matches (when fatigue would be at its greatest) have been found compared with the first quarter (Hendricks et al, 2016; Mc Fie et al, 2016). Gardner et al (2015) demonstrated that 65% concussions in professional rugby league occurred in the second or fourth quarter of matches. Gabbett (2008) demonstrated an association between fatigue and a decrement in tackling technique in rugby league players. A decrement in tackling technique may increase the likelihood of the head being impacted, increasing propensity for tackler concussion (Davidow et al, 2018; Tucker et al, 2017a).

However, a recent video analysis study of professional rugby demonstrated that tackling and ball carrying proficiency did not statistically deteriorate as player time in game increased (Tierney, Denvir, Farrell, & Simms, 2018). This study found a statistical difference in the number of tackles in the final quarter of the game. Any increase in tackle-related injuries towards the end of the game may therefore be explained by a greater number of tackles in this period (Tierney et al, 2018). This is supported by the fact that no statistical difference was found in concussion propensity per 1000 tackles between any match quarters in men's professional rugby (Tucker et al, 2017a). In order to fully understand the effect fatigue may have on concussion incidence in rugby, future studies should express concussion incidence by player-in-game time, as substitutes who are brought on in the final quarter of matches are likely confounding current data.

Genetics

Genetics may influence concussion incidence by modification of characteristics of neurophysiological/anatomical processes or structures which alter susceptibility to concussion injury; or through variations which alter risk-taking behaviours (Mc Fie & September, 2019; Panenka et al, 2017). The former will be covered in this current section, whilst the latter will be covered by risk taking behaviour risk factors (see below). Concussion is a multifactorial injury, and there may be many genes involved in altering probability of concussion (Mc Fie & September, 2019). Most previous research has focused on the apolipoprotein E and microtubule-associated protein tau genes.

The apolipoprotein E (*APOE*) gene is responsible for encoding the lipid carrier protein apolipoprotein E, which transports cholesterol and phospholipids for protection and repair of neurons after injury (Horsburgh, Graham, Stewart, & Nicoll, 1999). The function of apolipoprotein E within the central nervous system suggests different *APOE* gene isoforms or single nucleotide polymorphisms may affect an individual's ability to recover from repetitive mechanical stimuli, lowering the necessary threshold for concussion injury (Mc Fie & September, 2019). In a prospective cohort of 1,056 college athletes, presence of the *APOE* ε4 isoform was statistically associated with decreased incidence of concussion compared with ε2/ε3 isoforms (Terrell et al, 2018). However, other studies have found no association between *APOE* gene isoforms and concussion incidence (Abrahams et al, 2018; Kristman et al, 2008; Terrell et al, 2008). American football and soccer athletes with the *APOE* rs405509 TT genotype were statistically three times more likely to have experienced prior concussion compared with those who carried the GG genotype (Terrell et al, 2008). Conversely, presence of the rs405509 TT genotype was reported to be statistically greater in rugby players with no history of concussion compared to those who had been concussed (Abrahams et al, 2018). The effect of the *APOE* gene on concussion incidence appears unclear at this moment in time.

The microtubule-associated protein tau (*MAPT*) gene is responsible for encoding tau proteins, which stabilise microtubules in axons in the central nervous system. Single nucleotide polymorphisms within the *MAPT* gene have been associated with greater levels of tau protein in cerebrospinal fluid, an indicator of neurodegeneration in later life (Bekris et al, 2012). If polymorphisms result in alteration of axon microtubule structure, an altered susceptibility to concussion may be present in those who carry them (Mc Fie & September, 2019). The presence of the rs2435200 AA genotype has been statistically associated with reduced concussion susceptibility, whilst the rs2435200 AG genotype has been statistically associated with increased concussion susceptibility in rugby players (Abrahams et al, 2019). Although further studies are required to confirm findings, it appears there may be an association with single nucleotide polymorphisms within the *MAPT* gene and concussion susceptibility.

Behaviour

Athletes who score themselves highly on risk taking and sensation seeking scores have been shown to have a history of multiple sport related concussions (Beidler et al, 2017). However, findings in prospective cohort studies are mixed for the effect of behaviour on concussion incidence. Odds of sustaining a concussion was statistically greater amongst youth athletes who played ice hockey to reduce levels of tension and aggression compared with those who played for other reasons such as socialising and enjoyment (Gerberich et al, 1987). A greater preference to engage in body checking resulted in statistically increased incidence of severe concussion in youth ice hockey compared with those with a low preference (Emery et al, 2010). Yet a similar study in a different youth cohort found differing preferences to engage in body checking had no effect on concussion incidence (Emery et al, 2011). Incidence of concussion was greater amongst recreational rugby players who self-reported high impulsivity scores compared with those who reported low to medium scores, yet this was not a statistical difference through either univariate or multivariate analysis (Hollis et al, 2009). Whilst anecdotally there may appear a causal link between greater risk-taking behaviour, aggression and concussion incidence, previous prospective cohort studies report mixed findings.

2.3.3: Extrinsic Risk Factors for Concussion

Concussions occur primarily in contact situations, with tackling, being tackled, and collisions often the most common mechanisms (Cosgrave & Williams, 2019; Fuller et al, 2015a; Tucker et al, 2017a). However, this describes purely the inciting event, and does not provide detail on exposure to various risk factors within, or immediately preceding the event (Meeuwisse, 1994; Meeuwisse et al, 2007). Extrinsic risk factors associated with different contact mechanisms are detailed below, followed by other factors relevant to rugby.

Tackling

Compared with the ball carrier, the tackling player has been found to have a greater than 2-fold statistical increase in concussion incidence (Tucker et al, 2017a). Tackling is an open skill, and the tackler is reacting to the actions of the ball carrier (Hendricks et al, 2014b). A failure to react, or an element of technical deficiency may result in increased likelihood of the head of the tackler being impacted (Burger et al, 2016; Davidow et al, 2018). Tackler head impact with the ball carrier's head, elbow, knee, hip and shoulder all statistically increased tackler concussion propensity compared with no tackler head impact (Tucker et al, 2017a). Compared with correct head positioning (beside/behind the ball carrier), tackler head placement in-front of the ball carrier has also been reported to statistically increase tackler concussion propensity (Sobue et al, 2017; Suzuki et al, 2019).

Tackles where high impact forces are generated appear to increase concussion propensity to the tackler. Active shoulder tackles and front-on tackles both statistically increase concussion propensity compared with passive and smother tackles, and side-on and tackles from behind respectively (Tucker et al, 2017b). A tackler accelerating into a tackle (Suzuki et al, 2019; Tucker et al, 2017b), and a tackler at high speed both statistically increase tackler concussion propensity (Tucker et al, 2017b). A ball carrier accelerating into a tackle statistically increased concussion propensity to the tackler (Tierney, Denvir, Farrell, & Simms, 2019). Front-on and active shoulder tackles, or tackles where the tackler and/or ball carrier are accelerating into contact likely possess greater magnitude of energy transfer between tackler and ball carrier (Hendricks et al, 2014a; Seminati et al, 2017). Any situation in a tackle of high energy transfer where the head of the tackler is impacted, or sufficient energy is transferred to the brain of the tackler would likely increase tackler concussion propensity.

Being Tackled

Tucker et al (2017a) reported concussion propensity for the tackled player was statistically less than that of a tackler. Concussion propensity for the tackled player increases as their speed into contact increases (Tucker et al, 2017b). Higher speed into contact is likely to result in a larger peak impact force (Hendricks et al, 2014a; Seminati et al, 2017). If the ball carrier were to suffer a head impact, or large magnitudes of energy were transferred to the tackled player's brain, concussion may be more likely.

The tackled player is at their lowest chance of concussion when adopting a bent-at-the-waist body position, regardless of the body position of the tackler (Tucker et al, 2017b). The greatest concussion propensity for the tackled player is an upright body position, when a head-to-head or head-to-shoulder impact with the tackler is more likely (Tucker et al, 2017b).

Collisions

Data from both Fuller et al (2015a) and Cosgrave and Williams (2019) suggest collision is a regular concussive mechanism. However, whether these collisions were intentional or accidental was not described. An intentional collision is defined in the laws of rugby as attempting to "charge or knock down an opponent carrying the ball without attempting to grasp that player" (World Rugby, 2019c). Intentional collisions possess one of the highest incidences of injury per 1000 events and are against the laws of the game (Fuller et al, 2007b; World Rugby, 2019c). Suzuki et al (2019) demonstrated that the odds of concussion for a tackler statistically increased when the tackler did not attempt to grasp the ball carrier compared to when a legal tackle was used. Tucker et al (2017b) recorded five collisions/tackles which resulted in concussion where the tackling player did not use their arms. However, propensity could not be calculated as no collisions occurred that did not cause concussion.

Accidental collisions however may occur off the ball, or when two players collide whilst contesting a kick. Tucker et al (2017a) reported kick contests as the most frequent concussion mechanism after the tackle situation. However, due to the small number of kick contests per match (5.9), the frequency of concussions due to kick contests is relatively low (one concussion per 108.3 matches) (Tucker et al, 2017a). Hendricks et al (2016) found players approaching kick contests at high speed increased chances of concussion compared with slow/moderate speeds. High impact forces may increase the chance of sufficient energy directly or in-directly transferred to the head, resulting in concussion (Hendricks et al, 2014a; McCrory et al, 2017; Seminati et al, 2017). No study has investigated the propensity of concussion in unintentional off the ball collisions. Further work is required to illustrate the differences in concussion propensity between intentional and unintentional collisions.

Rucks

Previous studies have found that rucks contribute a relatively small proportion of all concussions in rugby (8.4%) and rugby sevens (2.9%) (Fuller et al, 2015a). Tucker et al (2017a) demonstrated an incidence of one ruck concussion every 20.8 matches in international and men's professional club rugby. This would be further diluted when it is realised that each ruck has to have at least one player from each team and often comprises more. A more accurate approach may be to consider the number of players in rucks per game. No other study has detailed risk factors around sustaining a concussion in ruck situations.

Other Contact Situations

Little evidence exists to suggest that remaining contact scenarios such as scrums and mauls are potent risk factors for concussion. Tucker et al (2017a) demonstrated one concussion would occur every 137.8 matches from a maul and one concussion every 168.4 matches from a scrum, demonstrating their low probability of resulting in concussive injury.

Playing Position

Based on incidence per 1000 hours, no statistical difference in concussion incidence has been reported between forwards and backs (Best et al, 2005; Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Holtzhausen et al, 2006; Moore et al, 2015; Rafferty et al, 2019; RFU, 2019; Schick et al, 2008; Taylor et al, 2011). However, when analysing concussion propensity by 1000 tackles (tackling and being tackled), backs possessed a statistically greater chance than forwards (Tucker et al, 2017a). Backs are more likely to tackle/be tackled at high speed compared with forwards (Brooks et al, 2005a; Cunningham et al, 2016; Whitehouse et al, 2016), which has been reported to increase chance of concussion (Cross et al, 2019; Tucker et al, 2017b).

Protective Equipment

Scrum caps (made of soft polyethylene foam padding) are believed by some players to reduce concussion incidence (Barnes, Rumbold, & Olusoga, 2017; Menger, Menger, & Nanda, 2016). However, previous studies have found mixed results on their effectiveness. In amateur New Zealand rugby players, Marshall et al (2005) found no statistical differences in concussive incidence between those who did and those who did not wear a scrum cap across a single season. Equally, concussive incidence in English Premiership players over the 2002/03, 2003/04 and 2005/06 seasons was not statistically different between those who wore a scrum cap and those who did not (Kemp et al, 2008). Conversely, in a sample of recreational rugby players multivariate analysis found that players who always wore a scrum cap were statistically less likely to sustain a concussion compared with those who never wore one (Hollis et al, 2009). Further studies, especially in professional rugby, are required to determine the effectiveness of scrum caps at reducing concussion incidence.

Mouthguards are used in rugby primarily to reduce orofacial and dental injuries (Quarrie, Gianotti, Chalmers, & Hopkins, 2005). Previous literature suggests a mouthguard may dissipate force sustained to the jaw, increasing separation of the head of the condyle and mandibular fossa, possibly reducing chances of concussion (Singh, Maher, & Padilla, 2009). Mouthguard use was statistically associated with reduced odds of concussion in youth ice hockey (Chisholm et al, 2020). However, studies in recreational and professional rugby have not demonstrated statistical reduction in concussion incidence from mouthguard use (Hollis et al, 2009; Kemp et al, 2008; Marshall et al, 2005).

2.3.4: Interaction of Intrinsic and Extrinsic Risks

The studies outlined above report the various intrinsic and extrinsic factors which may increase the probability of a player sustaining a concussion. However, to fully comprehend concussive aetiology, the interaction of intrinsic and extrinsic risks needs to be understood (Meeuwisse, 1994; Meeuwisse et al, 2007).

Most studies presented above have not considered a multifactorial approach when investigating concussion risk factors or have at very least looked solely at intrinsic or extrinsic factors. Comprehension of how intrinsic and extrinsic factors interact to provide a more valid assessment of concussion propensity in contact events remains largely unknown. The fact that concussion history may impact future incidence (Abrahams et al, 2014; Delaney et al, 2000; Hollis et al, 2009; McCrory, 2004) suggests that a dynamic, recursive approach would be required to further understand concussion aetiology (Meeuwisse et al, 2007). This would illustrate the effect that recovery from previous concussion injury has on probability of sustaining a future concussion (Meeuwisse et al, 2007). As many authors suggest that full recovery from prior concussion is not completed under current rehabilitation and return to sport guidelines (Barrett et al, 2014; Bussey et al, 2019; Cross et al, 2016; DiVirgilio et al, 2019; Hides et al, 2016; Hollis et al, 2009; Howell et al, 2018; Nordström et al, 2014), this appears an avenue of intrinsic risk factors for concussion which needs further understanding.

Meeuwisse et al (2007) developed an updated injury model from that which was developed by Meeuwisse (1994) (shown in figure 2.2 at the start of this section). This updated model allows for previous participation and recovery from injury to be considered as intrinsic risk factors for future injury. No study in professional rugby has appeared to use this model as a framework to investigate how intrinsic concussion history factors and extrinsic risk factors interact and affect overall concussion aetiology. Chapter 4 will attempt to use this model to demonstrate this. The updated model developed by Meeuwisse et al (2007) is shown below in figure 2.3, with risk factors that will be investigated in chapter 4 of this thesis.

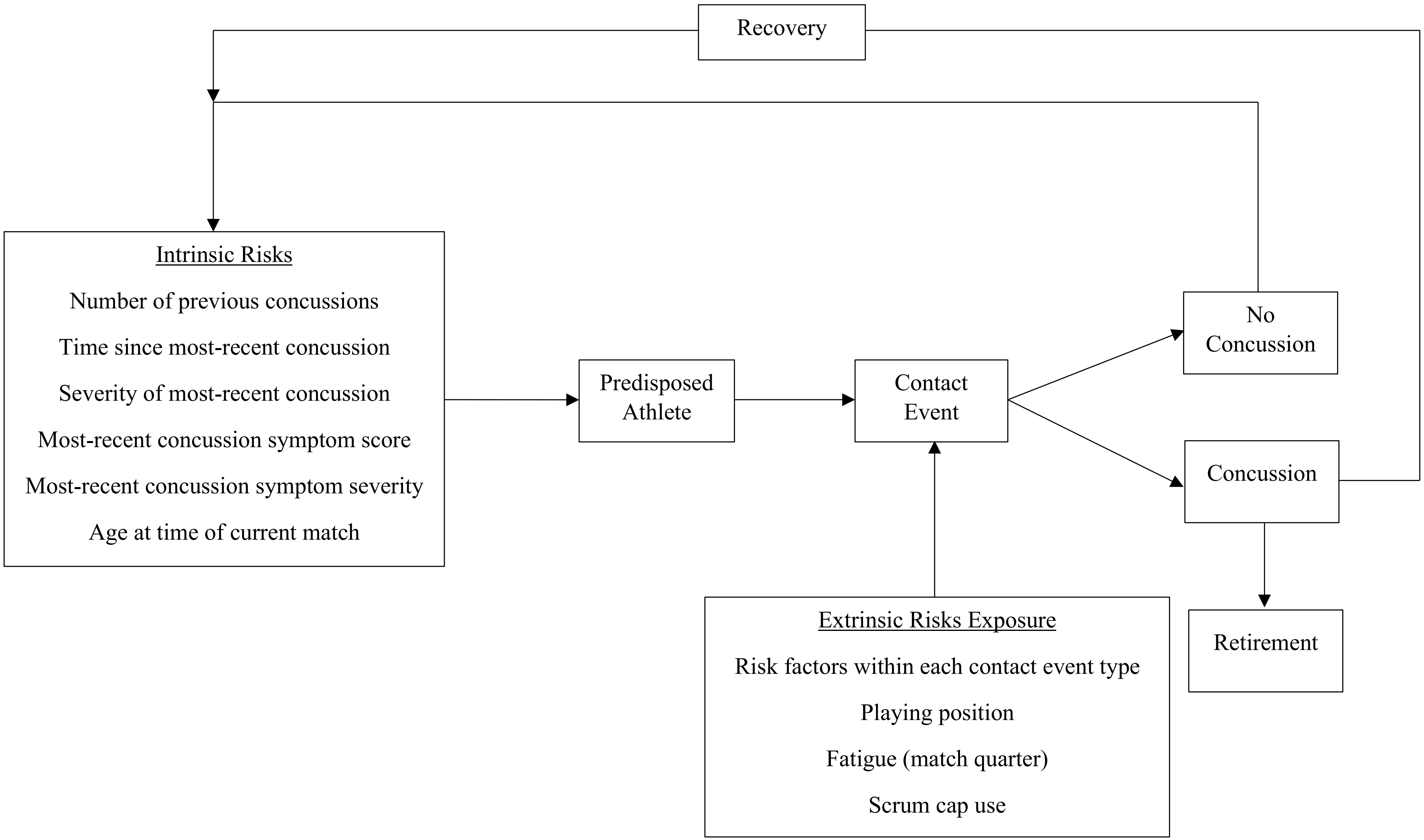

FIGURE 2.3: "A dynamic, recursive model of aetiology in sport injury". Adapted from Meeuwisse et al (2007) to illustrate intrinsic and extrinsic factors for future concussion injury which will be investigated in chapter 4 of this thesis.

2.3.5 Summary

Intrinsic and extrinsic risk factors around an injury can provide greater detail to the aetiology beyond the inciting event where the injury occurs. Numerous previous studies have investigated intrinsic and extrinsic factors for concussion injury, yet few have utilised a multifactorial model investigating the interaction of intrinsic and extrinsic risks. Chapter 4 of this thesis will investigate the effect concussion history and contact event specific risk factors have on concussion aetiology. Using the dynamic, recursive model of injury aetiology approach recommended by Meeuwisse et al (2007), concussion aetiology can be examined in the context of each individual's concussion history, and by extrinsic risk factors experienced in different contact events. This conforms to the second step of van Mechelen's research model "The sequence of prevention of sports injuries" and will provide greater detail on concussion aetiology in professional rugby through considering the context and complexity of concussion occurrence.

2.4: Concussion Prevention Methods (Steps Three and Four of Model)

The final two steps of van Mechelen's research model "The sequence of prevention of sports injuries" recommend that an intervention be implemented to reduce the incidence or severity of injury, and that the effectiveness of the intervention be monitored (van Mechelen et al, 1992). This would usually be based from risk factors discovered in step two of the model. Due to the time-limited nature of the PhD project, an injury intervention measure based around another concussion risk factor found from previous literature was to be chosen prospectively.

National governing bodies such as Scottish Rugby have a duty of care towards their professional players, as stipulated by several acts of United Kingdom health and safety legislation (Fuller, 1995; Fuller, 2018a; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992). It is therefore the role of Scottish Rugby to attempt to reduce injury incidence and severity to protect player welfare (Fuller, 1995; Fuller & Drawer, 2004; UK Public General Acts, 1974; UK Statutory Instruments, 1992). Not only do injuries have an immediate negative impact on player wellbeing, there may also be consequences in later life from injuries occurring during a sporting career, such as osteoarthritis and cognitive degeneration (Baugh et al, 2012; McKee et al, 2009; Stern et al, 2011; Turner, Barlow, & Heathcote-Elliott, 2000). Scottish Rugby also have a financial interest in optimising the possibilities of team success (Morgan, 2002; Zhang et al, 2003), which may be inhibited by player unavailability through injury (Drew et al, 2017; Williams et al, 2016). Mitigation strategies which reduce injury risk are therefore of interest to Scottish Rugby (Fuller & Drawer, 2004).

Two risk reduction methods are theoretically available: preventative interventions aiming to reduce the incidence of injury events; or therapeutic interventions aiming to reduce the severity of injury (Fuller & Drawer, 2004; Fuller, 2007; Fuller et al, 2012). Due to the negative short- and long-term implications of sustaining a concussion injury (Abrahams et al, 2014; Bertrand et al, 2016; Cross et al, 2016; de Beaumont et al, 2007; Decq et al, 2016; Gouttebarge et al, 2017; Hay et al, 2016; Hollis et al, 2009; Hume et al, 2016; Lewis et al, 2017; McGuine, et al, 2014; Nordström et al, 2014), as well the fact that there is currently a standardised concussion rehabilitation protocol (McCrory et al, 2017; see section 2.2), altering which is beyond the realms of this PhD, a preventative measure aiming to reducing concussion incidence appears more practicable in this case.

2.4.1: Injury Prevention Methods in Sport

Injury prevention measures can be broadly placed into three categories: alterations in rules and regulations; protective equipment; and training programmes (Klügl et al, 2010). Altering rules and regulations have been effective at reducing the incidence of injury, with examples from American football, baseball, and ice hockey all demonstrating statistical reductions in injury incidence after rule changes (Black et al, 2016; Cantu & Mueller, 2000; Heck, Clarke, Peterson, Torg, & Weis, 2004; Janda, Bir, & Kedroske, 2001; Marshall, Mueller, Kirby & Yang, 2003). The effectiveness of these forms of interventions may be due to elimination of risk factors responsible for increasing injury incidence, or harsh penalty sanctions to dissuade players from engaging in high-risk activities.

Interventions based around protective equipment and training programmes require behaviour change from the athlete and/or the staff implementing the programme to ensure high levels of adherence (Finch & Donaldson, 2010; Lund & Aarø, 2004; McGlashan & Finch, 2010; Verhagen et al, 2010; Vriend, Gouttebarge, Finch, Van Mechelen, & Verhagen, 2017). Previous studies have demonstrated that greater adherence to an injury prevention programme is often associated with greater reductions in injury risk (Hägglund, Atroshi, Wagner, & Waldén, 2013a; Hislop et al, 2017; Myklebust et al, 2003; Salmon et al, 2013; Soligard et al, 2010). Ensuring implementation methods are optimal, and proposed function and rationale of the programme are effectively communicated to staff and athletes is a vital step in ensuring the necessary behaviour change is caused (Finch, 2006; DiClemente et al, 2002; McGlashan & Finch, 2010; Steffen et al, 2010; Verhagen et al, 2010). This may result in greater levels of adoption, implementation and maintenance of any injury mitigation strategy, increasing the possibility of a positive outcome (Finch, 2006; Glasgow et al, 1999).

2.4.2: Concussion Prevention Programmes

Due to high incidences of concussion reported in rugby match play (Cosgrave & Williams, 2019; Rafferty et al, 2019; RFU, 2019) and negative implications of the injury around player welfare and team performance in both the short- and long-term (Baugh et al, 2012; Cross et al, 2016; de Beaumont et al, 2007; Drew et al, 2017; Gouttebarge et al, 2017; Guskiewicz et al, 2005; Hägglund et al, 2013b; Herman et al, 2016; Lewis et al, 2017; McKee et al, 2009; Nordström et al, 2014; Stern et al, 2011; Williams et al, 2016) interventions to reduce the incidence of concussion are of interest to Scottish Rugby. Strict protocol is imposed around concussion diagnosis and management within Scottish Rugby, and professional players are required to participate in compulsory education programmes around concussion recognition and the importance of adhering to Scottish Rugby, Sport Scotland, and World Rugby guidelines around concussion diagnosis and management (Scottish Rugby, 2018; Sport Scotland, 2018; World Rugby, 2017a). However, Scottish Rugby currently have no universal approach to concussion prevention.

Previous research investigating concussion prevention in sport have focused on all three intervention categories: policy/rule changes; protective equipment; and training interventions. Black, Hagel, Palacios-Derflingher, Schneider and Emery (2017) studied the effect of a nationwide policy change to ban body-checking in youth ice hockey until the ages of 13-14. A statistical reduction in concussion incidence was found pre- to post-policy change (Black et al, 2017). Harsher punishment for use of high elbows when heading in professional soccer led to a statistical reduction in head injuries (Bjørneboe, Bahr, & Andersen, 2013). A statistical reduction in concussion incidence was found from pre- to post-policy change limiting the amount of full-contact training in American football to 60 minutes per week (Pfaller, Brooks, Hetzel, & McGuine, 2019). Wiebe, D'Alonzo, Harris, Putukian and Campbell-McGovern (2018) assessed the efficacy of a rule change in Ivy League American football to limit the frequency and collision impact force of kick-off returns by moving the kick-off to the 40 yard line. This resulted in a statistical reduction in concussion incidence (Wiebe et al, 2018). These studies demonstrate the efficacy of regulation/policy alterations on reducing concussion incidence.

However, trials attempting to reduce concussion incidence through regulation alteration in rugby have yet to be proved successful. Previous risk factor studies investigating extrinsic risks in tackle events have suggested that lowering the legal tackle height may be an effective method to reduce concussion incidence (Cross et al, 2019; Tucker et al, 2017a). Stokes et al (2021) investigated whether lowering the maximum height of legal tackles to the armpit line (from the line of the shoulders) would reduce the incidence of concussion in men's elite club rugby. Pre- to post-policy change, the proportion of upright tacklers and ball carriers, tackles where the tackler made first contact with the ball carrier's head/neck, and tackles where the initial contact was above the armpit line were all statistically reduced, yet concussion incidence did not decrease (Stokes et al, 2021). Conversely, incidence and propensity of concussion to the tackling player statistically increased pre- to post-policy change (Stokes et al, 2021). The authors suggested that interaction of unintended consequences/behaviours around the tackle as a result of the rule change, other extrinsic risks such as weather conditions/time of season, and an enhanced focus on concussion reporting/diagnosis as a result of the policy change may have influenced the results (Stokes et al, 2021). No other studies appear to have been published on efficacy or effectiveness of regulation alterations in rugby to reduce concussion occurence.

As a form of protective equipment, mouthguards have been postulated as being able to dissipate force sustained to the jaw and increase separation of the head of the condyle and mandibular fossa, possibly reducing concussion incidence (Singh et al, 2009). Match concussion incidence was statistically reduced across a full season in American football for players wearing custom-fitted mouthguards compared with standard mouthguards (Winters & Demont, 2014), whilst mouthguard use statistically reduced odds of concussion in ice hockey (Chisholm et al, 2020). However, no study has found a protective effect of mouthguard use on concussion incidence in rugby (Hollis et al, 2009; Kemp et al, 2008; Marshall et al, 2005).

Scrum caps (made of soft polyethylene foam padding) are believed by some players to reduce concussion incidence (Barnes et al, 2017; Menger et al, 2016). Recent studies have suggested some brands of scrum caps are capable of attenuating linear and rotational accelerations to human headforms (Candy, Ma, McMahon, Farrell, & Mychasiuk, 2017; Ganly & McMahon, 2018). Scrum cap use was reported to statistically reduce concussion incidence in recreational rugby players over 1-3 seasons (Hollis et al, 2009). However, other studies have found no statistical reduction in concussion incidence from scrum cap use in amateur and professional rugby (Kemp et al, 2008; Marshall et al, 2005). The effect of scrum cap use to reduce concussion incidence appears unclear.

The majority of concussions occur in contact situations, with tackling the most common mechanism (Cosgrave & Williams, 2019; Tucker et al, 2017a). Technical deficiencies in tackling technique have been suggested to increase concussion propensity to both the tackling and tackled player (Cross et al, 2019; Sobue et al, 2017; Tucker et al, 2017b). Therefore, implementing a tackling technique training intervention may reduce concussion propensity in these contact types. It appears however that only one study has attempted to implement a tackling technique intervention in rugby. Kerr et al (2018) utilised a World Rugby training video to attempt to teach correct tackling technique amongst university and school-aged rugby players. However, no definite improvements were found, with some elements of tackle technique getting worse throughout the learning process (Kerr et al, 2018).

From literature reviewed, there appears limited evidence to suggest that protective equipment or technique interventions may be capable of reducing concussive incidence in rugby. Whilst rule/policy alterations in other sports suggest these may be capable of reducing concussion incidence, the one example of this in rugby has been unsuccessful (Stokes et al, 2021), and interventions such as this are beyond the scope of the current PhD. Training interventions to reduce concussive injury have begun to be explored in amateur and youth rugby, but not yet in professional or elite players. Attwood et al (2017) and Hislop et al (2017) monitored the efficacy of a pre-activity exercise intervention on reducing the incidence of rugby injuries in recreational rugby. Both studies found statistical reductions in incidence of concussion as a result of the intervention. The authors speculated that the reduction in concussion incidence was due to isometric neck resistance training exercises included in the programme, owing to the relationship between greater neck strength and reduced probability of concussion (Attwood et al, 2017; Collins et al, 2014; Hislop et al, 2017). An intervention targeting improvements in neck strength appears to have stronger rationale and potential than other equipment/training interventions to reduce incidence of concussion.

2.4.3: Neck Strength and Concussion

Concussion will occur as a result of direct or indirect force applied to the head, resulting in the sudden acceleration/deceleration of the head and brain (McCrory et al, 2017; Rowson & Duma, 2013). The cervical spine is responsible for controlling the acceleration of the head during impulsive loading (Dempsey et al, 2015; Gutierrez et al, 2014; Tierney et al, 2005), and the cervical spine musculature is responsible for approximately 80% of the stability of the cervical spine (Panjabi et al, 1998). Strength of each individual's cervical spine musculature may therefore influence their probability of concussion (Hrysomallis, 2016).

Viano et al (2007) reported that increased neck stiffness reduced peak head acceleration and change in velocity of the head in reconstructed head impacts using a Hybrid III dummy. The dynamic restraint system of muscles of the neck may be able to provide protective properties to the head through feed-forward control in an anticipated collision (Mansell et al, 2005). Stronger neck muscles may stabilise the head and incorporate the torso as the effective mass and therefore reduce head acceleration and concussion probability during impact (Broglio et al, 2012; Eckner et al, 2014). Both Newton's second law of motion and the law of energy conservation state a smaller mass will experience greater acceleration for a given force compared with a larger mass. Compared with the head and torso incorporated together, weak neck strength may result in the small mass of the head experiencing a large change in velocity pre- to post-collision, possibly increasing probability of concussion (Broglio et al, 2012; Eckner et al, 2014; Rowson & Duma, 2013; Viano et al, 2007; Zhang et al, 2004). Greater force production by muscles of the neck may therefore reduce concussion propensity in anticipated collisions. Overall neck strength was found to be a statistical predictor of concussion incidence over two years in girls' and boys' soccer, basketball and lacrosse (Collins et al, 2014). Athletes who were concussed across the two years were shown to have 11-22% less overall neck strength than those who were non-concussed (Collins et al, 2014). Through logistic regression, it was suggested a 0.45 kg increase in overall neck force production would decrease concussion probability by 5% (Collins et al, 2014).

Whilst Attwood et al (2017) and Hislop et al (2017) attributed reductions in concussion incidence to increased neck strength as a result of isometric neck strengthening exercises, changes in neck strength were not monitored. Their studies were also implemented in recreational and youth rugby as opposed to elite players. Previous studies in elite rugby have focused on enhancing neck strength (Geary, Green, &

Delahunt, 2014; Naish, Burnett, Burrow, Andrews, & Appleby, 2013) without monitoring subsequent alterations to concussion incidence. It appears no previous study has implemented a neck training programme aiming to enhance neck function and reduce concussion incidence in elite rugby. A controlled trial aiming to assess the effectiveness of a neck training programme in enhancing neck function and reducing concussion incidence in elite rugby players will form the aim of chapter 5 of this thesis.

2.4.4: Summary

Due to negative short- and long-term implications of concussion injury around player welfare and team performance, a primary concussion prevention measure should be of interest to Scottish Rugby, and applied rugby settings across the world. Protective equipment and technique interventions currently show limited promise. Whilst rule/policy changes in other sports appear capable of reducing concussion incidence, a recent attempt at this in rugby was not effective. An intervention based upon altering rules/regulations of rugby is beyond the scope of this thesis.

Recent work has attributed reductions in concussion incidence in recreational and youth rugby to neck strengthening exercises. This has yet to be investigated in elite rugby. Chapter 5 of this thesis will aim to assess the efficacy of a neck training programme aiming to enhance neck function and reduce match concussion incidence in elite Scottish rugby players. Although this will be a controlled trial and not implemented in a real-world setting, recommendations to improve chances of the necessary behaviour change required for programme adoption by staff and players will be followed. This conforms to the third and fourth steps of van Mechelen's research model "The sequence of prevention of sports injuries", with consideration of implementation context. This will complete the research model, and complete data collection for this thesis.

2.5: Summary

Rugby is a high intensity-contact sport where high injury incidences are often reported. In recent years, concussion has become the most frequently reported match injury in most professional cohorts. Due to negative short- and long-term implications of concussion injury around player welfare and team performance, accurately understanding the incidence and aetiology of concussion, and attempting to reduce the incidence should be of interest to national governing bodies such as Scottish Rugby. This enables Scottish Rugby to fulfil their legal requirements as stipulated by United Kingdom health and safety legislation, as well as increasing their opportunity for team and financial success (Fuller, 1995; HSE, 2013; Morgan, 2002; UK Public General Acts, 1974; UK Statutory Instruments, 1992; Zhang et al, 2003).

The proposed research will follow van Mechelen's research model "The sequence of prevention of sports injuries" in an attempt to further the understanding of concussion in professional rugby in Scotland. However, in order to address potential pitfalls with the sequence of prevention approach discussed in chapter one of this thesis concerning the lack of consideration of context and complexity of injury aetiology, and the context in which interventions are implemented (Bolling et al, 2018; Fuller, 2019; Fuller, 2020; Meeuwisse et al, 2007), adaptations to the model will be instigated to improve ecological validity of investigation. Modifications will also be followed due to time constraints placed on data collection throughout this PhD project.

Concussion epidemiology in professional rugby in Scotland is unknown in scientific literature. Due to rising concussion incidences reported in other cohorts around the world, concussion epidemiology research is warranted. Chapters 3A and 3B of this thesis will aim to establish the incidence, severity, and burden of concussion in comparison to all other injuries, and to report on concussion cause and mechanism. This is in-line with the first step of van Mechelen's research model.

Concussion is a multifactorial injury, with many intrinsic and extrinsic risks likely to affect probability of concussion outcome. In order to gain a more accurate understanding of concussion aetiology, a multifactorial approach to risk factor investigation is required (Bolling et al, 2018; Fuller, 2019; Meeuwisse et al, 2007). No previous study has investigated the potential interaction effect on concussion outcome from simultaneously analysing intrinsic concussion history and extrinsic contact event specific risk factors in professional rugby. Chapter four of this thesis will aim to achieve this, allowing concussion aetiology to be examined in the context of each individual's concussion history, and by extrinsic risk factors experienced in different contact events. This conforms with the second step of van Mechelen's research model, whilst considering the context and complexity of injury aetiology.

Concussion prevention strategies should be of interest to Scottish Rugby, and to other applied rugby institutions. Protective equipment such as mouthguards or scrum caps, or technique interventions such as tackling instruction appear to be ineffective at reducing concussion incidence, or at least there is insufficient evidence to support their effectiveness. Recent research has postulated on a link between enhanced neck strength and reduced concussion incidence. However, no study in elite rugby has assessed the effectiveness of a neck training programme aiming to enhance neck function and reduce concussion incidence. This will be the aim of chapter 5 of this thesis. This will be a controlled trial, aiming to provide proof of concept of whether the programme can enhance neck function, and in-turn whether those that complete the programme experience a reduction in concussion incidence. Factors to ensure the necessary behaviour change to observe high levels of adherence and adoption of the intervention programme will be considered (Finch, 2006; DiClemente et al, 2002; McGlashan & Finch, 2010; Steffen et al, 2010; Verhagen et al, 2010), improving the context of programme implementation (Finch, 2006). This investigation will complete stages three and four of van Mechelen's research model.

END OF CHAPTER TWO

CHAPTER 3A: INJURY EPIDEMIOLOGY

3A.1: Introduction

Rugby and rugby sevens are both defined as high intensity team-sports, with frequent player-on-player collisions (Quarrie et al, 2013). This results in a high injury incidence, even when compared to other full-contact sports such as ice-hockey and rugby league (Fitzpatrick et al, 2018; Fuller et al, 2017b; Tuominen et al, 2015). Comprehension by sporting national governing bodies of the incidence, severity, type, location and causes of injury will allow identification of areas of greatest risk and review of current injury rehabilitation, management and prevention programmes.

Professional rugby injury incidences appear to vary on a season-by-season and methodological basis (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Moore et al, 2015, RFU, 2019, Whitehouse et al, 2016). Since 2011/2012, studies have recorded an increase in reported incidence of concussion (Brooks et al, 2005a; Brooks et al, 2005c; Rafferty et al, 2019; RFU, 2019). Recent studies suggest that concussion is the most frequent match injury in professional rugby (Fuller et al, 2017b; Rafferty et al, 2019; RFU, 2019). Due to possible short- and long-term player welfare implications of concussive injury, and the negative impact player absence may have on team success, increasing the understanding of concussion incidence in professional rugby in Scotland is of high importance (Cross et al, 2016; Drew et al, 2017; Gouttebarge et al, 2017; McKee et al, 2009; Stern et al, 2011; Williams et al, 2016).

Since a study of men's professional club rugby in the early days of professionalism (Garraway et al, 2000), there has been no contemporary injury surveillance study of professional rugby in Scotland. Context specific research is necessary to enable Scottish Rugby to understand the risk of injury in general, and concussion specifically on availability of professional players in Scotland. The primary aim of the current chapter is therefore to undertake a detailed epidemiological study of all match and training injuries sustained by professional Scottish Rugby cohorts across the 2017/18 and 2018/19 seasons, describing the incidence, severity, burden, and nature of injuries. Concussion specific epidemiology will follow in Chapter 3B.

3A.2: Methods

3.2.1: Participants

Players from the following cohorts were included in the study: men's international rugby; women's international rugby; men's professional club rugby; men's international rugby sevens; and women's international rugby sevens. Players included in at least part of one match, or at least one training session were included. As members of a union which is centrally controlled, all players state upon signing contracts/agreements with Scottish Rugby that they consent for injury data to be used and/or analysed by Scottish Rugby, or any affiliates which it sees fit (appendix 2). Edinburgh Napier University Ethics Committee provided ethical approval for the study.

3.2.2: Procedures

This was a prospective cohort study of all injuries recorded in match and training during the 2017/18 and 2018/19 seasons. Data collection commenced on the 1st June 2017 and finished on 24th June 2019. The seasons were demarcated as outlined in figure 3A.1.

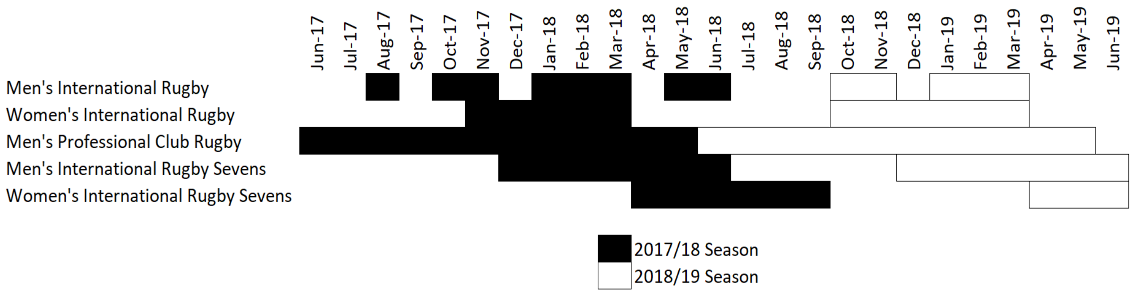

FIGURE 3A.1: Season demarcation for cohorts involved in the study.

A new injury audit structure was introduced throughout Scottish Rugby for this research. A workshop event was held in Summer 2017, providing information for Scottish Rugby medical staff on how to record and classify injuries, with examples and definition handouts provided. This was reinforced on two occasions by email throughout the data collection period, and ahead of the 2018/19 season.

Injuries throughout the 2017/18 and 2018/19 season were recorded by qualified Scottish Rugby medical staff on an online database that itemised injuries by type and location by using the Orchard Sports Injury Classification System (OSICS) version 10, and detailed playing position and match quarter, as recommended by Rae and Orchard (2007). Throughout the 2017/18 season, a commercially available online platform EDGE 10 (EDGE, London, UK) was used to store injury information. This was changed to using an online Microsoft Excel spreadsheet (Microsoft, Redmond, Washington, USA) for the 2018/19 season. Injuries were attributed to either match or training, allowing these injuries to be analysed separately. Training injuries were attributed to the training activity where the injury was sustained. Information pertaining to the state of injury recurrence, cause, and rugby specific mechanism were noted, as recommended by the international consensus statement for injury epidemiology studies in rugby, and the International Olympic Committee injury and illness surveillance system (Fuller et al, 2007d; Junge et al, 2008). Injuries were allocated to whichever cohort (men's international rugby, women's international rugby, men's professional club rugby, men's international rugby sevens, or women's international rugby sevens) the player was training or playing with at the time. Injuries sustained outwith training or match-play in sanctioned and official Scottish Rugby occasions were not included.

Injury Validation Procedure

Injury data was downloaded from the online databases by the Scottish Rugby Medical Services Manager and collected by this researcher at 3-monthly intervals. Prior to analysis, collected data was examined objectively in Microsoft Excel to ensure the validity of the information provided. The aims of this procedure are listed below:

- To identify and remove any duplicate injury entries, ensuring the correct number of injuries were reported for each player throughout the data collection period.
- To assess and prove beyond reasonable doubt that injuries reported as "Match" or "Training" injuries did occur in official and sanctioned Scottish Rugby match-play or training events. This ensured the incidence of injury for each cohort in matches and training was as accurate as possible.
- To ensure reported injury severity data for each injury was correct, by assessing whether players were participating in matches whilst reported injury severity from a prior injury suggested they were still unavailable for match selection.

In any situation where injury data provided by Scottish Rugby was not clear, clarification was sought with Scottish Rugby medical staff who had entered the data in question.

3.2.3: Injury definitions

An injury was defined as recommended by the international consensus statement for injury epidemiology studies in rugby (Fuller et al, 2007d), and is described as follows:

"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."

Injury severity was defined as the number of days the injured player was unavailable for match selection and unable to take a full part in training, excluding the day of injury and the day of return (Fuller et al, 2007d). For injuries that were still ongoing by October 2019, Scottish Rugby medical staff were asked to estimate completion dates. In-line with previous rugby injury surveillance studies (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Moore et al, 2015; West et al, 2020) and the consensus statement for injury epidemiology studies in rugby, only time-loss injuries with ≥ 2 days severity are presented in this research (Fuller et al, 2007d).

Recurrent injuries were defined as recommended by Fuller et al (2007d):

"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"."

3.2.4: Exposure

Match Exposure

Match exposure was defined as play between two teams (Fuller et al, 2007d). Match exposure time was recorded individually for each player. This was determined as the time spent on the pitch from kick-off/when they first appear as a substitute, up until the final whistle/leaving the pitch to be replaced by a substitute. Time spent off the pitch due to half-time, yellow/red cards, blood injury and head injury assessment was not included in match exposure.

Exposure was recorded solely by Global Positioning System (GPS) software for men's and women's international rugby and men's professional club rugby. Men's international rugby and one professional club (Edinburgh Rugby) used Catapult Optimeye S5 devices (Catapult; Melbourne, Australia) for the entire study duration. The other men's professional club (Glasgow Warriors) used GPSports Evo devices (GPSports; Canberra, Australia) for the 2017/18 season, and Catapult Optimeye S5 devices for the 2018/19 season. Women's international rugby used GPSports Evo devices across the two seasons. Men's international rugby sevens match exposure for each player was recorded by Scottish Rugby video analysts. International women's rugby sevens was recorded by Scottish Rugby medical or performance staff stationed pitch-side during the 2017/18 season, and used GPSports Evo GPS devices during the 2018/19 season.

Match exposure for each player was represented as a proportion of the total team exposure, calculated as recommended by Fuller et al (2007d):

$$N_M P_M D_M/60$$

With N_M representing the number of matches played, P_M the number of players in a team, and D_M as match duration. Table 3A.1 lists matches included for in the study for match exposure for each cohort.

TABLE 3A.1: Match exposure for all cohorts

Men's International Rugby
2017 Autumn Internationals
2018 Six Nations
2018 Summer Tour
2018 Autumn Internationals
2019 Six Nations
Women's International Rugby
2017 Autumn Internationals
2018 Six Nations
2018 Autumn Internationals
2019 Six Nations
Men's Professional Club Rugby
2017 Pre-Season Matches
2017/18 Pro 14
2017/18 European Rugby Champions/Challenge Cup
2018 Pre-Season Matches
2018/19 Pro 14
2018/19 European Rugby Champions/Challenge Cup
Men's International Rugby Sevens
2017/18 World Series
2018 Commonwealth Games
2018/19 World Series
Women's International Rugby Sevens
2018 Amsterdam Sevens
2018 European Grand Prix
2019 European Grand Prix
2019 Hong Kong Sevens

Training Exposure

Training exposure was defined using the recommended definition of Fuller et al (2007d):

"Team-based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' rugby skills or physical condition."

Scottish Rugby performance staff were responsible for recording training exposure for each player. Training exposure was recorded as time spent in different activities for each player, which were then attributed to the categories listed in table 3A.2. Activities were placed into categories depending on the primary aim of that activity.

TABLE 3A.2: Categories of training activity

Training Activity Categories	
General Play/Phase Work	Endurance WB
Defence	Endurance NWB
Scrums	Weights
Lineouts	Fitness Testing
Skills	Rehabilitation
Rucking/Mauling	Other

WB = Weight Bearing; NWB = Non-Weight Bearing

Several inconsistencies were found with data recording in training (missing player and session exposure data) amongst women's international rugby, men's international rugby sevens and women's international rugby sevens. This resulted in an inaccurate description of training exposure. Epidemiology of training injuries were therefore not analysed within these cohorts.

On-Pitch Training Exposure

Training exposure for on-feet pitch activities was recorded using the aforementioned GPS devices for men's international rugby and men's professional club rugby. Each session was divided into multiple periods, named with the type of drill that was being performed (see figure 3A.2). Scottish Rugby video analysts and sport scientists present at each training session annotated each player's GPS device with the periods they were involved in. The software associated with these devices produces a configurable team report (CTR) output for each training session (see appendix 3 for example). Each training period was attributed to the list of activities in table 3A.2 by the primary researcher**.** The duration of each period (from start-time to end-time) was taken as the training exposure. For total training exposure across the two seasons, all periods that each player had participated in were summed. If a player's GPS device did not record correctly, their GPS output was estimated by copying the data from a player in the same positional group in the same session.

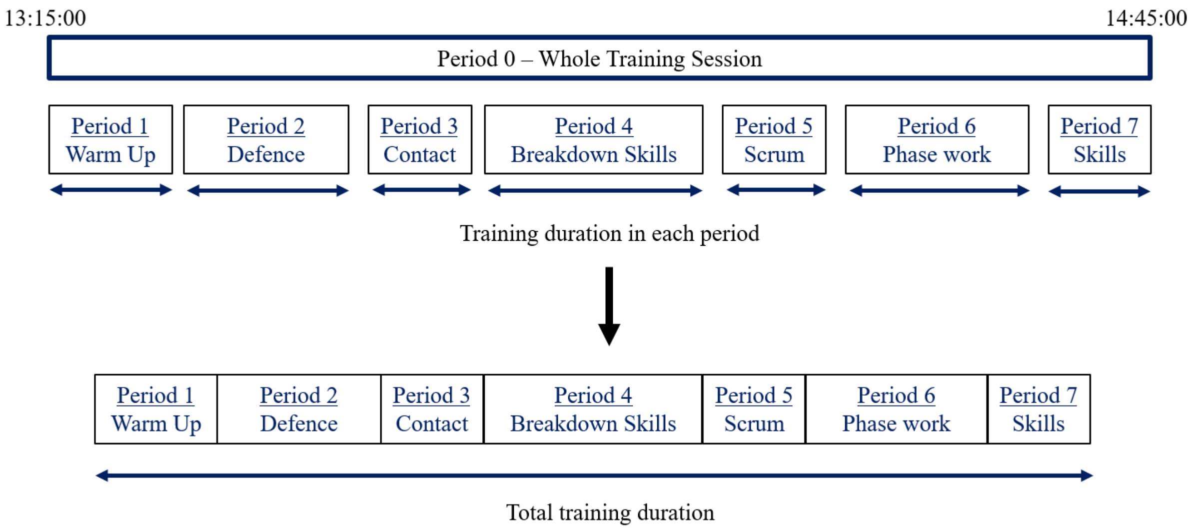

FIGURE 3A.2: On-pitch training session structure with periods

In order to ensure accuracy of raw CTR exports, training exposure and distance covered during each training session for each player was checked against Scottish Rugby's training databases for each team. These checks were performed with Microsoft Excel. Any differences found were queried and solved upon discussion with Scottish Rugby sport science staff.

For periods that were named with a combination of two possible training activities (i.e. "Scrums and Lineouts"), the ratio of time spent in these activities in that cohort across the two seasons were used to divide these periods into their respective training activities. Periods that were termed "Units" were divided differently for forwards and backs. "Units" periods for backs were split into "Skills", "Defence", and "General Play/Phase Work", with training duration based on the ratio of time spent in these activities across the cohort in question. “Units” periods for forwards were split into “Lineouts”, “Scrums”, “Skills”, and “Rucking & Mauling”. For men’s international rugby during the data collection period, 135.2 hours of training were split using this method (2.8% of all training exposure). For men’s professional club rugby, 5,338.1 hours of training were split (11.4% of all training exposure).

Off-Pitch Training Exposure

Exposure to off-pitch training modalities (resistance training, rehabilitation, off-feet conditioning) was recorded by each player on a custom designed mobile-phone application to document session duration. This information was uploaded and stored centrally at Scottish Rugby. Duration was taken as the time from the start of the session to the end, ignoring rest/recovery periods.

For sessions where duration was not recorded, duration was estimated by the duration of time allocated to that activity in the daily schedule (men’s international rugby only, only including players training with the squad at the time), or by predictive formula based upon resistance training log-books. Log-books were recorded by Scottish Rugby performance staff, and documented repetitions and load used in resistance training sessions by each player. Based on the data available in different log-books, two formulae were developed and used:

1) (total sets x VL) x 0.2
2) LOG_{10}(Different Lifts x Cumulative VL) x 17.45

Where VL = Load x Reps. Results from formula 1) were capped between 20 and 90 minutes and had an absolute error of 12.9 ± 23.5 mins. Formula 2) had an absolute error of 8.8 ± 7.4 mins. Total estimated off-pitch training exposure was 590.0 hours (12.4% of total training exposure) and 3,118.2 hours (6.7% of total training exposure) for men’s international rugby and men’s professional club rugby respectively.

3.2.5: Data Analysis

Injury incidence for training and matches was expressed as number of injuries per 1000 player hours (match or training). Both mean injury severity (total days absence divided by number of injuries) and median injury severity (middle value of data set) were calculated to account for positive skew in severity data distribution caused by small numbers of high severity injuries. Due to positive skew of injury severity data, statistical comparisons were only sought between median severity values. Injury burden was calculated as mean severity multiplied by injury incidence and expressed as days absence/1000 player hours (match or training) (Fuller, 2018b). Injury incidence and injury burden data were accompanied by 95% Confidence Intervals (CI) calculated by normal approximation according to the Poisson distribution:

$$\lambda \pm z(\alpha/2) \times \mathrm{sqrt}(\lambda/n)$$

Where λ = injury incidence or burden, z = 1.96 for 95% CI, and n = total exposure (hours) (van Belle, Fisher, Heagerty, & Lumley, 2004). To facilitate comparisons between cohorts in some instances, number of injuries and injury burden were also expressed as proportions with 95% CI calculated by approximation to a normal distribution as follows:

$$p \pm (z \times (\sqrt{(p(1-p))/n}))$$

Where p = calculated proportion, z = 1.96 for 95% CI, and n = sample size (Kirkwood & Sterne, 2006). Confidence intervals for mean injury severity data were calculated as follows:

$$a \pm (z \times s/\sqrt{n})$$

Where a = mean severity, z = 1.96 for 95% CI, s = standard deviation of mean severity and n = sample size (Kirkwood & Sterne, 2006). Confidence intervals for median injury severity data were calculated as follows:

$$q = nq \pm z\sqrt{(nq(1-q))}$$

Where q = median severity, n = sample size and z = 1.96 for 95% CI (Conover, 1980). In all instances, lower 95% CIs were capped at 0.0, and at 100.0% for proportions. Data is presented by position or positional group for rugby cohorts in some instances – this is not performed for rugby sevens cohorts due to potential for interchanging between positional groups in these cohorts. Data analysis was performed using Microsoft Excel.

3.2.6: Statistical Analysis

Differences in player anthropometrics (mean ± SD) were assessed by t-test. Differences in injury incidence and median severity were assessed by incidence rate ratios (IRR) and Mann-Whitney U tests respectively. When directly comparing one cohort to another, comparisons were made as presented in table 3A.3. Chi-squared tests (Fisher's exact tests if expected counts were small) were used to determine differences in injury proportions and injury burden proportions across multiple cohorts. Effect size of chi-squared analysis was estimated by Cramer's V to estimate effect size, and post-hoc testing was performed by analysis of adjusted standardised residuals by cell-by-cell comparison (Agresti, 2018; Cohen, 1988). A statistical significance value of 0.05 was used. However, numerous statistical tests were conducted throughout this chapter, potentially causing a number of results to appear statistically significant at the $p \leq 0.05$ level by chance through type I error (Armstrong, 2014). For this reason, exact *p* values are reported to allow for evaluation certainty to be interpreted (unless $p < 0.001$), as is recommended in epidemiology research (Rothman, 1990), and with previous injury epidemiology studies in rugby union (Fuller et al, 2020a). Statistical analysis was performed using Microsoft Excel and IBM SPSS statistics for Windows Version 26 (IBM, Armonk, New York, USA).

TABLE 3A.3: Comparisons between cohorts for incidence and severity

Men's International Rugby	vs.	Women's International Rugby
Men's International Rugby	vs.	Men's Professional Club Rugby
Men's International Rugby	vs.	Men's International Rugby Sevens
Women's International Rugby	vs.	Women's International Rugby Sevens
Men's International Rugby Sevens	vs.	Women's International Rugby Sevens

<u>*3A.3: Results:*</u>

3A.3.1: Match Injuries

Baseline Data

Two-hundred and eight different players (men: 163; women: 45) participated in at least one match across all cohorts during the 2017/18 and 2018/19 seasons (table 3A.4; certain players participated in at least one match for more than one cohort). Forwards were heavier than backs within each rugby cohort each season ($p < 0.001$). Rugby sevens cohorts were not split into forwards and backs due to the greater interchangeability between positional groups in rugby sevens.

TABLE 3A.4: Player data for each professional cohort within Scottish Rugby over the 2017/18 and 2018/19 seasons

Cohort	Season	Players (n)		Age (years)		Mass (kg)	
		F	B	F	B	F	B
Men's International Rugby	2017/18	28	23	27.1 ± 3.8	27.0 ± 3.1	113.4 ± 7.2*	92.0 ± 6.7
	2018/19	23	18	26.1 ± 3.3	26.3 ± 3.3	114.0 ± 6.8*	92.9 ± 7.3
	Total	35	25	26.3 ± 3.6	26.6 ± 3.1	113.4 ± 6.8*	92.2 ± 6.8
Women's International Rugby	2017/18	15	14	25.6 ± 4.6	24.4 ± 2.9	81.4 ± 6.7*	68.4 ± 6.8
	2018/19	19	14	23.6 ± 3.3	24.9 ± 3.0	82.0 ± 9.3*	68.2 ± 6.3
	Total	21	16	24.6 ± 4.4	24.7 ± 3.0	82.0 ± 9.3*	68.3 ± 6.6
Men's Professional Club Rugby	2017/18	62	49	26.3 ± 3.9	25.9 ± 3.2	112.3 ± 9.2*	94.2 ± 8.1
	2018/19	59	46	25.6 ± 3.9	25.4 ± 3.4	113.1 ± 8.1*	93.5 ± 7.8
	Total	77	57	26.2 ± 4.1	25.8 ± 3.3	112.8 ± 8.8*	94.0 ± 7.9
Men's International Rugby Sevens	2017/18	26		25.6 ± 3.9		91.6 ± 9.2	
	2018/19	20		24.9 ± 4.0		91.0 ± 9.4	
	Total	29		25.3 ± 3.9		91.3 ± 8.8	
Women's International Rugby Sevens	2017/18	14		26.2 ± 3.8		68.8 ± 7.2	
	2018/19	22		25.6 ± 4.1		68.2 ± 6.4	
	Total	25		25.7 ± 4.2		68.7 ± 6.5	

F = Forwards; B = Backs. * ($p < 0.001$) forwards to backs within cohort.

Table 3A.5 presents number of match injuries and match exposure for all cohorts. Four-hundred and eighty-seven injuries were recorded across all professional cohorts with 139 players sustaining at least one injury. This resulted in 66.8% of players sustaining at least one injury across the 2017/18 and 2018/19 seasons. From all injured players, the majority (106 players; 76.3% of injured players) incurred at least two injuries, whilst 34 players (24.4% of injured players) sustained five or more injuries, representing 51.1% of all injuries.

TABLE 3A.5: Match injuries and exposure for each professional cohort in Scotland across the 2017/18 and 2018/19 seasons.

Cohorts	Season	Injuries (n)			Match Exposure (h)		
		Forwards	Backs	All	Forwards	Backs	All
Men's International Rugby	**2017/18**	14	9	23	117.3	102.7	220.0
	2018/19	14	11	25	96.0	84.0	180.0
	All	28	20	48	213.3	186.7	400.0
Women's International Rugby	**2017/18**	10	8	18	74.7	65.3	140.0
	2018/19	23	9	32	85.3	74.7	160.0
	All	33	17	50	160.0	140.0	300.0
Men's Professional Club Rugby	**2017/18**	76	62	138	650.7	569.3	1,220.0
	2018/19	95	102	197	661.3	578.7	1,240.0
	All	171	164	335	1,312.0	1,148.0	2,460.0
Men's International Rugby Sevens	**2017/18**			19	-	-	96.4
	2018/19			24	-	-	91.5
	All			43	-	-	187.8
Women's International Rugby Sevens	**2017/18**			4	-	-	23.6
	2018/19			7	-	-	48.1
	All			11	-	-	71.6

Table 3A.6 presents injury incidence for each cohort by season and positional group (rugby cohorts only). The greatest overall injury incidence was found for men's international rugby sevens (229.0/1000 player match hours) followed by women's international rugby (166.7/1000 hours) and women's international rugby sevens (153.6/1000 hours). A statistically greater overall incidence of injury was found for men's international rugby sevens compared with men's international rugby (IRR: 1.9; 95% CI: 1.3-2.9; $p = 0.002$).

Examining overall injury incidence by positional group, the greatest injury incidence was recorded for women's international forwards (206.3/1000 hours), followed by men's professional club backs (142.9/1000 hours) and men's international forwards (131.3/1000 hours). No statistical differences in overall injury incidence were found between positional groups within cohorts, or within positional groups between cohorts.

Aside from women's international rugby sevens, and women's international rugby backs, injury incidence was greater in the 2018/19 season compared with 2017/18 for all cohorts. However, statistically greater incidences of injury in 2018/19 compared with 2017/18 were only found for men's professional club backs (IRR: 1.6; 95% CI: 1.2-2.2; $p = 0.003$) and men's professional club rugby overall (IRR: 1.4; 95% CI: 1.1-1.8; $p = 0.002$).

TABLE 3A.6: Match injury incidence for each professional cohort in Scotland across the 2017/18 and 2018/19 seasons.

Cohorts (injuries, n)	**Season**	**Injury Incidence (95% CI)**		
		Forwards	**Backs**	**All**
Men's International Rugby (48)	**2017/18**	119.4 (56.8-181.9)	87.6 (30.4-144.9)	104.5 (61.8-147.3)
	2018/19	145.8 (69.4-222.2)	131.0 (53.6-208.3)	138.9 (84.4-193.3)
	All	131.3 (82.6-179.9)	107.1 (60.2-154.1)	120.0 (86.1-153.9)
Women's International Rugby (50)	**2017/18**	133.9 (50.9-216.8)	122.5 (37.6-207.4)	128.6 (69.2-188.0)
	2018/19	269.6 (159.4-379.8)	120.5 (41.8-199.2)	200.0 (130.7-269.3)
	All	206.3 (135.9-276.6)	121.4 (63.7-179.2)	166.7 (120.5-212.9)
Men's Professional Club Rugby (335)	**2017/18**	116.8 (90.5-143.1)	108.9 (81.8-136.0)	113.1 (94.2-132.0)
	2018/19	143.7 (114.8-172.5)	176.3 (142.1-210.5)[a]	158.9 (136.7-181.1)[b]
	All	130.3 (110.8-149.9)	142.9 (121.0-164.7)	136.2 (121.6-150.8)
Men's International Rugby Sevens (43)	**2017/18**			197.1 (108.5-285.7)
	2018/19			262.3 (157.4-367.2)
	All			229.0 (160.5-297.4)*
Women's International Rugby Sevens (11)	**2017/18**	-	-	169.5 (3.4-335.6)
	2018/19	-	-	145.5 (37.7-253.3)
	All	-	-	153.6 (62.8-244.4)

*(IRR: 1.9; 95% CI: 1.3-2.9; $p = 0.002$) men's international rugby sevens to men's international rugby. [a](IRR: 1.6; 95% CI: 1.2-2.2; $p = 0.003$) 2018/19 to 2017/18. [b](IRR: 1.4; 95% CI: 1.1-1.8; $p = 0.002$) 2018/19 to 2017/18.

Table 3A.7 presents match injury severity and burden for each cohort. Women's international rugby sevens had the greatest mean injury severity (45.6 days), followed by men's international rugby (31.2 days) and women's international rugby (30.2 days). Men's international rugby and men's international rugby sevens had the greatest median injury severity (both 12.0 days) followed by women's international rugby and women's international rugby sevens (both 11.0 days). Due to non-normal distribution of severity data, differences between cohorts were only assessed by comparison of median severity. No statistical differences were found.

The greatest injury burden was recorded for women's international rugby sevens (7,011.2 days absence/1000 player match hours) followed by women's international rugby (5,040.0 days /1000 hours) and men's international rugby sevens (4,728.4 days /1000 hours). For each match during the 2017/18 and 2018/19 seasons, women's international rugby would be expected to lose 100.8 player days, men's international rugby 74.9 player days and men's professional club rugby 57.7 player days. Women's international rugby sevens would be expected to lose 11.5 player days per 14-minute match, compared with 7.7 player days for men's international rugby sevens.

TABLE 3A.7: Match injury severity and burden for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons

Cohort	Injuries (n)	Severity (days)		Burden (95% CI)
		Mean (95% CI)	Median (95% CI)	
Men's International Rugby	48	31.2 (20.0-42.4)	12.0 (6.0-26.0)	3,745.0 (3,555.4-3,934.6)
Women's International Rugby	50	30.2 (13.3-47.1)	11.0 (7.0-13.0)	5,040.0 (4,786.0-5,294.0)
Men's Professional Club Rugby	335	21.2 (17.5-24.9)	7.0 (5.0-8.0)	2,887.0 (2,819.8-2,954.1)
Men's International Rugby Sevens	43	20.7 (14.2-27.1)	12.0 (8.0-19.0)	4,728.4 (4,417.4-5,039.4)
Women's International Rugby Sevens	11	45.6 (0.0-108.6)	11.0 (6.0-40.0)	7,011.2 (6,397.8-7,624.5)

Injury Recurrence

Table 3A.8 presents new and recurrent injuries across all cohorts. New injury incidence was greatest for men's international rugby sevens (207.7/1000 player match hours), followed by women's international rugby sevens (139.7/1000 hours) and men's professional club rugby (111.4/1000 hours). Women's international rugby had the greatest recurrent injury incidence (56.7/1000 hours), followed by men's professional club rugby (22.0/1000 hours) and men's international rugby (15.0/1000 hours). Aside from women's international rugby, incidence of new injuries were statistically greater than recurrent injuries for all cohorts. Incidence rate ratios were: 6.7 (95% CI: 2.8-15.7) $p < 0.001$ for men's international; 5.1 (95% CI: 3.8-6.8) $p < 0.001$ for men's professional club; 19.5 (95% CI: 4.7-80.8) $p < 0.001$ for men's international sevens; and 10.0 (95% CI: 1.3 – 78.1) $p = 0.028$ for women's international sevens. Incidence of new injury was statistically greater for men's international rugby sevens compared with men's international rugby (IRR: 2.1; 95% CI: 1.3-3.2; $p = 0.001$).

The greatest proportion of recurrent injury was for women's international rugby (34.0%), followed by men's professional club rugby (16.1%) and men's international rugby (12.5%). Distribution of proportion of new and recurrent injuries were statistically different across cohorts (χ^2 (8) = 27.5; $p = 0.003$; Cramer's V = 0.168). The only adjusted standardised residuals of a magnitude greater than ± 3.0 were for women's international rugby new injuries (-4.6) and recurrent injuries (3.5).

The greatest new median injury severity was found for men's international rugby (15.0 days) followed by men's international rugby sevens (12.0 days) and women's international rugby sevens (11.5 days). The greatest recurrent median injury severity was found for men's professional club rugby (10.0 days) followed by women's international rugby (8.0 days) and men's international rugby (3.5 days). Median severity of recurrent injuries was statistically greater than new injuries for men's professional club rugby (U = 9,014.5; $z = 2.546$; $p = 0.011$). Median severity of new injuries for men's international rugby was statistically greater than men's professional club rugby (U = 3,807.0; $z = 3.130$; $p = 0.002$).

The greatest new injury burden was found in women's international rugby sevens (6,899.4 days absence/1000 player match hours), followed by men's international rugby sevens (4,339.7 days absence/1000 player match hours) and men's international rugby (3,505.0 days absence/1000 player match hours). The greatest recurrent injury burden was found in women's international rugby (1,700.0 days absence/1000 player match hours), followed by men's professional club rugby (554.1 days absence/1000 player match hours) and men's international rugby (137.5 days absence/1000 player match hours).

TABLE 3A.8: New and recurrent injury proportion, incidence, median severity, and burden for professional cohorts in Scotland across 2017/18 and 2018/19.

Cohort	Injury (n)	Proportion (95% CI)	Incidence (95% CI)	Median Severity (95% CI)	Burden (95% CI)
Men's International Rugby	**New** (40)	83.3 (72.8-93.9)	100.0 (69.0-131.0)[a]	15.0 (8.0-32.0)[d]	3,505.0 (3,321.5-3,688.5)
	Recurrent (6)	12.5 (3.1-21.9)	15.0 (3.0-27.0)	3.5 (2.0-33.0)	137.5 (101.2-173.8)
Women's International Rugby	**New** (28)	56.0 (42.2-69.8)	93.3 (58.8-127.9)	11.0 (6.0-18.0)	3,146.7 (2,945.9-3,347.4)
	Recurrent (17)	34.0 (20.9-47.1)	56.7 (29.7-83.6)	8.0 (4.0-15.0)	1,700.0 (1,552.5-1,847.5)
Men's Professional Club Rugby	**New** (274)	81.8 (77.7-85.9)	111.4 (98.2-124.6)[a]	6.0 (5.0-7.0)	2,164.2 (2,106.1-2,222.4)
	Recurrent (54)	16.1 (12.2-20.1)	22.0 (16.1-27.8)	10.0 (8.0-16.0)[c]	554.1 (524.7-583.5)
Men's International Rugby Sevens	**New** (39)	90.7 (82.0-99.4)	207.7 (142.5-272.8)*[,a]	12.0 (8.0-23.0)	4,339.7 (4,041.8-4,637.7)
	Recurrent (2)	4.7 (0.0-11.0)	10.6 (0.0-25.4)	(n = 2)	106.5 (59.8-153.2)
Women's International Rugby Sevens	**New** (10)	90.9 (73.9-100.0)	139.7 (53.1-226.2)[b]	11.5 (6.0-40.0)	6,899.4 (6,291.0-7,507.9)
	Recurrent (1)	9.1 (0.0-26.1)	14.0 (0.0-41.3)	(n = 1)	111.7 (34.3-189.2)

Proportion reported as a percentage of all injuries for each cohort, including those of an unknown recurrence status. New or recurrent injury status unknown for two (men's international), five (women's international), seven (men's professional club) and two injuries (men's international sevens). *($p = 0.001$) men's international rugby sevens to men's international rugby new injuries. [a] ($p < 0.001$) new to recurrent injury incidence within-cohort. [b] ($p = 0.028$) new to recurrent injury incidence within-cohort. [c]($p = 0.011$) recurrent to new injury severity within-cohort. [d]($p = 0.002$) men's international to men's professional club rugby new injury severity.

Playing Position

Table 3A.9 presents injury proportion, median severity and burden for forwards and backs within the three rugby cohorts. Proportion of injuries was highest for forwards across all three cohorts: 66.0% (women's international); 58.3% (men's international); and 51.0% (men's professional club). The proportion of injuries sustained by forwards and backs did not differ across cohorts (χ^2 (2) = 4.403; $p = 0.111$).

The greatest median severity was found for men's international backs (22.0 days) followed by women's international forwards and backs (both 11.0 days). Median severity for men's international backs was statistically greater than men's professional club backs ($U = 1138.00$; $z = 2.239$; $p = 0.025$). No other statistical differences in median severity were found within positional groups between cohorts, or between positional groups within cohorts.

Women's international forwards had the greatest injury burden (5,512.5 days absence/1000 player match hours), followed by women's international backs (4,500.0 days /1000 hours) and men's international forwards (4,129.7 days /1000 hours).

TABLE 3A.9: Match injury proportion, median severity and burden for forwards and backs within three professional rugby cohorts in Scotland during the 2017/18 and 2018/19 seasons

Positional Group	Injuries (n)	Proportion (95% CI)	Median Severity (95% CI)	Burden (95% CI)
		Men's International Rugby		
Forwards	28	58.3 (44.4-72.3)	10.0 (5.0-19.0)	4,129.7 (3,857.0-4,402.4)
Backs	20	41.7 (27.7-55.6)	22.0 (10.0-50.0)*	3,305.4 (3,044.5-3,566.2)
		Women's International Rugby		
Forwards	33	66.0 (52.9-79.1)	11.0 (7.0-13.0)	5,512.5 (5,148.7-5,5876.3)
Backs	17	34.0 (20.9-47.1)	11.0 (3.0-24.0)	4,500.0 (4,148.6-4,851.4)
		Men's Professional Club Rugby		
Forwards	171	51.0 (45.7-56.4)	7.0 (5.0-9.0)	2,836.9 (2,745.7-2,928.0)
Backs	164	49.0 (43.6-54.3)	6.5 (5.0-9.0)	2,944.3 (2,845.0-3,043.5)

*(p = 0.025) to men's professional club rugby backs.

Figure 3A.3 presents injury incidence by playing position for the three rugby cohorts. The greatest incidence of injury in all three cohorts was for the hooker position: 350.0 (women's international); 225.0 (men's international); and 207.3/1000 player match hours (men's professional club rugby). Injury incidence for hooker was greater than centre (IRR: 3.5; 95% CI: 1.0-12.0; $p = 0.046$) and back three (IRR: 3.5; 95% CI: 1.2-10.4; $p = 0.024$) for women's international rugby. For men's professional club rugby, injury incidence for hooker was greater than prop (IRR: 1.6; 95% CI: 1.0-2.5; $p = 0.037$), second row (IRR: 2.1; 95% CI: 1.3-3.3; $p = 0.003$), back row (IRR: 1.7; 95% CI: 1.1-2.5; $p = 0.020$), scrum half (IRR: 1.9; 95% CI: 1.1-3.3; $p = 0.029$), stand off (IRR: 1.9; 95% CI: 1.1-3.3; $p = 0.029$), and back three (IRR: 1.5; 95% CI: 1.0-2.3; $p = 0.046$). No statistical differences within playing positions between cohorts was found.

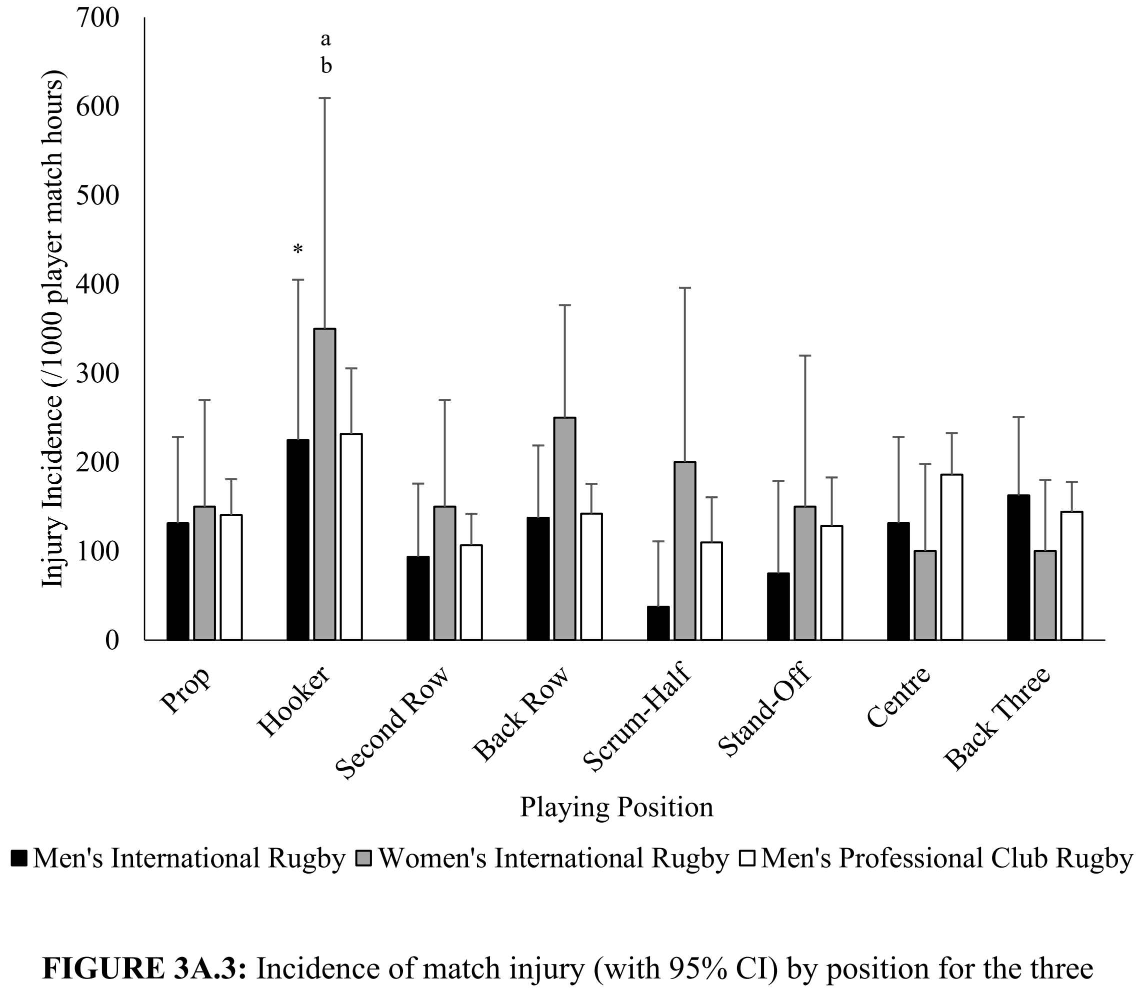

FIGURE 3A.3: Incidence of match injury (with 95% CI) by position for the three professional rugby cohorts in Scotland across the 2017/18 and 2018/19 seasons. *($p < 0.05$) hooker to centre and back three within cohort. [a] ($p < 0.05$) hooker to prop, back row, scrum half, stand-off, and back three within cohort. [b] ($p < 0.01$) hooker to second row within cohort.

Injury severity and burden data for individual positions were not presented in figure 3A.3 due to a small number of data points and skewed distribution in some instances for men's and women's international rugby. Figure 3A.4 presents injury incidence, mean severity, and injury burden for each playing position for men's professional club rugby. Back row had the greatest mean severity (27.2 days; 95% CI: 17.0-37.4), followed by hooker (23.9 days; 95% CI: 11.1-36.8) and scrum half (22.9 days; 95% CI: 6.1-39.8). Hooker had the greatest injury burden (4,957.3 days absence/1000 player match hours; 95% CI: 4,616.6.0-5,298.1), followed by centre (3,634.1 days/1000 hours; 95% CI: 3,427.8-3,840.5) and back row (3,428.9 days/1000 hours; 95% CI: 3,265.20-3,592.5).

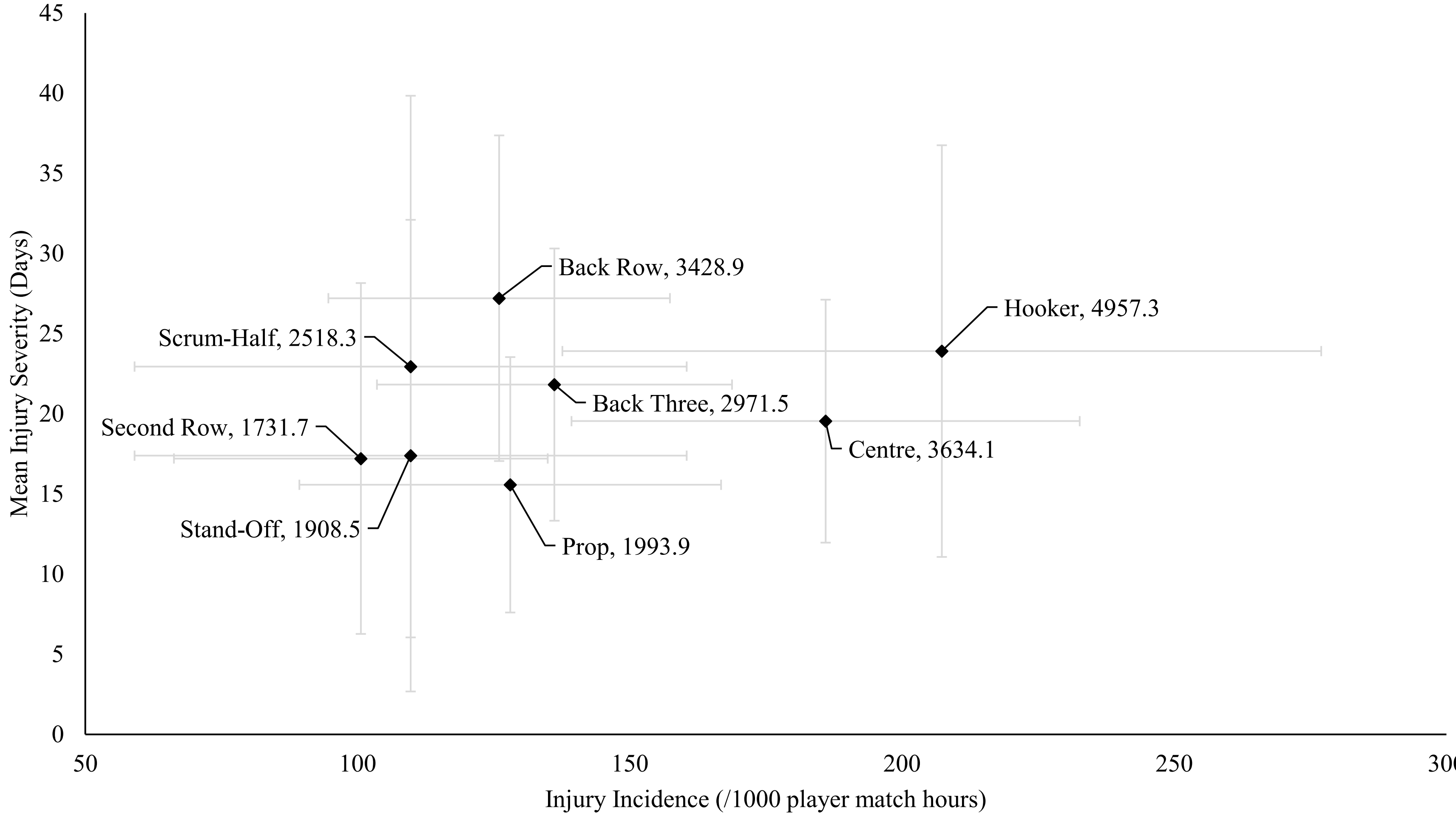

FIGURE 3A.4: Injury incidence (with 95% CI), mean severity (with 95% CI) and injury burden (data label; days absence/1000 player match hours) for each playing position for men's professional club rugby in Scotland across 2017/18 and 2018/19.

Due to non-normal distribution, differences were not sought in mean severity data between positions. Back three had the greatest median injury severity (9.0 days; 95% CI: 5.0-11.0), followed by back row (8.0 days; 95% CI: 6.0-13.0), centre (7.0 days; 95% CI: 5.0-11.0), hooker (6.5 days; 95% CI: 4.0-13.0), stand-off (5.5 days; 95% CI: 3.0-10.0), second row and prop (both 5.0 days; 95% CI: 4.0-9.0) and scrum half (5.0 days; 95% CI: 3.0-16.0). Compared with back three, no statistical differences in median severity were found to other positions.

Injury Location and Type

Table 3A.10 presents injury proportion, median severity and proportion of injury burden by body location for each professional cohort. The greatest proportion of injury in all cohorts was to the lower limb: 45.8% (men's international); 46.0% (women's international); 50.4% (men's professional club); 46.5% (men's international sevens); and 54.5% (women's international sevens). Injury proportion across locations were not statistically different between cohorts (χ^2 (12) = 4.31; p = 0.977).

Upper limb had the greatest median injury severity for women's international (17.0 days), men's professional club rugby (9.0 days), and men's (36.0 days) and women's international rugby sevens (13.0 days). Lower limb had the greatest median injury severity for men's international rugby (30.0 days). Within-cohorts, no statistical differences in median injury severity between locations were found. Between cohorts, lower limb median injury severity was statistically greater for men's international compared with men's professional club rugby (U = 1186.00; z = 2.768; p = 0.006).

The greatest proportion of injury burden was to the lower limb for all cohorts: 67.9% (men's international); 61.6% (women's international); 45.5% (men's professional club); 53.2% (men's international sevens); and 83.2% (women's international sevens). Due to small sample size, women's international rugby sevens was not included whilst assessing proportion of injury burden between cohorts. Proportions of injury burden across injury locations were statistically different between remaining cohorts with a small effect (χ^2 (9) = 386.856; p < 0.001; Cramer's V = 0.108). Adjusted standardised residuals of the greatest magnitude were lower limb injuries for men's professional club rugby (-16.6) and men's international rugby (13.7) and head/neck injuries for men's professional club rugby (11.8).

TABLE 3A.10: Proportion, median severity, and proportion of injury burden for match injuries by location for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Injury Location (injuries, n)	**Proportion of Injury (95% CI)**	**Median Severity (95% CI)**	**Proportion of Injury Burden (95% CI)**
Men's International Rugby (injuries n = 48)			
Head/Neck (11)	22.9 (11.0-34.8)	10.0 (5.0-19.0)	10.5 (9.5-11.5)
Upper Limb (9)	18.8 (7.7-29.8)	10.0 (2.0-86.0)	17.7 (16.5-18.9)
Trunk (6)	12.5 (3.1-21.9)	4.5 (3.0-25.0)	3.9 (3.3-4.6)
Lower Limb (22)	45.8 (31.7-60.0)	30.0 (6.0-68.0)*	67.9 (66.4-69.4)
Women's International Rugby (injuries n = 50)			
Head/Neck (12)	24.0 (12.2-35.8)	12.0 (6.0-15.0)	10.9 (10.1-11.8)
Upper Limb (11)	22.0 (10.5-33.5)	17.0 (7.0-70.0)	24.3 (23.1-25.5)
Trunk (4)	8.0 (0.48-15.5)	11.0 (2.0-24.0)	3.2 (2.7-3.7)
Lower Limb (23)	46.0 (32.2-59.8)	6.0 (4.0-13.0)	61.6 (60.3-63.0)
Men's Professional Club Rugby (injuries n = 335)			
Head/Neck (82)	24.5 (19.9-29.1)	6.0 (5.0-8.0)	20.4 (18.9-21.8)
Upper Limb (57)	17.0 (13.0-21.0)	9.0 (5.0-20.0)	26.1 (24.5-27.7)
Trunk (27)	8.1 (5.1-11.0)	6.0 (3.0-8.0)	8.0 (7.0-9.0)
Lower Limb (169)	50.4 (45.1-55.8)	7.0 (5.0-9.0)	45.5 (43.7-47.3)
Men's International Rugby Sevens (injuries n = 43)			
Head/Neck (11)	25.6 (12.5-38.6)	8.0 (5.0-14.0)	14.3 (13.3-15.3)
Upper Limb (7)	16.3 (5.2-27.3)	36.0 (4.0-82.0)	27.8 (26.5-29.1)
Trunk (5)	11.6 (2.1-21.2)	7.0 (2.0-19.0)	4.7 (4.1-5.3)
Lower Limb (20)	46.5 (31.6-61.4)	17.0 (9.0-28.0)	53.2 (51.7-54.6)
Women's International Rugby Sevens (injuries n = 11)			
Head/Neck (2)	18.2 (0.0-41.0)	(n = 2)	4.2 (2.4-5.9)
Upper Limb (3)	27.3 (0.95-53.6)	12.0 (8.0-40.0)	12.0 (9.1-14.8)
Trunk (0)	-	-	-
Lower Limb (6)	54.5 (25.1-84.0)	9.5 (2.0-365.0)	83.9 (80.7-87.1)

*(p = 0.006) to men's professional club rugby lower limb median injury severity.

Table 3A.11 presents injury proportion, median severity and proportion of injury burden by injury type for each professional cohort. Joint and ligament injuries were the most common for men's international rugby (33.3%). For all other cohorts, muscle and tendon injuries were the most common: 38.0% (women's international); 35.5% (men's professional club); 44.2% (men's international sevens); and 36.4% (women's international sevens). Injury proportion across injury types were not statistically different between cohorts (χ^2 (24) = 30.869; p = 0.158).

Aside from women's international rugby sevens, bone injuries presented with the greatest median severity in all cohorts: 85.0 days (men's international); 70.0 days (women's international); 30.0 days (men's professional club); and 44.0 days (men's international sevens). Joint and ligament injuries had the greatest median severity for women's international rugby sevens (29.0 days). Due to the small number of bone injuries within each cohort coupled with the high median severity, the distribution of bone injury severities did not match other injury types. Differences in median severity between injury types within cohorts were therefore not investigated. Between cohorts, muscle and tendon median injury severity was statistically greater for men's international rugby compared with men's professional club rugby (U = 508.00; z = 2.401; p = 0.016). No other differences between cohorts were found.

The greatest proportion of injury burden was due to joint and ligament injuries for all cohorts aside from men's international rugby sevens: 42.3% (men's international rugby); 34.9% (women's international rugby); 48.8% (men's professional club rugby); 80.9% (women's international rugby sevens). The greatest proportion of injury burden was due to muscle and tendon injuries for men's international rugby sevens (41.8%). Due to small sample size, women's international rugby sevens was not included whilst assessing proportion of injury burden between groups. Proportions of injury burden across injury types was statistically different between remaining cohorts with a small-moderate effect (χ^2 (18) = 2,2182.3; p < 0.001; Cramer's V = 0.259). Adjusted standardised residuals of the greatest magnitude were for men's professional club rugby bone injures (-17.2), men's international rugby sevens muscle and tendon injuries (17.0), and women's international rugby bone injuries (15.7).

TABLE 3A.11: Proportion, median severity, and proportion of injury burden for match injuries by type for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Injury Type (injuries, n)	**Proportion of Injury (95% CI)**	**Median Severity (95% CI)**	**Proportion of Injury Burden (95% CI)**
Men's International Rugby (injuries n = 48)			
Bone (3)	6.3 (0.0-13.1)	85.0 (2.0-147.0)	15.6 (13.8-17.5)
CNS/PNS (11)	22.9 (11.0-34.8)	10.0 (5.0-18.0)	9.9 (8.4-11.4)
Joint & Ligament (16)	33.3 (20.0-46.7)	32.5 (5.0-68.0)	42.3 (39.8-44.8)
Muscle & Tendon (14)	29.2 (16.3-42.0)	12.0 (3.0-28.0)*	19.6 (17.6-21.6)
Skin (-)	-	-	-
Other (2)	4.2 (0.0-9.8)	(n = 2)	0.4 (0.08-0.72)
Unknown (2)	4.2 (0.0-9.8)	(n = 2)	12.1 (10.5-13.8)
Women's International Rugby (injuries n = 50)			
Bone (3)	6.0 (0.0-12.6)	70.0 (27.0-233.0)	21.8 (19.7-23.9)
CNS/PNS (11)	22.0 (10.5-33.5)	12.0 (5.0-42.0)	11.6 (10.0-13.3)
Joint & Ligament (15)	30.0 (17.3-42.7)	12.0 (4.0-24.0)	34.9 (32.5-37.3)
Muscle & Tendon (19)	38.0 (24.6-51.5)	9.0 (4.0-11.0)	10.7 (9.2-12.3)
Skin (-)	-	-	-
Other (1)	2.0 (0.0-5.9)	(n = 1)	20.4 (18.4-22.5)
Unknown (1)	2.0 (0.0-5.9)	(n = 1)	0.53 (0.16-0.89)
Men's Professional Club Rugby (injuries n = 335)			
Bone (13)	3.9 (1.8-6.0)	30.0 (8.0-47.0)	6.7 (6.1-7.2)
CNS/PNS (78)	23.3 (18.8-27.8)	6.5 (5.0-9.0)	18.8 (17.9-19.7)
Joint & Ligament (108)	32.2 (27.2-37.2)	12.0 (7.0-20.0)	48.8 (47.6-50.0)
Muscle & Tendon (119)	35.5 (30.4-40.7)	5.0 (4.0-5.0)	19.3 (18.4-20.2)
Skin (4)	1.2 (0.03-2.4)	9 (4.0-21.0)	0.61 (0.43-0.79)
Other (6)	1.8 (0.37-3.2)	13.5 (2.0-149.0)	3.8 (3.3-4.2)
Unknown (7)	2.1 (0.56-3.6)	9.0 (2.0-99.0)	2.2 (1.8-2.5)
Men's International Rugby Sevens (injuries n = 43)			
Bone (3)	7.0 (0.0-14.6)	44.0 (16.0-44.0)	11.7 (9.6-13.8)
CNS/PNS (8)	18.6 (7.0-30.2)	8.0 (4.0-12.0)	7.1 (5.4-8.8)
Joint & Ligament (8)	18.6 (7.0-30.2)	20.5 (4.0-82.0)	29.6 (26.6-32.6)
Muscle & Tendon (19)	44.2 (29.3-59.0)	12.0 (6.0-28.0)	41.8 (38.5-45.0)
Skin (4)	9.3 (0.62-18.0)	11.0 (5.0-14.0)	4.6 (3.2-6.0)
Other (1)	2.3 (0.0-6.8)	(n = 1)	5.2 (3.7-6.6)
Unknown (-)	-	-	-
Women's International Rugby Sevens (injuries n = 11)			
Bone (2)	18.2 (0.0-41.0)	(n = 2)	9.6 (7.0-12.1)
CNS/PNS (2)	18.2 (0.0-41.0)	(n = 2)	4.2 (2.4-5.9)
Joint & Ligament (3)	27.3 (0.95-53.6)	29.0 (12.0-365.0)	80.9 (77.4-84.3)
Muscle & Tendon (4)	36.4 (7.9-64.8)	6.5 (2.0-12.0)	5.4 (3.4-7.4)
Skin (-)	-	-	-
Other (-)	-	-	-
Unknown (-)	-	-	-

CNS/PNS = Central nervous system/peripheral nervous system. * (p = 0.016) to men's professional club rugby muscle and tendon injuries.

Table 3A.12 presents the three most frequent match injuries diagnosed for each professional cohort in Scotland (haematomas excluded). Only two diagnoses are shown for women's international rugby sevens due to all remaining injuries having an equal incidence (n = 1). Concussion was the most common specific diagnosis in all cohorts aside from women's international rugby sevens, where it was the second most common. Men's international rugby sevens recorded the greatest incidence of concussion (37.3/1000 player match hours) followed by men's professional club rugby (28.5/1000 player match hours) and women's international rugby sevens (27.9/1000 player match hours). No statistical differences were present between cohorts for concussion incidence.

TABLE 3A.12: Most frequent match injury diagnoses for each professional cohort in Scotland during the 2017/18 and 2018/19 seasons.

Injury	N	Incidence (95% CI)
Men's International Rugby		
Concussion	9	22.5 (7.8-37.2)
Ankle sprain/ligament injury	5	12.5 (1.5-23.5)
Knee sprain/ligament injury	3	7.5 (0.0-16.0)
Women's International Rugby		
Concussion	8	26.7 (8.2-45.1)
Ankle sprain/ligament injury	4	13.3 (0.3-26.4)
Neck/cervical spine muscle rupture/tear/strain/cramps	3	10.0 (0.0-21.3)
= Shoulder/clavicula nerve injury	3	10.0 (0.0-21.3)
= Shoulder/clavicula sprain/ligament injury	3	10.0 (0.0-21.3)
Men's Professional Club Rugby		
Concussion	70	28.5 (21.8-35.1)
Ankle sprain/ligament injury	27	11.0 (6.8-15.1)
Knee sprain/ligament injury	25	10.2 (6.2-14.1)
Men's International Rugby Sevens		
Concussion	7	37.3 (9.7-64.9)
Head/face abrasion/laceration	3	16.0 (0.0-34.1)
= Lateral/medial thigh muscle rupture/tear/strain/cramps	3	16.0 (0.0-34.1)
= Knee tendon injury/rupture/tendinopathy/bursitis	3	16.0 (0.0-34.1)
Women's International Rugby Sevens		
Knee sprain/ligament injuries	3	41.9 (0.0-89.3)
Concussion	2	27.9 (0.0-66.6)

Haematoma/contusion/bruise injuries excluded.

Table 3A.13 presents specific match injuries with the greatest burden for each cohort (other/unknown/undiagnosed injuries excluded). The greatest burden for a match injury was knee/sprain ligament injury for women's international rugby sevens (5,709.1 days absence/1000 player match hours) followed by foot/toe fracture (780.0 days/1000 hours) for women's international rugby, and posterior thigh muscle rupture/tear/strain/cramps (676.3 days/1000 hours) for men's international rugby sevens.

TABLE 3A.13: Specific match injuries with the greatest associated burden for each professional cohort in Scotland during the 2017/18 and 2018/19 seasons

Injury	N	Burden (95% CI)
Men's International Rugby		
Ankle sprain/ligament injury	5	545.0 (475.7-617.3)
Knee fracture	1	367.5 (308.1-426.9)
Knee sprain/ligament injury	3	320.0 (264.4-375.4)
Women's International Rugby		
Foot/toe fracture	1	776.7 (676.9-876.4)
Knee sprain/ligament injury	2	646.7 (555.7-737.7)
Shoulder/clavicula sprain/ligament injury	3	586.7 (500.0-673.3)
Men's Professional Club Rugby		
Concussion	70	501.6 (473.6-529.6)
Knee sprain/ligament injury	25	361.0 (337.2-384.7)
Shoulder/clavicula sprain/ligament injury	20	315.0(292.9-337.2)
Men's International Rugby Sevens		
Posterior thigh muscle rupture/tear/strain/cramps	2	665.6 (548.9-782.3)
Wrist/hand/finger/thumb sprain/ligament injury	1	436.6 (342.1-531.1)
Concussion	7	287.5 (210.8-364.2)
Women's International Rugby Sevens		
Knee sprain/ligament injury	3	5,670.4 (5,118.8-6,222.0)
Wrist/hand/finger/thumb fracture	1	558.7 (385.5-731.8)
Concussion	2	293.3 (167.9-418.7)

Other/unknown/undiagnosed injuries excluded.

Injury Cause and Mechanism

Contact (with another player) was the primary cause of injury for all cohorts (table 3A.14): 83.3% (men's international); 72.0% (women's international); 74.3% (men's professional club); 74.4% (men's international sevens); and 63.6% (women's international sevens). To avoid low expected counts, all injury causes aside from contact (with another player) were collapsed into one category. Injury proportion cause across contact (with another player) and all other causes were not statistically different between cohorts (χ^2 (4) = 2.827; p = 0.587).

The greatest median severity was due to non-contact trauma injuries for men's international rugby (66.0 days) and overuse (gradual onset) for women's international rugby (11.0; excluding injuries with an unknown cause). The greatest median severity for men's professional club rugby was injuries caused by contact (with a static object) (14.0 days). Injuries caused by contact (with another player) had the greatest median severity for women's (12.0 days) and men's international rugby sevens (10.5 days; excluding injuries with an unknown cause). Due to small number of non-contact trauma injuries in men's international rugby, distribution of severities did not match those reported for contact (with another player), therefore differences in median injury severity were not investigated for this cohort. No statistical differences in median severity between causes within other cohorts were found. Due to small sample sizes in some cohorts, only differences in median severity within contact (with another player) were sought between cohorts. No statistical differences were found.

Aside from women's international rugby sevens, the greatest proportion of injury burden was found for injuries caused by contact (with another player) for all cohorts: 79.4% (men's international); 67.8% (women's international); 76.3% (men's professional club); and 66.4% (men's international sevens). The greatest proportion of injury burden for women's international sevens was due to non-contact trauma injuries (74.1%). Due to small sample size, women's international rugby sevens was not included whilst assessing proportion of injury burden between groups. Proportion of injury burden across causes were statistically different between remaining cohorts with a small-moderate effect (χ^2 (15) = 1,451.661; $p < 0.001$; Cramer's V = 0.210). Adjusted standardised residuals of the greatest magnitude were for overuse (gradual onset) injuries for women's international rugby (26.5), followed by overuse (sudden onset) injuries for men's international rugby sevens (18.2) and injuries caused by contact (with a static object) for men's professional club rugby (11.1).

TABLE 3A.14: Injury proportion, median severity, and proportion of injury burden for match injuries by cause for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Injury Cause (injuries, n)	**Proportion of Injury (95% CI)**	**Median Severity (95% CI)**	**Proportion of Injury Burden (95% CI)**
Men's International Rugby (injuries n = 48)			
Contact (another player) (40)	83.3 (72.8-93.9)	11.5 (6.0-19.0)	79.4 (77.3-81.4)
Contact (static object) (-)	-	-	-
Non-contact trauma (3)	6.3 (0.0-13.1)	66.0 (26.0-147.0)	16.0 (14.1-17.8)
Overuse (gradual onset) (2)	4.2 (0.0-9.8)	(n = 2)	0.33 (0.04-0.63)
Overuse (sudden onset) (1)	2.1 (0.0-6.1)	(n = 1)	0.27 (0.01-0.53)
Unknown (2)	4.2 (0.0-9.8)	(n = 2)	4.1 (3.1-5.1)
Women's International Rugby (injuries n = 50)			
Contact (another player) (36)	72.0 (59.6-84.5)	10.5 (6.0-14.0)	67.8 (65.4-70.2)
Contact (static object) (1)	2.0 (0.0-5.9)	(n = 1)	0.20 (0.0-0.42)
Non-contact trauma (3)	6.0 (0.0-12.6)	17.0 (4.0-68.0)	5.9 (4.7-7.1)
Overuse (gradual onset) (6)	12.0 (3.0-21.0)	11.0 (3.0-309.0)	23.2 (21.1-25.3)
Overuse (sudden onset) (1)	2.0 (0.0-5.9)	(n = 1)	0.73 (0.30-1.2)
Unknown (3)	6.0 (0.0-12.6)	11.0 (4.0-18.0)	2.2 (1.5-2.9)
Men's Professional Club Rugby (injuries n = 335)			
Contact (another player) (249)	74.3 (69.7-79.0)	7.0 (5.0-8.0)	76.3 (75.4-77.3)
Contact (static object) (9)	2.7 (0.96-4.4)	14.0 (3.0-48.0)	4.2 (3.7-4.6)
Non-contact trauma (30)	9.0 (5.9-12.0)	9.5 (5.0-17.0)	8.0 (7.4-8.7)
Overuse (gradual onset) (19)	5.7 (3.2-8.2)	5.0 (2.0-10.0)	5.5 (5.0-6.1)
Overuse (sudden onset) (6)	1.8 (0.37-3.2)	13.0 (2.0-118.0)	2.7 (2.3-3.1)
Unknown (22)	6.6 (3.9-9.2)	3.5 (3.0-15.0)	3.2 (2.8-3.6)
Men's International Rugby Sevens (injuries n = 43)			
Contact (another player) (32)	74.4 (61.4-87.5)	10.5 (7.0-19.0)	66.4 (63.3-69.6)
Contact (static object) (1)	2.3 (0.0-6.8)	(n = 1)	1.8 (0.93-2.7)
Non-contact trauma (2)	4.7 (0.0-11.0)	(n = 2)	5.9 (4.3-7.4)
Overuse (gradual onset) (3)	7.0 (0.0-14.6)	9.0 (6.0-9.0)	2.7 (1.6-3.8)
Overuse (sudden onset) (2)	4.7 (0.0-11.0)	(n = 2)	12.7 (10.5-14.9)
Unknown (3)	7.0 (0.0-14.6)	44.0 (5.0-44.0)	10.5 (8.5-12.5)
Women's International Rugby Sevens (injuries n = 11)			
Contact (another player) (7)	63.6 (35.2-92.1)	12.0 (8.0-40.0)	24.3 (20.6-28.1)
Contact (static object) (1)	9.1 (0.0-26.1)	(n = 1)	0.40 (0.0-0.95)
Non-contact trauma (2)	18.2 (0.0-41.0)	(n = 2)	74.1 (70.3-77.9)
Overuse (gradual onset) (1)	9.1 (0.0-26.1)	(n = 1)	1.2 (0.24-2.2)
Overuse (sudden onset) (-)	-	-	-
Unknown (-)	-	-	-

Figure 3A.5 presents injury proportion by mechanism for each professional cohort. Injury severity and burden are not presented due to small sample sizes and skewed distribution in some cohorts. Being tackled was the primary injury mechanism for men's international (31.3%), women's international (26.0%), and women's international sevens (27.3%). Tackling was the most common injury mechanism for men's professional club

(29.9%) and men's international sevens (34.9%). Non-contact mechanisms were responsible for 6.3% (men's international), 14.0% (women's international), 13.7% (men's professional club), 11.6% (men's international sevens) and 18.2% (women's international sevens) of injuries. Across all cohorts, 88.9% (95% CI: 81.1-96.7) of non-contact injuries were either joint (non-bone) and ligament or muscle and tendon injuries, whilst 98.4% (95% CI: 95.3-100.0) were to the lower limb.

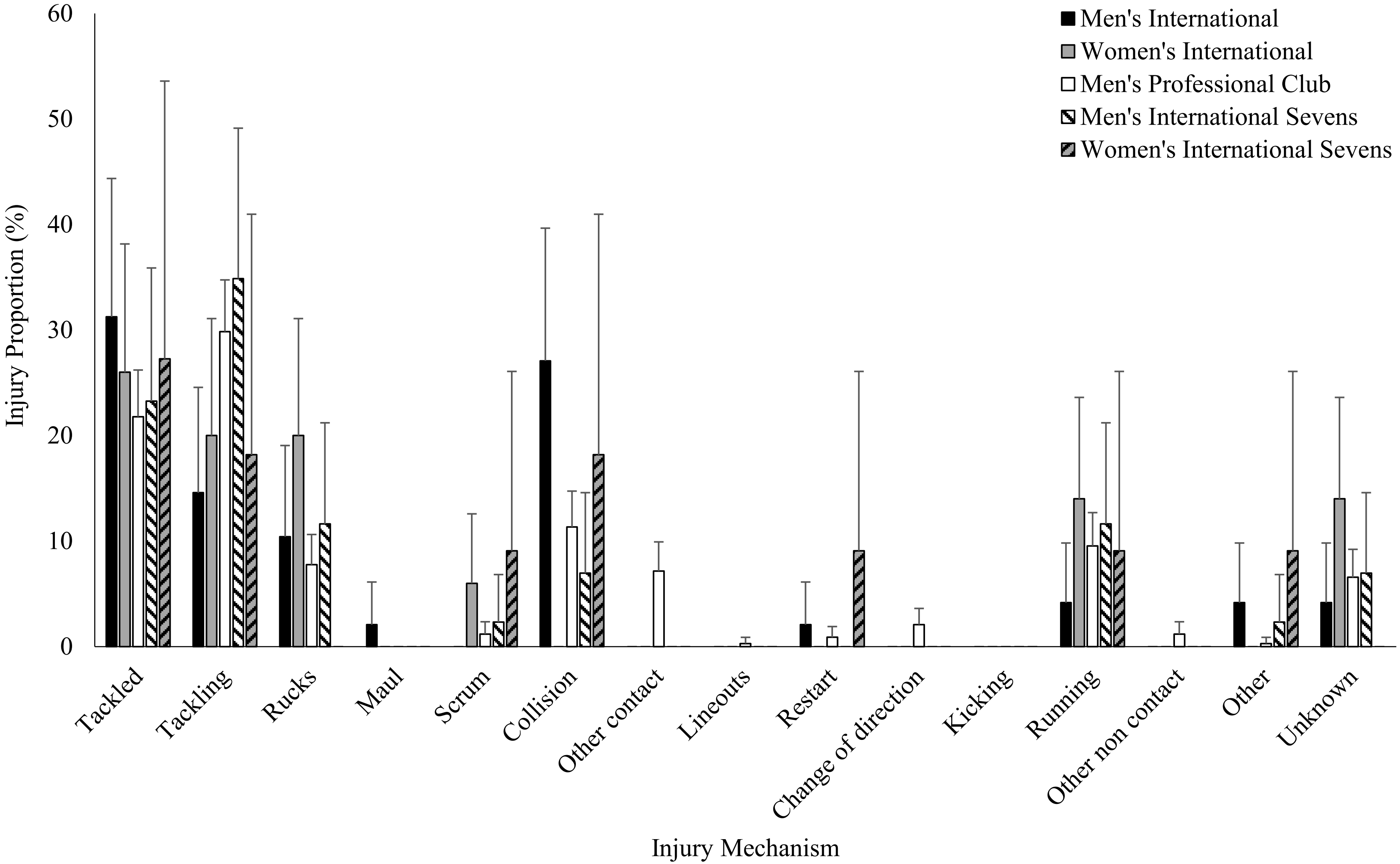

FIGURE 3A.5: Match injury proportion (with 95% CIs) by mechanism for professional cohorts in Scotland across the 2017/18 and 2018/19 seasons.

Figure 3A.6 presents injury incidence, mean injury severity and injury burden by injury mechanism for men's professional club rugby. Tackling injuries occurred most frequently (40.7/1000 player match hours; 95% CI: 32.7-48.6), followed by being tackled (29.7/1000 hours; 95% CI: 22.9-36.5) and collision injuries (15.4/1000 hours; 95% CI: 10.5-20.4). Injuries whilst tackling had a statistically greater incidence than being tackled (IRR: 1.4; 95% CI: 1.0-1.9; $p = 0.041$) and all other mechanisms (IRR range: 2.6-100.0; $p < 0.001$ in all instances).

Injuries occurring during restarts had the greatest mean injury severity (51.3 days; 95% CI: 0.0-139.3), albeit from a small sample size (n = 3). This was followed by ruck injuries (32.5 days; 95% CI: 15.4-49.6) and tackling injuries (26.3 days; 95% CI: 18.2-34.4). The greatest injury burden was for tackling injuries (1,069.1 days absence/1000 player match hours; 95% CI: 1,028.2-1,110.0), followed by being tackled (659.8 days/1000 hours; 95% CI: 627.7-691.9) and ruck injuries (343.5 days/1000 hours; 95% CI: 320.3-366.7). Of the burden associated with tackling, 53.9% (95% CI: 52.0-55.8) was attributed to the upper limb. Of the burden associated with being tackled, 51.5% (95% CI: 49.1-54.0) was attributed to lower limb injuries.

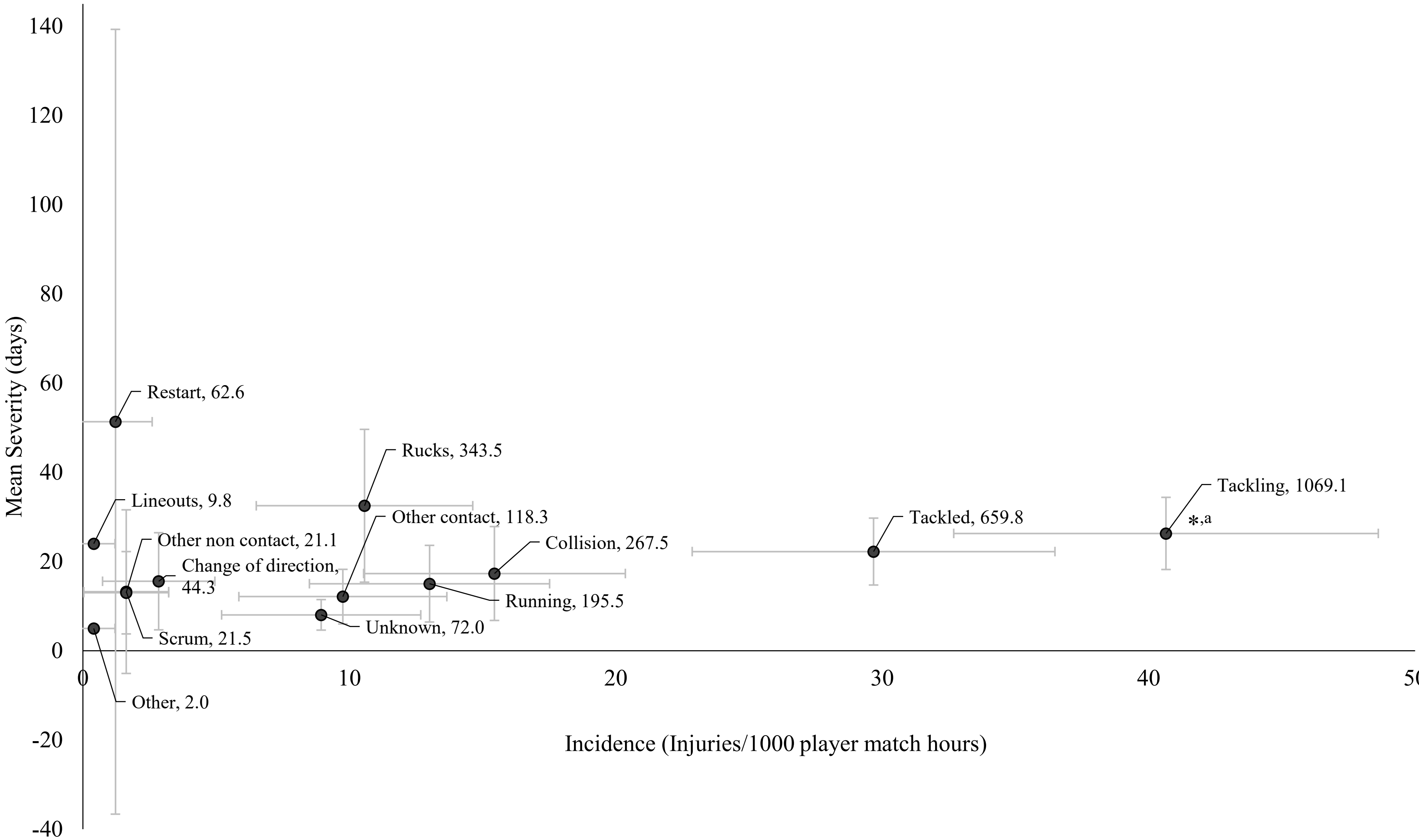

FIGURE 3A.6: Injury incidence (with 95% CI), mean injury severity (with 95% CI) and injury burden (data label; days absence/1000 player match hours) by injury mechanism for men's professional club rugby in Scotland across 2017/18 and 2018/19 seasons. *($p = 0.041$) Incidence to Tackled; [a] ($p < 0.001$) Incidence to all other mechanisms.

Differences in mean injury severity were not sought due to positive skew of the data. The greatest median injury severity was due to other non-contact injuries (12.5 days; 95% CI: 4.0-23.0), followed by change of direction (10.0 days; 95% CI: 3.0-47.0) and restart injuries (10.0 days; 95% CI: 3.0-141.0). No differences in median severity between other non-contact injuries and remaining injury mechanisms were found.

Time in Match

Table 3A.15 presents injury proportion, median severity, and burden by match quarter for the three rugby cohorts. The second match quarter had the greatest proportion of injury for men's international (29.2%) and women's international (28.0%), whilst the greatest proportion of injury for men's professional club rugby was in the third match quarter (27.2%). Injury proportion across different match quarters was not statistically different between cohorts (χ^2 (8) = 11.471; p = 0.176).

Median severity was greatest in the first match quarter for all rugby cohorts: 18.0 days (men's international; equal with fourth quarter); 15.0 days (women's international); and 10.0 days (men's professional club). Within cohorts, median severity in the first match quarter was statistically greater than the fourth match quarter for men's professional club rugby (U = 1397.50; z = 2.344; p = 0.019). Median severity was greater in the fourth match quarter for men's international rugby compared with men's professional club rugby (U = 161.50; z = 2.378; p = 0.017).

The greatest injury burden for both men's and women's international rugby was recorded in the second match quarter (men: 4,380.0, women: 9,773.3 days absence/1000 player match hours). The greatest injury burden for men's professional club rugby was found in the third match quarter (3,718.7 days/1000 hours).

TABLE 3A.15: Injury proportion, median severity, and injury burden for injuries by match quarter for professional rugby cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Match Quarter (injuries, n)	**Proportion of Injury (95% CI)**	**Median Severity (95% CI)**	**Injury Burden (95% CI)**
Men's International Rugby (injuries n = 48)			
Q1 (9)	18.8 (7.7-29.8)	18.0 (4.0-94.0)	3,390.0 (3,029.1-3,750.9)
Q2 (14)	29.2 (16.3-42.0)	11.5 (3.0-76.0)	4,380.0 (3,969.8-4,790.2)
Q3 (13)	27.1 (14.5-39.7)	10.0 (3.0-50.0)	3,960.0 (3,570.0-4,350.0)
Q4 (9)	18.8 (7.7-29.8)	18.0 (10.0-66.0)[a]	2,850.0 (2,519.1-3,180.9)
Unknown (3)	6.3 (0.0-13.1)	N/A	N/A
Women's International Rugby (injuries n = 50)			
Q1 (4)	8.0 (0.48-15.5)	15.0 (4.0-45.0)	1,053.3 (821.1-1285.6)
Q2 (14)	28.0 (15.6-40.5)	13.0 (3.0-70.0)	9,773.3 (9,065.8-10,480.9)
Q3 (10)	20.0 (8.9-31.1)	7.0 (5.0-14.0)	1,480.0 (1,204.7-1,755.3)
Q4 (9)	18.0 (7.4-28.7)	14.0 (4.0-152.0)	6,306.7 (5,738.3-6,875.0)
Unknown (13)	26.0 (13.8-38.2)	N/A	N/A
Men's Professional Club Rugby (injuries n = 335)			
Q1 (53)	15.8 (11.9-19.7)	10.0 (6.0-23.0)*	2,526.8 (2,401.2-2,652.5)
Q2 (71)	21.2 (16.8-25.6)	6.0 (5.0-11.0)	2,335.0 (2,214.2-2,455.7)
Q3 (91)	27.2 (22.4-31.9)	8.0 (6.0-12.0)	3,718.7 (3,566.3-3,871.1)
Q4 (70)	20.9 (16.5-25.3)	5.0 (5.0-8.0)	1,824.4 (1,717.6-1,931.1)
Unknown (50)	14.9 (11.1-18.7)	N/A	N/A

Q1 = first match quarter (0-20 mins); Q2 = second match quarter (21-40+ mins); Q3 = third match quarter (41-60 mins); Q4 = fourth match quarter (61-80+ mins).
*(p = 0.019) to median severity in Q4 within-cohort. [a](p = 0.017) to median severity for men's professional club rugby Q4.

Time in Season

Injury incidence, mean injury severity and injury burden by month of the season for men's professional club rugby is presented in figure 3A.7. The greatest incidence of injury was recorded in April (176.9/1000 player match hours; 95% CI: 125.8-228.1), followed by November (155.6/1000 hours; 95% CI: 97.9-213.2) and October (153.1/1000 hours; 95% CI:110.3-196.0). Incidence of injury in April was statistically greater than

December (IRR: 1.7; 95% CI: 1.1-2.6; $p = 0.016$). The greatest mean injury severity was recorded in January (41.3 days; 95% CI: 23.2-59.4), followed by May (29.5 days; 95% CI: 5.4-53.7), and March (25.6 days; 95% CI: 12.0-39.2). The greatest burden was recorded for January (5,164.3 days absence/1000 player match hours; 95% CI: 4,898.1-5,430.5), followed by April (4,200.0 days/1000 hours; 95% CI: 3,950.9-4,449.1) and May (4,062.5 days/1000 hours; 95% CI: 3,620.8-4,504.2).

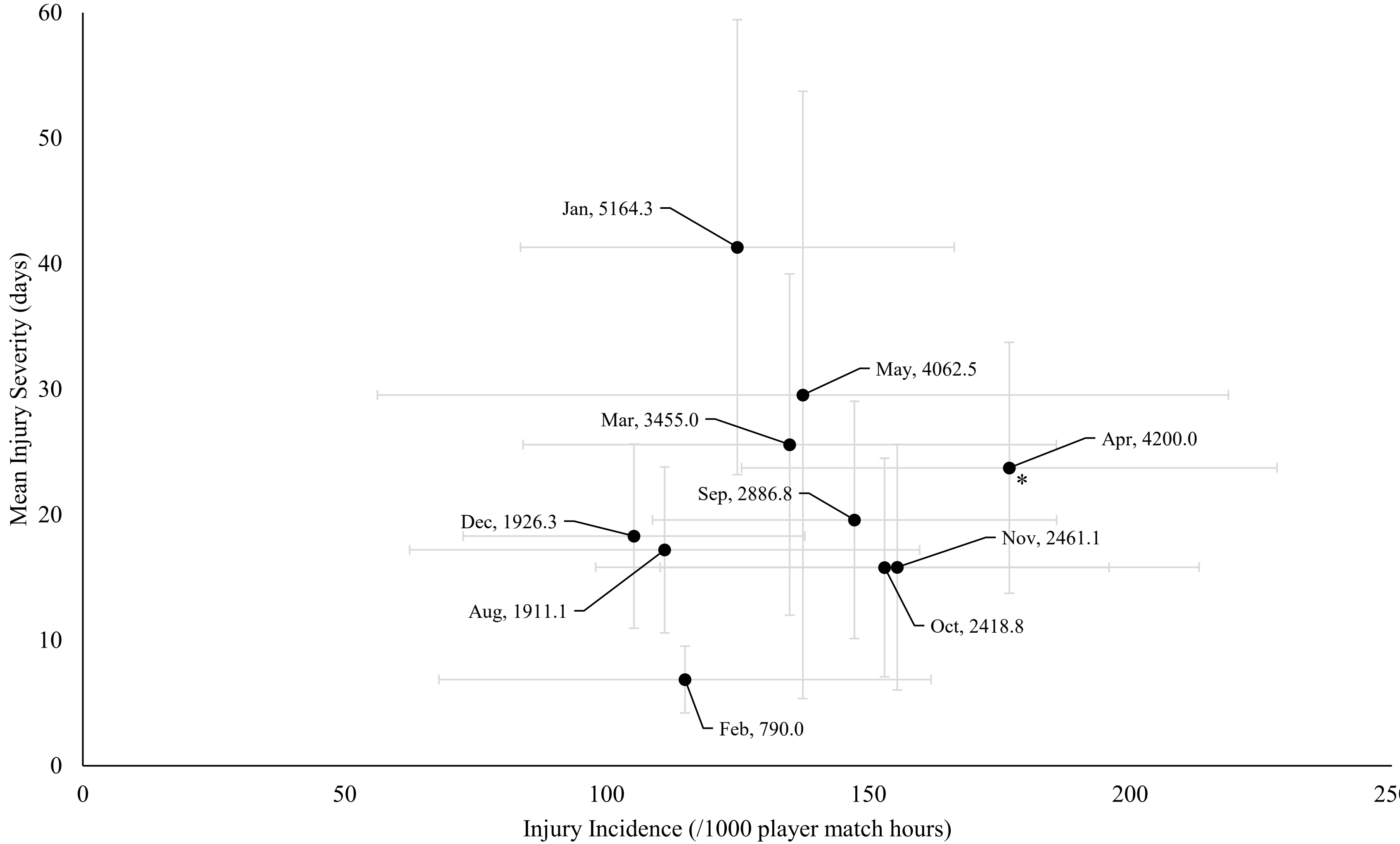

FIGURE 3A.7: Injury incidence (with 95% CI), mean injury severity (with 95% CI) and injury burden (data label; days absence/1000 player match hours) by month of the season for men's professional club rugby in Scotland across 2017/18 and 2018/19 seasons. * (*p* = 0.016) Incidence to December.

Due to the positive skew of severity data, differences in mean injury severity were not sought. January had the greatest median injury severity (14.0 days; 95% CI: 5.0-46.0), followed by August (11.5 days; 95% CI: 5.0-23.0), and April (10.0 days 95% CI: 5.0-15.0). Median injury severity in January was greater than October (5.0 days; 95% CI: 4.0-6.0) (U = 567.00; z = 2.648; p = 0.008) and February (5.0 days; 95% CI: 3.0-5.0) (U = 237.00; z = 2.645; p = 0.008).

3A.3.2: Training Injuries

Baseline Data

Two hundred and three different players took part in at least one training session with men's international rugby and men's professional club rugby during the 2017/18 and 2018/19 seasons (table 3A.16; certain players participated in at least one training session for both cohorts). Forwards were heavier than backs within each rugby cohort each season ($p < 0.001$).

TABLE 3A.16: Training player data for each professional cohort within Scottish Rugby over the 2017/18 and 2018/19 seasons

Cohort	Season	Players (n)		Age (years)		Mass (kg)	
		F	B	F	B	F	B
Men's International Rugby	2017/18	46	34	26.9 ± 4.4	26.2 ± 3.5	111.7 ± 7.4*	93.5 ± 8.0
	2018/19	40	29	25.7 ± 3.9	25.9 ± 3.4	110.9 ± 7.1*	93.5 ± 7.8
	Total	56	39	26.3 ± 4.4	26.0 ± 3.6	111.4 ± 6.9*	93.5 ± 8.0
Men's Professional Club Rugby	2017/18	81	65	25.6 ± 4.3	25.0 ± 3.6	111.1 ± 8.5*	92.9 ± 7.9
	2018/19	81	54	24.5 ± 4.1	24.9 ± 3.5	111.9 ± 8.9*	92.9 ± 7.4
	Total	106	75	25.1 ± 4.5	24.9 ± 3.7	111.2 ± 8.8*	92.8 ± 7.8

F = Forwards; B = Backs. * ($p < 0.001$) forwards to backs within cohort.

Table 3A.17 presents number of training injuries and training exposure for both cohorts. Two hundred and eight injuries were recorded across both professional cohorts with 99 players sustaining at least one injury. This resulted in 47.6% of players sustaining at least one injury across the 2017/18 and 2018/19 seasons. From all injured players, 52 (52.5% of injured players) incurred at least two injuries, whilst seven players (7.1% of injured players) sustained five or more injuries, representing 18.3% of all injuries.

TABLE 3A.17: Training injuries and training exposure for professional cohorts in Scotland across the 2017/18 and 2018/19 seasons.

Cohorts	Season	Injuries (n)			Training Exposure (h)		
		F	B	All	F	B	All
Men's International Rugby	**2017/18**	6	4	10	1,497.6	1,090.2	2,587.8
	2018/19	2	2	4	1,215.5	925.2	2,140.7
	All	8	6	14	2,713.1	2,015.3	4,728.5
Men's Professional Club Rugby	**2017/18**	49	32	81	13,508.8	10,608.3	24,117.1
	2018/19	66	47	113	12,896.0	9,869.3	22,765.3
	All	115	79	194	26,404.8	20,477.6	46,882.3

Table 3A.18 presents injury incidence for each cohort by season and positional group. The greatest overall injury incidence was found for men's professional club rugby (4.1/1000 player training hours) compared with men's international rugby (3.0/1000 hours). No statistical differences were found between cohorts for overall injury incidence.

Examining overall injury incidence by positional group, injury incidence was greater for backs compared with forwards for men's international rugby, yet forwards had a greater injury incidence than backs in men's professional club rugby. No statistical differences in overall injury incidence between cohorts for positional groups, or within-cohorts between positional groups were found.

Injury incidence was greater in 2017/18 compared with 2018/19 for men's international rugby, yet was greater in 2018/19 compared with 2017/18 for men's professional club rugby, a difference which reached statistical significance (IRR: 1.5; 95% CI: 1.1-2.0; $p = 0.007$).

TABLE 3A.18: Training injury incidence for each professional cohort in Scotland across the 2017/18 and 2018/19 seasons.

Cohort (injuries, n)	**Season**	**Injury Incidence (95% CI)**		
		Forwards	**Backs**	**All**
Men's International Rugby (14)	**2017/18**	4.0 (0.80-7.2)	3.7 (0.07-7.3)	3.9 (1.5-6.3)
	2018/19	1.6 (0.0-3.9)	2.2 (0.0-5.2)	1.9 (0.04-3.7)
	All	2.9 (0.91-5.0)	3.0 (0.59-5.4)	3.0 (1.4-4.5)
Men's Professional Club Rugby (194)	**2017/18**	3.6 (2.6-4.6)	3.0 (2.0-4.1)	3.4 (2.6-4.1)
	2018/19	5.1 (3.9-6.4)	4.8 (3.4-6.1)	5.0 (4.0-5.9)*
	All	4.4 (3.6-5.2)	3.9 (3.0-4.7)	4.1 (3.6-4.7)

*(p = 0.007) 2018/19 to 2017/18 within cohort.

Table 3A.19 presents training injury severity and burden for each cohort. Men's professional club rugby had the greatest mean and median severity, and the greatest injury burden. No statistical difference in median severity was found between cohorts.

TABLE 3A.19: Training injury mean and median severity, and injury burden for men's professional rugby cohorts in Scotland during the 2017/18 and 2018/19 seasons

Cohort	Injuries (n)	Severity (days)		Burden (95% CI)
		Mean (95% CI)	Median (95% CI)	
Men's International Rugby	14	19.9 (2.8-36.9)	6.0 (3.0-24.0)	58.8 (51.9-65.7)
Men's Professional Club Rugby	194	24.7 (17.9-31.5)	7.5 (6.0-10.0)	102.3 (99.4-105.2)

Injury Recurrence

Table 3A.20 presents new and recurrent injuries by cohort. New and recurrent injury incidence were greater for men's professional club rugby, yet no differences were found between cohorts. Proportion of new and recurrent injuries across both cohorts were also not statistically different (Fisher's exact: $p = 0.660$). New injuries had a statistically greater incidence than recurrent injuries in men's professional club rugby (IRR: 3.6; 95% CI: 2.6-5.1; $p < 0.001$).

Between cohorts, median severity of new injuries was greater in men's international rugby, whilst median severity of recurrent injuries was greater in men's professional club rugby. No differences were found in median severity between cohorts, yet median severity of recurrent injuries was statistically greater than new injuries for men's professional club rugby ($U = 3652.50$; $z = 2.002$; $p = 0.045$). Burden of new injuries was greater in both cohorts compared to recurrent injuries. Injury burden for new and recurrent injuries was greater for men's professional club compared with men's international rugby.

TABLE 3A.20: New and recurrent training injury proportion, incidence, severity, and burden for cohorts in Scotland across 2017/18 and 2018/19 seasons.

Cohort	Injury (n)	Proportion (95% CI)	Incidence (95% CI)	Median Severity (95% CI)	Burden (95% CI)
Men's International Rugby	**New** (10)	71.4 (47.8-95.1)	2.1 (0.80-3.4)	9.0 (4.0-46.0)	51.2 (44.7-57.6)
	Recurrent (4)	28.6 (4.9-52.2)	0.85 (0.02-1.7)	4.5 (3.0-24.0)	7.6 (5.1-10.1)
Men's Professional Club Rugby	**New** (148)	76.3 (70.3-82.3)	3.2 (2.7-3.7)*	7.0 (6.0-9.0)	70.4 (68.0-72.8)
	Recurrent (41)	21.1 (15.4-26.9)	0.88 (0.61-1.1)	11.0 (6.0-22.0)[a]	28.9 (27.4-30.5)

Proportion reported as a percentage of all injuries for each cohort, including those of an unknown recurrence status. New or recurrent injury status unknown for 5 injuries (men's professional club rugby). *($p < 0.001$) new to recurrent injury incidence within-cohort; [a]($p = 0.045$) recurrent to new median injury severity within-cohort.

Playing Position

Table 3A.21 presents training injury proportion, median severity and injury burden by positional group for each cohort. Backs sustained the greater proportion of injuries for men's international rugby, whilst forwards sustained the greatest proportion of injuries for men's professional club rugby. The proportion of injuries sustained by forwards and backs did not statistically differ across cohorts (χ^2 (1) = 1.447; p = 0.229).

Forwards had the greatest median severity for men's international rugby, whilst backs had the greatest median severity for men's professional club rugby. Median severity for men's international forwards was statistically greater than backs (U = 8.00; z = 2.084; p = 0.043). Between cohorts, men's international forwards had a greater median severity than men's professional club rugby, whilst men's professional club backs had a greater median severity than men's international backs. No statistical differences in median severity were found between cohorts for positional groups.

Forwards' injury burden was greater than backs for both cohorts. Between cohorts, injury burden for men's professional club forwards and backs was greater than men's international rugby.

TABLE 3A.21: Training injury proportion, median severity and burden for forwards and backs in professional rugby cohorts in Scotland during the 2017/18 and 2018/19 seasons

Positional Group	Injuries (n)	Proportion (95% CI)	Median Severity (95% CI)	Burden (95% CI)
Men's International Rugby				
Forwards	6	42.9 (16.9-68.8)	17.5 (4.0-125.0)*	81.8 (71.1-92.6)
Backs	8	57.1 (31.2-83.1)	5.5 (3.0-24.0)	27.8 (20.5-35.1)
Men's Professional Club Rugby				
Forwards	115	59.3 (52.4-66.2)	7.0 (6.0-11.0)	115.7 (111.6-119.8)
Backs	79	40.7 (33.8-47.6)	8.0 (6.0-10.0)	85.0 (81.0-89.0)

*(p = 0.043) forwards to backs median severity within-cohort.

Figure 3A.8 presents training injury incidence, mean severity and burden for individual positions in men's professional club rugby (data not shown for men's international rugby due to small sample sizes and skewed distribution in some instances). Second row had the greatest injury incidence (5.3/1000 player training hours; 95% CI: 3.4-7.3), followed by back three (5.3/1000 hours; 95% CI: 3.6-6.9) and stand-off (5.1/1000 hours; 95% CI: 2.4-7.8). Injury incidence for second row was statistically greater than scrum half (IRR: 4.9; 95% CI: 1.7-13.9; $p = 0.003$).

Second row had the greatest mean injury severity (39.0 days; 95% CI: 12.8-65.2), followed by back three (31.0 days; 95% CI: 12.1-49.8) and prop (25.8 days; 95% CI: 12.8-38.8). These three positions also had the greatest injury burden: second row 207.7 days absence/1000 player training hours (95% CI: 195.6-219.8); back three 162.7 days/1000 hours (95% CI: 153.6-171.7); and prop 123.2 days/1000 hours (95% CI: 115.6-130.9).

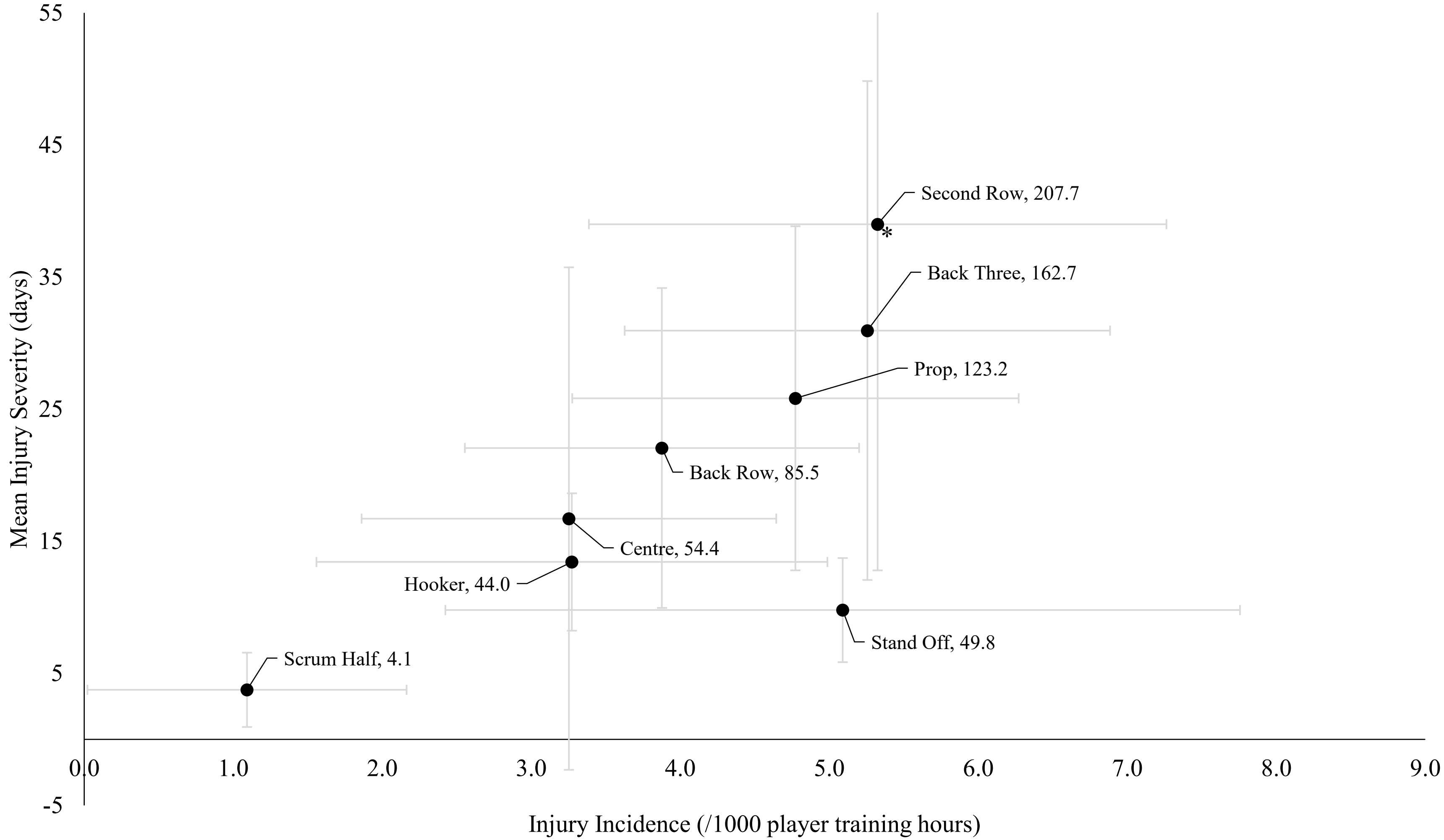

FIGURE 3A.8: Training injury incidence (with 95% CI), mean severity (with 95% CI) and injury burden (data label; days absence/1000 player match hours) for each playing position for men's professional club rugby in Scotland across 2017/18 and 2018/19. * ($p = 0.003$) Incidence to Scrum Half.

Due to non-normal distribution, differences were not sought in mean severity data between positions. Back three had the greatest median injury severity (12.0 days; 95% CI: 6.0-21.0), followed by hooker (9.5 days; 95% CI: 4.0-27.0), prop (8.0 days; 95% CI: 5.0-15.0), stand-off (8.0 days; 95% CI: 4.0-16.0), back row (6.0 days; 95% CI: 4.0-18.0), second row (6.0 days; 95% CI: 3.0-12.0), centre (5.0 days; 95% CI: 2.0-10.0) and scrum-half (2.5 days; 95% CI: 2.0-8.0). Median injury severity for back three players was statistically greater than scrum half (U = 26.50; z = 2.189; p = 0.025) and centre (U = 272.50; z = 2.246; p = 0.025).

Injury Location & Type

Table 3A.22 presents injury proportion, median severity and proportion of injury burden by body location for each professional cohort. The greatest proportion of injury in both cohorts was to the lower limb: 78.6% (men's international); and 66.5% (men's professional club rugby). Injury proportion across locations were not statistically different between cohorts (Fisher's exact p = 0.709).

Lower limb was the only body location with greater than two injuries for men's international rugby, which had a median severity of 6.0 days. For men's professional club rugby, upper limb injuries had the greatest median severity (8.5 days) followed by lower limb injuries (8.0 days). No statistical differences in median injury severity were found between cohorts for lower limb injuries, or compared with upper limb injuries within men's professional club rugby.

The greatest proportion of injury burden was to the lower limb for both cohorts: 51.8% (men's international); and 70.6% (men's professional club). Statistical differences in proportions of injury burden across injury locations were not sought due to small sample size of injuries men's international rugby.

TABLE 3A.22: Proportion, median severity, and proportion of injury burden for training injuries by location for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Injury Location (injuries, n)	**Proportion of Injury (95% CI)**	**Median Severity (95% CI)**	**Proportion of Injury Burden (95% CI)**
Men's International Rugby (injuries n = 14)			
Head/Neck (2)	14.3 (0.0-32.6)	(n = 2)	3.2 (1.2-5.3)
Upper Limb (1)	7.1 (0.0-20.6)	(n = 1)	45.0 (39.1-50.8)
Trunk (-)	-	-	-
Lower Limb (11)	78.6 (57.1-100.0)	6.0 (3.0-24.0)	51.8 (45.9-57.7)
Men's Professional Club Rugby (injuries n = 194)			
Head/Neck (23)	11.9 (7.3-16.4)	7.0 (5.0-9.0)	10.6 (9.7-11.4)
Upper Limb (20)	10.3 (6.0-14.6)	8.5 (4.0-19.0)	12.5 (11.5-13.4)
Trunk (22)	11.3 (6.9-15.8)	6.0 (3.0-17.0)	6.3 (5.7-7.0)
Lower Limb (129)	66.5 (59.9-73.1)	8.0 (6.0-11.0)	70.6 (69.4-71.9)

Table 3A.23 presents injury proportion, median severity and proportion of injury burden by injury type for each professional cohort. The greatest proportion of injury in both cohorts was due to muscle and tendon injuries (men's international: 57.1%; men's professional club: 53.1%), followed by joint and ligament injuries (men's international: 14.3%; men's professional club: 28.4%) and CNS/PNS injuries (men's international: 14.3%; men's professional club: 10.3%). Injury proportion across types were not statistically different between cohorts (Fisher's exact $p = 0.367$).

Muscle and tendon injuries were the only injury type that had at least three injuries from men's international rugby, and had a median severity of 13.0 days. For men's professional rugby, the greatest median severity was for bone injuries (75.5 days), followed by joint and ligament injuries (11.0 days) and CNS/PNS and muscle and tendon injuries (both 8.0 days) (excluding other and unknown injuries). No statistical differences in median severity were found between cohorts for muscle and tendon injuries, or within men's professional club rugby for different injury types compared with bone injuries.

The greatest proportion of injury burden for men's international rugby was due to muscle and tendon injuries (75.9%), followed by joint and ligament (17.6%) and CNS/PNS injuries (3.2%). For men's professional club, the greatest proportion of injury burden was due to joint and ligament injuries (37.9%), followed by muscle and tendon (33.8%) and CNS/PNS injuries (11.1%). Statistical differences in proportions of injury burden across injury types were not sought due to small sample size of injuries men's international rugby.

TABLE 3A.23: Proportion, median severity, and proportion of injury burden for training injuries by type for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Injury Type (injuries, n)	**Proportion of Injury (95% CI)**	**Median Severity (95% CI)**	**Proportion of Injury Burden (95% CI)**
Men's International Rugby (injuries n = 14)			
Bone (-)	-	-	-
CNS/PNS (2)	14.3 (0.0-32.6)	(n = 2)	3.2 (1.2-5.3)
Joint & Ligament (2)	14.3 (0.0-32.6)	(n = 2)	17.6 (13.2-22.1)
Muscle & Tendon (8)	57.1 (31.2-83.1)	13.0 (3.0-125.0)	75.9 (70.9-80.9)
Skin (-)	-	-	-
Other (-)	-	-	-
Unknown (2)	14.3 (0.0-32.6)	(n = 2)	3.2 (1.2-5.3)
Men's Professional Club Rugby (injuries n = 194)			
Bone (4)	2.1 (0.06-4.1)	75.5 (38.0-112.0)	6.3 (5.6-7.0)
CNS/PNS (20)	10.3 (6.0-14.6)	7.0 (5.0-12.0)	11.1 (10.3-12.1)
Joint & Ligament (55)	28.4 (22.0-34.7)	11.0 (20.0-36.0)	37.9 (36.5-39.2)
Muscle & Tendon (103)	53.1 (46.1-60.1)	7.0 (5.0-9.0)	33.8 (32.5-35.1)
Skin (2)	1.0 (0.0-2.5)	(n = 2)	1.5 (1.2-1.9)
Other (4)	2.1 (0.06-4.1)	20.5 (2.0-151.0)	4.0 (3.5-4.6)
Unknown (6)	3.1 (0.66-5.5)	8.5 (2.0-209.0)	5.4 (4.8-6.0)

Table 3A.24 presents the three most frequent training injuries diagnosed for each cohort. Concussion and muscle rupture/tear/strain/cramps to the lower leg/Achilles tendon and posterior thigh all had equal incidence for men's international rugby (0.42/1000 player training hours). Posterior thigh muscle rupture/tear/strain/cramps was the most common injury for men's professional club rugby (0.41/1000 hours).

TABLE 3A.24: Most frequent training injury diagnoses for each professional cohort in Scotland during the 2017/18 and 2018/19 seasons.

Injury	N	Incidence (95% CI)
Men's International Rugby		
Concussion	2	0.42 (0.0-1.0)
= Lower leg/Achilles tendon muscle rupture/tear/strain/cramps	2	0.42 (0.0-1.0)
= Posterior thigh muscle rupture/tear/strain/cramps	2	0.42 (0.0-1.0)
Men's Professional Club Rugby		
Posterior thigh muscle rupture/tear/strain/cramps	19	0.41 (0.22-0.59)
Concussion	14	0.30 (0.14-0.46)
Ankle tendon injury/rupture/tendinopathy/bursitis	10	0.21 (0.08-0.35)
= Ankle sprain/ligament injury	10	0.21 (0.08-0.35)

Table 3A.25 presents the three training injuries with the greatest burden for each cohort. Shoulder/clavicula tendon injury/rupture/tendinopathy/bursitis injuries had the greatest burden for men's international rugby (26.4 days absence/1000 player training hours). Lesion of knee meniscus/cartilage/disc injuries had the greatest burden for men's professional club rugby (14.2 days/1000 hours). Knee injuries in general represented 25.3% (95% CI: 24.1-26.6) of the total training injury burden for men's professional club rugby (25.9 days/1000 hours; 95% CI:24.4-27.4).

TABLE 3A.25: Training injuries with the greatest burden for each professional cohort in Scotland during the 2017/18 and 2018/19 seasons.

Injury	N	Burden (95% CI)
Men's International Rugby		
Shoulder/clavicula tendon injury/rupture/tendinopathy/bursitis	1	26.4 (21.8-31.1)
Knee sprain/ligament injury	1	9.7 (6.9-12.5)
Lower leg/Achilles tendon muscle rupture/tear/strain/cramps	2	5.7 (3.6-7.9)
Men's Professional Club Rugby		
Lesion of knee meniscus/cartilage/disc	7	14.2 (13.1-15.3)
Knee sprain/ligament injury	3	8.7 (7.9-9.6)
Concussion	4	8.5 (7.6-9.3)

Cause and Mechanism

Table 3A.26 presents injury proportion, median severity and proportion of injury burden by injury cause for each professional cohort. The greatest proportion of injury in men’s international rugby was due injuries caused by contact (with another player) (35.7%), followed by non-contact trauma (28.6) and overuse (gradual onset) (21.4%). Injuries caused by non-contact trauma were most common for men’s professional club rugby (32.5%), followed by contact (with another player) (30.4%) and overuse (gradual onset) (14.4%). Injury proportion across causes were not statistically different between cohorts (Fisher’s exact $p = 0.968$).

Overuse (gradual onset) injuries had the greatest median severity for men’s international rugby (19.0 days), followed by non-contact trauma (7.5 days) and contact (with another player) injuries (5.0 days). For men’s professional club rugby, injuries caused by contact (with static object) had the greatest median severity (30.0 days), followed by overuse (gradual onset) (12.0 days) and non-contact trauma injuries (8.0 days). No statistical differences in median severity were found between cohorts for each injury cause. Within cohorts, no statistical differences in median severity were found to injuries caused by overuse (gradual onset) for men’ s international, or contact (with static object) for men’s professional club rugby.

For both cohorts, the greatest proportion of injury burden was due to non-contact trauma injuries (men’s international: 58.3%; men’s professional club: 33.8%), followed by contact (with another player) (men’s international: 22.7%; men’s professional club: 26.6%) and overuse (gradual onset) injuries (men’s international: 12.9%; men’s professional club: 20.1%). Statistical differences in proportions of injury burden across injury causes were not sought due to small sample size of injuries men’s international rugby.

TABLE 3A.26: Injury proportion, median severity, and proportion of injury burden for training injuries by cause for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Injury Cause (injuries, n)	**Proportion of Injury (95% CI)**	**Median Severity (95% CI)**	**Proportion of Injury Burden (95% CI)**
Men's International Rugby (injuries n = 14)			
Contact (another player) (5)	35.7 (10.6-60.8)	5.0 (3.0-46.0)	22.7 (17.7-27.6)
Contact (moving object) (-)	-	-	-
Contact (static object) (-)	-	-	-
Non-contact trauma (4)	28.6 (4.9-52.2)	7.5 (2.0-69.0)	58.3 (52.5-64.1)
Overuse (gradual onset) (3)	21.4 (0.0-42.9)	19.0 (15.0-27.0)	12.9 (9.0-16.9)
Overuse (sudden onset) (1)	7.1 (0.0-20.6)	(n = 1)	5.0 (2.5-7.6)
Unknown (1)	7.1 (0.0-20.6)	(n = 1)	1.1 (0.0-2.3)
Men's Professional Club Rugby (injuries n = 194)			
Contact (another player) (59)	30.4 (23.9-36.9)	7.0 (5.0-11.0)	26.6 (25.4-27.9)
Contact (moving object) (4)	2.1 (0.06-4.1)	4.0 (2.0-14.0)	0.5 (0.30-0.70)
Contact (static object) (3)	1.5 (0.0-3.3)	30.0 (2.0-38.0)	1.5 (1.1-1.8)
Non-contact trauma (63)	32.5 (25.9-39.1)	8.0 (5.0-13.0)	33.8 (32.5-35.2)
Overuse (gradual onset) (28)	14.4 (9.5-19.4)	12.0 (6.0-24.0)	20.1 (19.0-21.3)
Overuse (sudden onset) (22)	11.3 (6.9-15.8)	6.5 (4.0-15.0)	6.2 (5.5-6.8)
Unknown (15)	7.7 (4.0-11.5)	5.0 (3.0-10.0)	11.3 (10.4-12.2)

Figure 3A.9 presents injury mechanisms for each cohort. Running was the primary training injury mechanism for each cohort (men's international: 35.7%, 95% CI 10.6-60.8; men's professional club: 36.6%, 95% CI 29.8-43.4). For men's international rugby, this was followed by collision (28.6%; 95% CI: 4.9-52.2), followed by several mechanisms with an equal occurrence (n = 1; 7.1% of injuries). For men's professional club rugby, running was followed by tackled and being tackled (both 8.0%; 95% CI: 4.3-11.9) (excluding injuries of an unknown mechanism).

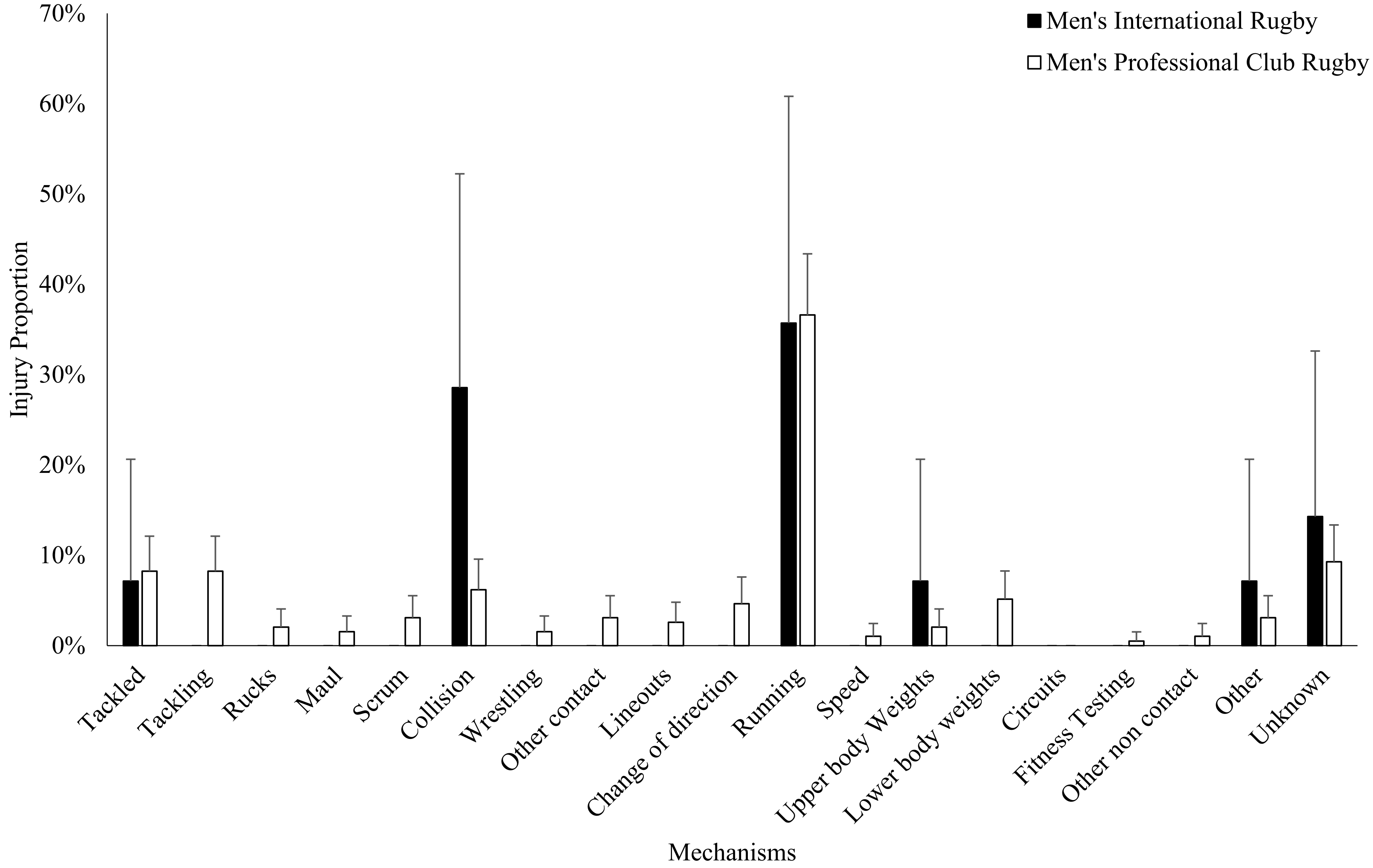

FIGURE 3A.9: Training injury proportion (with 95% CIs) by mechanism for professional cohorts in Scotland across the 2017/18 and 2018/19 seasons.

Figure 3A.10 presents injury incidence, mean injury severity and injury burden by injury mechanism for men's professional club rugby (only injury mechanisms where n > 3 injuries included, men's international rugby not shown due to small numbers of injuries). Running injuries had the greatest incidence (1.5/1000 player training hours; 95% CI: 1.16-1.87), followed by tackling and being tackled (both 0.34/1000 hours; 95% CI: 0.17-0.52). Incidence of running injuries were statistically greater than all other injury mechanisms (IRR range: 2.1-17.8; $p < 0.001$ in all cases).

Excluding other and unknown injury mechanisms, change of direction injuries had the greatest mean injury severity (38.4 days; 95% CI: 0.0-96.6), followed by lineouts (30.4 days; 95% CI: 0.0-77.0) and being tackled (28.9 days; 95% CI: 8.0-49.9). Running injuries had the greatest injury burden (41.9 days absence/1000 player training hours; 95% CI: 40.0-43.7), followed by being tackled (9.9 days/1000 hours; 95% CI: 9.0-10.8) and change of direction mechanisms (7.4 days/1000 hours; 95% CI: 6.6-8.2).

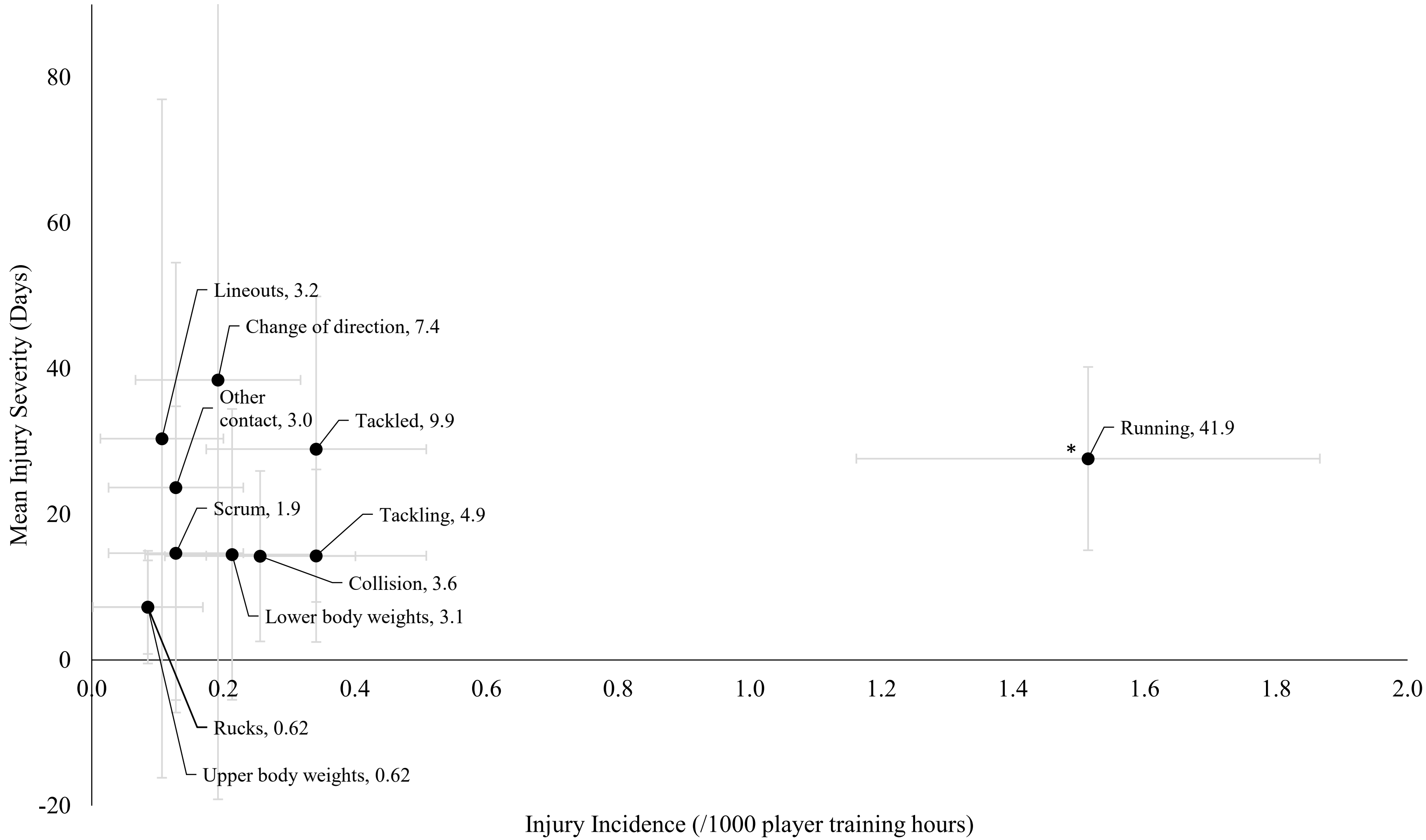

FIGURE 3A.10: Injury incidence (95% CI), mean severity (95% CI), and injury burden (data label; days absence/1000 player match hours) by training injury mechanism for men's professional club rugby in Scotland for the 2017/18 and 2018/19 seasons. Maul, wrestling, speed, fitness testing and other non-contact mechanisms not shown due to small sample sizes (≤ 3 injuries). * ($p < 0.001$) incidence to all other mechanisms.

Due to non-normal distribution, differences were not sought in mean severity data between mechanisms. From mechanisms displayed in figure 3A.10, running had the greatest median severity (10.0 days; 95% CI: 7.0-16.0), followed by being tackled (8.0 days; 95% CI: 3.0-27.0) and tackling (7.5 days; 95% CI: 3.0-12.0). Running injuries had a statistically greater median severity than lower body weights injuries (4.5 days; 95% CI: 2.0-9.0) (U = 211.50; z = 2.066; p = 0.039). No other statistical differences were found.

Training Activity

Figure 3A.11 presents injury incidence, mean injury severity and injury burden by training activity for men's professional club rugby (only training activities where a minimum of 100.0 hours exposure are shown). Fifty-four injuries were excluded due to unclear training activity attribution, whilst 1,196.4 hours of training exposure were excluded due to unknown training activity content. Training activities where the primary content was rucking/mauling had the greatest injury incidence (10.8/1000 player training hours; 95% CI: 3.7-17.8), followed by general play/phase work (7.1/1000 hours; 95% CI: 5.5-8.8) and scrums (5.9/1000 hours; 95% CI: 0.73-11.0). Injury incidence in rucking/mauling training activities was statistically greater than skills (IRR: 14.7; 95% CI: 4.5-47.9; $p < 0.001$), weights (IRR: 10.6; 95% CI: 4.7-24.3; $p < 0.001$), rehabilitation (IRR: 5.2; 95% CI: 1.1-24.1; $p = 0.035$), endurance (weight bearing) (IRR: 4.5; 95% CI: 1.8-11.3; p = 0.001) and lineouts (IRR: 3.1; 95% CI: 1.2-8.4; p = 0.023). General play/phase work training activities had the greatest mean severity (29.3 days; 95% CI: 15.2-43.5), followed by rucking/mauling (25.1 days; 95% CI: 2.4-47.8) and lineouts (23.3 days; 95% CI: 0.0-56.7).

Rucking/mauling training activities had the greatest injury burden (270.7 days absence/1000 player training hours; 95% CI: 235.4-306.0), followed by general play/phase work (208.1 days/1000 hours; 95% CI: 199.1-217.0) and defence (103.8 days/1000 hours; 95% CI: 92.3-115.3). This data suggests that for one hour of rucking/mauling training with 40 players, 10.8 player days would be lost to injury, compared with 8.3 days for general play/phase work and 4.2 days for defence training activities.

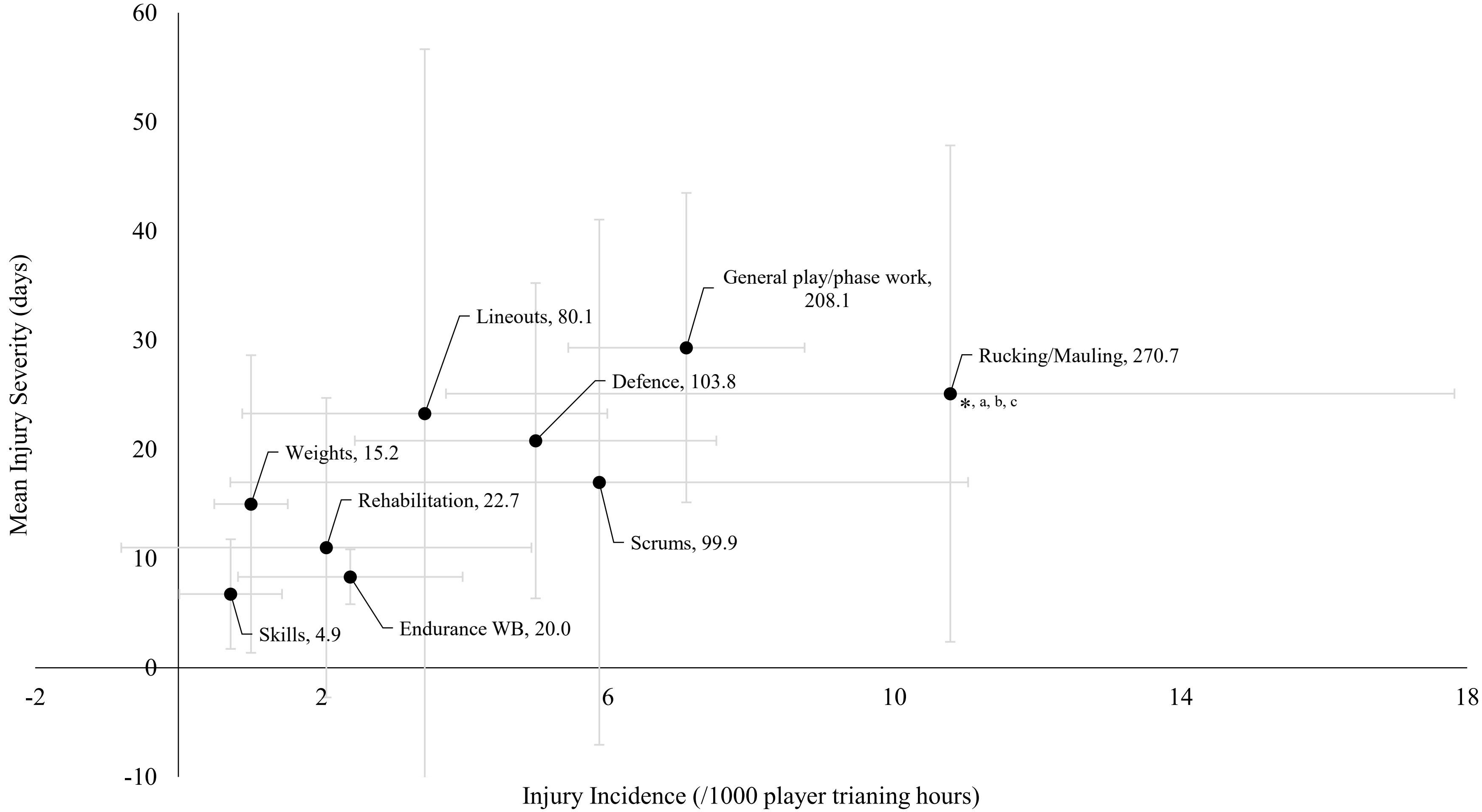

FIGURE 3A.11: Injury incidence (95% CI), mean severity (95% CI), and injury burden (data label; days absence/1000 player match hours) by training activity for men's professional club rugby in Scotland for the 2017/18 and 2018/19 seasons. WB = Weight Bearing. Fitness testing training activities not shown due to exposure < 100.0 hours; Endurance non-weight bearing and speed/agility training activities not shown due to no injuries recorded. *($p < 0.001$) greater injury incidence than Skills and Weights training. [a] ($p = 0.001$) greater injury incidence than Endurance WB. [b] ($p = 0.023$) greater injury incidence than Lineouts. [c] ($p = 0.035$) greater injury incidence than Rehabilitation.

Due to non-normal distribution, differences were not sought in mean severity data between training activities. From activities displayed in figure 3A.11, rucking/mauling training activities had the greatest median severity (12.0 days; 95% CI: 2.0-41.0), followed by defence (9.0 days; 95% CI: 3.0-35.0) and endurance weight bearing (8.0 days; 95% CI: 6.0-11.0). Compared with rucking/mauling training activities, no statistical differences in median severity to other training activities were found.

No statistical differences in injury incidence or median severity between forwards and backs for each training activity were found. However, injury burden was substantially greater for forwards compared with backs in defence training activities (forwards: 213.8 days/1000 hours, 95% CI 188.3-239.3; backs: 24.1 days/1000 hours, 95% CI 16.8-31.4). Backs also sustained no injuries during rucking/mauling training activities. Subsequently, injury incidence (15.3/1000 hours; 95% CI: 5.3-25.3) and burden (383.4 days/1000 hours; 95% CI: 333.5-433.4) for forwards in rucking/mauling training activities was greater than when reported for all players.

Season Phase

Table 3A.27 presents injury incidence, median severity, and burden by season-phase for men's professional club rugby. Injury incidence in pre-season (June, July, and August) was statistically greater than in-season (all remaining months) (IRR: 1.3; 95% CI: 1.0-1.8; $p = 0.048$). Median severity and injury burden in pre-season was greater than in-season. No statistical differences were found between the two season phases for median injury severity.

TABLE 3A.27: Training injury incidence, severity, and burden in pre- and in-season for men's professional club rugby in Scotland during the 2071/8 and 2018/19 season

Season Phase (injuries, n)	**Incidence (95% CI)**	**Median Severity (95% CI)**	**Injury Burden (95% CI)**
Pre-season (71)	5.0 (3.9-6.2)*	9.0 (7.0-12.0)	141.0 (134.8-147.2)
In-season (123)	3.8 (3.1-4.4)	6.0 (5.0-9.0)	85.6 (82.5-88.8)

*($p = 0.048$) to In-Season

Figure 3A.12 presents injury incidence, mean severity and injury burden by month of the season for men's professional club rugby. March had the greatest injury incidence (6.8/1000 player training hours; 95% CI: 4.0-9.6), followed by February (6.0/1000 hours; 95% CI: 3.3-8.6) and May (5.9/1000 hours; 95% CI: 2.6-9.3). Injury incidence in March was statistically greater than September (IRR: 3.2; 95% CI: 1.5-6.7; $p = 0.002$), October (IRR: 2.2; 95% CI: 1.1-4.2; $p = 0.018$), November (IRR: 2.6; 95% CI: 1.1-6.0; $p = 0.028$), December (IRR: 3.1; 95% CI: 1.4-6.6; $p = 0.004$), and April (IRR: 2.1; 95% CI: 1.1-4.1; $p = 0.030$). December had the greatest mean injury severity (41.0 days; 95% CI: 0.0-98.4). followed by June (33.3 days; 95% CI: 0.0-71.9) and March (31.0 days; 95% CI: 1.2-60.9).

March had the greatest training injury burden (211.3 days absence/1000 player training hours; 95% CI: 195.8-226.8), followed by July (149.3 days/1000 hours; 95% CI: 138.2-160.4) and August (138.3 days/1000 hours; 95% CI: 129.5-147.0).

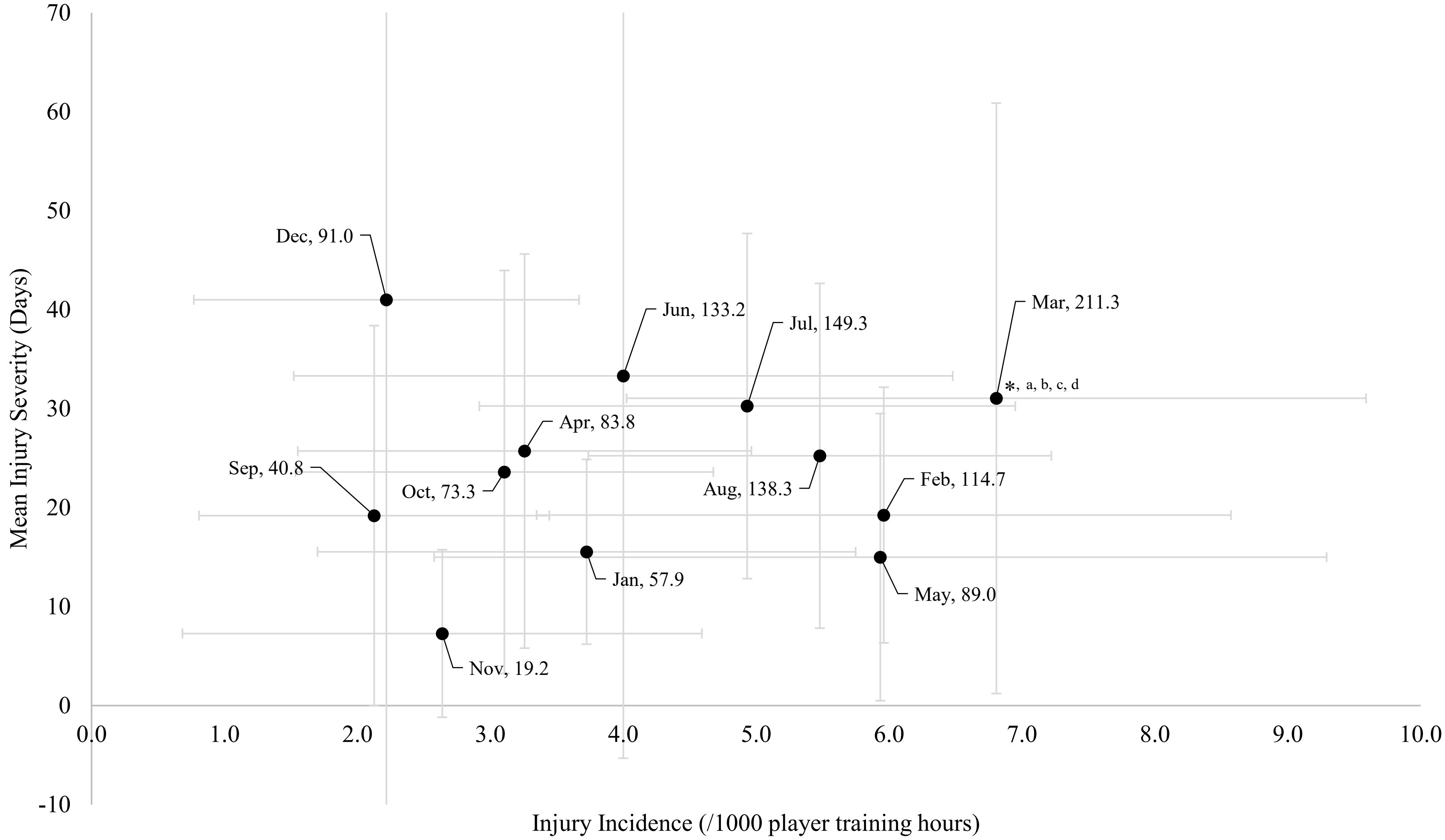

FIGURE 3A.12: Injury incidence (95% CI), mean severity (95% CI), and injury burden (data label; days absence/1000 player match hours) by month for men's professional club rugby in Scotland for the 2017/18 and 2018/19 seasons. *($p = 0.002$) greater injury incidence than September. [a] ($p = 0.018$) greater injury incidence than October. [b] ($p = 0.028$) greater injury incidence than November. [c] ($p = 0.004$) greater injury incidence than December. [d] ($p = 0.030$) greater injury incidence than April.

Due to non-normal distribution, differences were not sought in mean severity data between months of the year. July had the greatest median injury severity (13.0 days; 95% CI: 7.0-27.0), followed by April (12.0 days; 95% CI: 4.0-23.0) and January (10.0 days; 95% CI: 2.0-38.0) and February (10.0 days; 95% CI: 4.0-19.0). Median injury severity in July was statistically greater than August (6.5 days; 95% CI: 4.0-11.0) ($U = 289.50$; $z = 2.201$; $p = 0.028$) and November (3.0 days; 95% CI: 2.0-33.0) ($U = 29.00$; $z = 2.534$; $p = 0.010$).

3A.4: Discussion

The aim of the current study was to undertake a detailed epidemiological study of all match and training injuries sustained by professional Scottish Rugby cohorts across the 2017/18 and 2018/19 seasons, describing the incidence, severity, burden, and nature of injuries. Match injury incidences of 120.0 (men's international), 166.7 (women's international), 136.2 (men's professional club), 229.0 (men's international sevens) and 153.6/1000 player match hours (women's international sevens) were found. Match injury severity ranged from 20.7 - 45.6 days (mean) and 7.0 - 12.0 days (median), whilst match injury burden ranged from 2,887.0 – 7,011.2 days absence/1000 player match hours. Concussion was the most frequent specific match pathology for all cohorts aside from women's international rugby sevens, where it was the second most frequent. Training injury incidences of 3.0 (men's international) and 4.1/1000 player training hours (men's professional club), mean injury severities of 19.9 (men's international) and 24.7 days (men's professional club) and median injury severities of 6.0 (men's international) and 7.5 days (men's professional club) were found. Training injury burden was 58.8 (men's international) and 102.3 days absence/1000 player training hours (men's professional club). Concussion was the most frequent training injury for men's international rugby (equal with posterior thigh and lower leg muscle injuries), and the second most frequent for men's professional club rugby.

3A.4.1: Match Injuries

Injuries by Cohort

The current study utilised a single cohort methodology to study injury epidemiology. Match injury incidences in the current study were greater than previous literature using a multiple cohort methodology. These studies have reported injury incidences of 79.4-90.1/1000 player match hours for men's international (compared with 120.0 in the current study), 35.5-53.3/1000 hours for women's international (166.7 in the current study), 62-103/1000 hours for men's professional club (136.2 in the current study), 106.2-124.5/1000 hours for men's international sevens (229.0 in the current study) and 71.1-109.4/1000 hours for women's international sevens (153.6 in the current study (Brooks et al, 2005a; Fuller et al, 2008; Fuller et al, 2009; Fuller et al, 2010b; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller et al, 2020a; Fuller & Taylor, 2014; Fuller & Taylor, 2017; RFU, 2019; Schick et al, 2008; Schwellnus et al, 2018; Starling et al, 2018; Starling et al, 2019; Starling et al, 2020; Taylor et al, 2011; Whitehouse et al, 2016; West et al, 2020). Studies utilising a single cohort methodology have found injury incidences similar to the current study, with incidences ranging from 92-218/1000 player match hours for men's international rugby, women's international rugby and women's international rugby sevens (Brooks et al, 2005c; Gabb et al, 2014; Moore et al, 2015; Rugby Safe, 2019; Rugby Safe, 2020).

Differences in overall injury incidence between studies which employ either a single or multiple cohort methodology may be due to two potential factors. Firstly, Moore et al (2015) suggested that single cohort studies may provide a more accurate description of injury incidence in rugby, as recognising, diagnosing, and reporting of injury is likely to be more reliable and consistent amongst single medical teams, providing a greater external validity to data (Moore et al, 2015). Whilst injury data recorded for men's professional club rugby in the current study came from two separate clubs, medical staff at each club are employed by Scottish Rugby. A workshop on how to report injury in the current study was used to ensure all medical staff throughout Scottish Rugby recognised the definition of an injury, and how injuries were to be reported. These instructions were followed up twice throughout the study by email, suggesting a reliable and valid approach to injury reporting. Secondly however, it is essential to consider the possible variation in injury incidence season-to-season. For example, from 2002/03-2017/18, the England men's international team had a mean injury incidence of 127/1000 player match hours, yet a range of 62 – 221/1000 player match hours was recorded season-by-season (RFU, 2019). Moore et al (2015) reported an injury incidence of 180/1000 player match hours, yet this ranged from 178.6 – 262.5/1000 player match hours depending on the different tournaments where data was collected. Variations in injury incidence were also found in the current study season-to-season. Injury incidence reported from single cohort studies may also be influenced by the playing style, tactics, and contact technique employed by the team being studied, or representative of the intrinsic risk factors present amongst players within the single squad (Alexander, Kennedy & Kennedy, 1980; Bolling et al, 2018; Fuller & Drawer, 2004; Fuller et al, 2010b; Gissane, Jennings, White & Cumine, 1998; Quarrie & Hopkins, 2008). The smaller sample sizes of injuries and exposure also suggest resultant data may not be as statistically powerful as multiple cohort studies, illustrated by wider confidence intervals (Brooks & Fuller, 2006). Multiple cohort studies therefore likely provide an estimate of injury incidence across the game as a whole, taking into consideration different playing styles and season-to-season and team-to-team variations. Larger sample sizes also likely result in a greater statistical power of the study, as seen by narrower confidence intervals when reporting data (Brooks & Fuller, 2006). Whilst this will provide general awareness for international governing bodies to the probability of injury to those participating in their sport, it does not necessarily provide great insight for individual teams/national governing bodies such as Scottish Rugby in this instance. Single cohort studies will reflect the probability of injury from the way the studied team plays/has played during the data collection period, offering useful and accurate assessment of the probability of injury to the team in question. The data presented from this PhD thesis suggests that reported incidence of injury is greater than would be expected when considering large sample sizes from multiple cohort studies. Whether this reflects playing tactics, contact skill proficiency, and intrinsic injury risk factors present amongst professional players in Scotland, greater diligence and accuracy when recognising, diagnosing, and reporting injuries by Scottish Rugby medical staff, or a combination of all these factors is currently unknown. Studies designed to improve the understanding of differences in injury recognition and reporting between single and multiple cohort studies would be required to further the comprehension of the effect these different methodologies may have on reported injury incidence in rugby. Despite finding similar injury incidence values to other single cohort studies, further investigation by Scottish Rugby is also recommended to identify potential injury risk factors which may contribute for the greater frequency of reported injury when compared to wider-scale, multiple cohort studies.

Men's international rugby sevens had the greatest injury incidence in the current study. As with previous research, there was a greater incidence of injury amongst this cohort compared with men's international rugby in the current study (Fuller et al, 2008; Fuller et al, 2010b; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2020b). However, the margin of difference found in the current study is far greater than previously reported. As injury data from both cohorts was collected in a similar manner (e.g., a single cohort methodology; all medical staff abiding to identical instructions around injury recognition and reporting), reasons for the greater difference in injury incidence is unclear. The current study found no difference in the proportion of injury type, location, or cause between cohorts, whilst the tackle (tackling or being tackled) was the most common injury mechanism for both cohorts. This suggests that the injury profile between men's international rugby and men's international rugby sevens is similar in Scotland, yet injuries occurred more frequently in the latter. Rugby sevens matches are played at a greater relative intensity compared with rugby matches, with greater distances covered at higher speeds (Higham et al, 2012; Ross et al, 2014). Fatigue resulting from greater match intensity may partly explain the greater injury incidences recorded (Fuller et al, 2016; West et al, 2014). Interestingly however, a greater injury incidence was not found for women's international rugby sevens compared with women's international rugby in the current study, despite previous work suggesting this would be the case (Fuller & Taylor, 2017; Fuller et al, 2017c; Fuller & Taylor, 2020a). The small sample size of injuries (n = 11) and exposure (71.6 hours) recorded for women's international rugby sevens in the current study may limit the validity of any potential comparison with women's international rugby. Methods to improve the understanding of injury frequency for men's international rugby sevens in Scotland (e.g., time-motion and playing style analysis of Scottish Rugby men's international rugby sevens, propensity for injury in contact events and identification of intrinsic risk factors for injury), and whether any of these potential risk factors are also present within women's international rugby sevens, is recommended to Scottish Rugby.

Mean (21.2 days) and median injury severity (7.0 days) for men's professional club rugby in the current study were similar to previous studies (mean: 13.0-37.5 days; median: 4.0-14.0 days) (Brooks et al, 2005a; Fuller et al, 2009; Starling et al, 2018; Starling et al, 2019; Starling et al, 2020; West et al, 2020; Whitehouse et al, 2016), as was mean injury severity for men's international rugby (current study: 31.2 days; previous research: 14.7-30.0 days) (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Moore et al, 2015; RFU, 2020). From the 2007 tournament, mean injury severity at men's Rugby World Cups has increased from 14.7 days to 29.8 days (2015) and 28.9 days (2019), whilst median severity has remained stable (6.0-8.0 days), suggesting increasing mean severity is due to a small number of higher severity injuries (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a). The current research reported a mean severity at the higher end of the range reported previously, supporting greater mean severity in more recent studies in men's international rugby. However, the current work also found an increased median severity (12.0 days) compared with previous men's Rugby World Cup studies, and that of Moore et al (2015) amongst Welsh men's international rugby (median severity of 8.0 days). A greater median severity in the current research would suggest a greater number of more severe injuries for Scotland men's international rugby. Whether this is a true increase in the number of more severe injuries, or whether rehabilitation of injuries is more conservative and occurs over a longer period of time in Scotland compared with previous research is currently unclear. Identifying any differences in rehabilitation practices across men's international cohorts would highlight potential reasons for the greater median injury severity reported in the current study for men's international rugby.

Similarly, women's international rugby in the current study had a greater median severity (11.0 days) than previous studies at Women's Rugby World Cups (2010: 9.0 days; 2014: 7.0 days; 2017: 9.0 days) (Fuller & Taylor, 2014; Fuller & Taylor 2017; Taylor et al, 2011), once more suggesting a greater number of more severe injuries. Again, this is currently unclear whether this is due to more conservative rehabilitation protocols, or a genuine increase in the number of injuries of a greater severity. However, mean injury severity amongst this cohort in the current study (30.2 days) was reduced compared to the last three Women's Rugby World Cups (40.9-55.0 days) (Fuller & Taylor, 2014; Fuller & Taylor 2017; Taylor et al, 2011). Mean injury severity for men's international sevens in the current study (20.7 days) was also lower than previous studies (39.0-86.0 days) (Fuller et al, 2010b; Fuller et al, 2017c; Fuller & Taylor, 2020b), and although mean injury severity for women's international sevens in the current study (45.6 days) was within the range of previous data, the small sample size and mean value was heavily influenced by one injury of 366 days. With this injury omitted, mean injury severity would have been reported at 13.7 days, substantially lower than previous multiple cohort studies (40.9-92.0 days) (Fuller et al, 2010b; Fuller et al, 2017c; Fuller & Taylor, 2020a). Median injury severities values for both men's (12.0 days) and women's international rugby sevens (11.0 days) were also reduced compared with previous research amongst multiple cohorts (men's international sevens: 21.0-40.0; women's international sevens: 30.0-42.0) (Fuller et al, 2010b; Fuller et al, 2017c; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b).

When comparing injury severity values from these cohorts in the current study to previous studies which have also utilised a single cohort methodology, more similarities are found. Mean and median injury severity values for women's international rugby in the current study were similar to that reported by the England women's international team for the 2017/18 and 2018/19 seasons (mean: 14-31 days; median: 11-20 days) (Rugby Safe 2019; Rugby Safe 2020), whilst Gabb et al (2014) found a median injury severity of 14.0 days amongst England women's international rugby sevens players. Moore et al (2015) previously suggested that recognising and reporting of injury is likely to be more reliable and consistent amongst single cohort studies. Use of this methodology may result in greater reporting of injuries of a minor severity when compared with multiple cohort studies. Further research examining differences in reporting of minor injuries amongst multiple cohort studies is required to determine whether this is true, or whether differing numbers of less severe injuries may be a reflection of other factors such as playing style, tactics, and contact technique, or intrinsic risk factors present amongst players within the different squads under observation (Alexander et al, 1980; Bolling et al, 2018; Fuller & Drawer, 2004; Fuller et al, 2010a; Gissane et al, 1998; Quarrie & Hopkins, 2008).

Although injury incidence and injury severity data can provide useful information on frequency and seriousness of injury, true risks to player welfare are understood by the analysis of injury burden. Injury burden can provide governing bodies with a greater understanding of the injury situation, and therefore fulfil Scottish Rugby's legal obligation to monitor risks to player welfare, as well as improving chances of team success through greater understanding of player (un)availability over a period of time (Fuller, 1995; Fuller, 2018b; Fuller, 2018c; Fuller, 2020).

Overall injury burden for men's international (3,745.0) and women's international rugby (5,040.0 days absence/1000 player match hours) in the current study were increased compared to previous multiple cohort studies at previous Rugby World Cups (men's: 1,233.3-2,685.0; women's: 1,864.8-2,180.0 days absence/1000 player match hours) (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Fuller & Taylor, 2014; Fuller & Taylor 2017; Taylor et al, 2011). As previously discussed, these studies have tended to report reduced injury incidence values in comparison to the current research, providing an explanation for the lesser injury burden. Whilst men's professional club rugby injury burden from the current study (2,887.0 days absence/1000 player match hours) was also greater than the majority of previous multiple cohort studies (1,222-2,629 days absence/1000 player match hours), it did fall within the range of values reported each season from the English Premiership from 2002/03-2017/18 (range: 1,556 - 3,479 days absence/1000 player match hours) (West et al, 2020).

Single cohort studies in men's international rugby have previously recorded mean injury burdens of 2,408 (England men's international rugby 2002/03-2018/19) and 3,240 (Welsh men's international rugby 2011-2014), yet values ranged from 813 - 4,264 (England men's international rugby) and 1,250.2 – 7,612.5 days absence/1000 player match hours (Welsh men's international rugby) dependent upon season or tournament (Moore et al, 2015; RFU, 2020). Injury burden for men's international rugby in the current study falls within these ranges, suggesting similar risks to player welfare and availability when season-to-season variations are considered. However, even when compared to other single cohort research, injury burden values recorded for women's international rugby in the current study remain greater than season-to-season ranges (injury burden from England women's international team 2017/18-2018/19: 2,046-2,842 days absence/1000 player match hours) (Rugby Safe, 2019; Rugby Safe, 2020).

Scottish Rugby has a legal duty of care to understand the risk to player welfare and attempt to mitigate risks to an acceptable level (Fuller, 1995, Fuller & Drawer, 2004; HSE, 2001), as well as a financial interest to maximise team performance through greater player availability (Morgan, 2002; Zhang et al, 2003). When considering season-to-season variations in injury incidence and severity, injury burden recorded for men's international and men's professional club rugby appear to fall within previously established values. However, even considering potential season-to-season variation, women's international rugby players in Scotland appear at a greater risk of time-loss through match injury than has been recorded previously. This may suggest an increased risk to player welfare and reduced player availability for match selection, potentially decreasing chances of team success (Williams et al, 2016). This discussion will highlight different areas around the nature of injuries and specific diagnoses which represent the greatest injury burden. This will present Scottish Rugby with potential areas for injury mitigation strategies particular to women's international rugby. It is also advised that Scottish Rugby investigate daily injury burden, establishing the number of players unavailable due to injury on any specified day, as discussed by Fuller (2017) and Fuller

(2018c). The high incidence of injury, coupled with low mean severity when compared with previous research suggests that a large proportion of injury burden may be composed of short-term injuries, which would have a reduced effect on player availability compared with low incidence/high severity injuries (Fuller, 2018b; Fuller, 2018c). Understanding how injury burden effects player availability throughout the season would provide a greater specificity to any future injury mitigation strategy (Fuller, 2017; Fuller, 2018b).

Previous research suggests injury burden in international rugby sevens is higher than rugby as a result of greater injury incidence and mean severity values reported in the majority of cases (Fuller et al, 2008; Fuller et al, 2009; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a). Similarly, injury burden for men's international sevens (4,728.4 days absence/1000 player match hours) was greater than injury burden recorded for men's international rugby in the current study, likely due to the statistically greater incidence of injury. Compared with previous research, injury burden for men's international rugby sevens was similar to that reported from all teams in the Men's Sevens World Series in 2008/09 and 2010/11-2018/19 (5,263 days absence/1000 player match hours) (Fuller & Taylor, 2020b). Despite far greater injury incidences reported in the current study for men's international sevens compared with multiple cohort studies such as Fuller and Taylor (2020b), a greatly reduced mean injury severity was reported in the current study, illustrating how similar values of injury burden can reflect differing incidence and severity data (Fuller, 2018b). The reduced mean injury severity for men's international rugby sevens in the current study suggests high incidence/low severity injuries are more responsible for overall injury burden. The distinction between these injuries and low incidence/high severity injuries is an important factor when considering potential injury mitigation strategies: high incidence/low severity injuries (i.e., those that would recover before the following tournament) are less likely to affect overall team performance than injuries of low incidence/high severity (Fuller, 2018b). As a result, it is again advised Scottish Rugby determine daily injury burden for this cohort. Establishing the number of players unavailable due to injury on any specified day, and how the reported injury burden affects player availability for tournament selection would further the understanding of the injury risk associated with this cohort (Fuller, 2017; Fuller, 2018c).

Injury burden recorded for women's international rugby sevens (7,011.2. days absence/1000 player match hours) was also greater than women's international rugby in the current study, as well as previous studies in both multiple cohort (Women's Sevens

World Series 2012/13-2019/20: 5,640 days absence/1000 player match hours) and single cohort settings (England women's international sevens squad 2013: 6,171 days absence/1000 player match hours) (Fuller & Taylor, 2020a; Gabb et al, 2014). However, a small sample of injuries (n = 11) and exposure (71.6 hours) was recorded for women's international rugby sevens across the 2017/18 and 2018/19 seasons, with one injury having a severity of 366 days. This injury had a large effect on mean injury severity and represented a substantial proportion of total injury burden (5,670.4 days absence/1000 player match hours; 72.7% of total injury burden). Although the prospective data collection methods in the current study accurately reflect injury epidemiology over the 2017/18 and 2018/19 seasons, the small sample size and the resultant disproportionate effect one large severity injury can have on overall injury burden suggests heavy caution should be applied when comparing injury burden data from this cohort to previous research.

Playing Position

No statistical differences in injury incidence or median severity were found between forwards and backs for either of men's international, women's international, or men's professional club rugby. Whilst injury burden was similar between forwards and backs for men's professional club rugby, injury burden was greater for forwards in both men's and women's international rugby. This is the opposite for previous findings from the previous three Rugby World Cups for both men and women (Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Fuller & Taylor, 2017). This highlights the necessity of injury epidemiology research and understanding injury risks specific to a single cohort, providing Scottish Rugby with greater insight into risks to player welfare and availability, and developing targeted injury mitigation strategies (Fuller & Drawer, 2004).

Across all three rugby cohorts, hooker recorded the greatest incidence of injury, as well as the greatest injury burden for men's professional club rugby. Hookers experience high levels of force during scrummaging, which has previously been postulated to increase probability of scrummaging injury (Cazzola, Preatoni, Stokes, England, & Trewartha, 2015; Swaminathan, Williams, Jones, & Theobald, 2016). However, in the current study, minimal injuries were recorded at scrums for hookers (0, 1, and 1 injury for men's international, women's international and men's professional club rugby respectively). Hookers have been shown to be involved in a high number of tackles per game in professional rugby (Tucker et al, 2017a). This, combined with fatigue from involvement in other contact situations such as scrums, mauls and rucks may elevate injury incidence and burden (Brooks & Kemp, 2011; Lindsay et al, 2015; Nicholas, 1997).

Injury Recurrence

Aside from women's international rugby, incidence of new injuries were statistically greater than recurrent injuries for all cohorts. Proportion of recurrent injuries in the current study ranged from 4.7 – 16.1% for men's international rugby, men's professional club rugby, and men's and women's international rugby sevens, similar to what has been found previously in professional rugby (5.6 - 17.6%) (Brooks et al, 2005a; Fuller et al, 2008; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b). Women's international rugby recorded a statistically greater recurrent injury proportion when compared across all other cohorts of 34.0%. Recurrent injuries in this cohort were responsible for an injury burden substantially larger than any other cohort, suggesting that recurrent injuries may partly be responsible for the elevated overall injury burden recorded for women's international rugby in the current study. This data suggests current injury rehabilitation strategies utilised by medical teams with women's international rugby may possess limited effectiveness, and it is advised Scottish Rugby investigate the efficacy of injury rehabilitation protocols and validity of return-to-play assessments within this cohort to identify potential strategies to mitigate risk of recurrent injury (Fuller & Drawer, 2004). Fuller, Bahr, Dick and Meeuwisse (2007a) also recommend distinction between recurrent injuries versus exacerbation injuries, based on whether the player was fully recovered from the index injury. Future research including this distinction may enable greater understanding of the efficacy of the rehabilitation process.

A statistically increased median injury severity was found for recurrent injuries compared with new injuries for men's professional club rugby, as has been found previously (Williams, Trewartha, Kemp, & Stokes, 2013). This also highlights the need to ensure effective injury rehabilitation strategies are in place and valid return-to-play assessments are utilised to prevent a greater injury severity and further time-loss from recurrent injury (Brooks et al, 2005a). However, this analysis does not consider the severity of a recurrent injury in comparison to the respective index injury (Williams et al, 2013). Recurrence of particular injuries may be more likely than others, and if those have a greater severity then this would artificially enhance injury severity of recurrent injury. Future research should include analysis of type and location of recurrent injury.

Location and Type of Injury

Lower limb, muscle and tendon and joint and ligament injuries represented the greatest proportion of injury in all cohorts, as well as the largest proportion of total injury burden, agreeing with previous literature in professional rugby (Brooks et al, 2005a; Fuller et al, 2008; Fuller et al, 2009; Fuller et al, 2010b; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2017; Fuller et al, 2020a; Gabb et al, 2014; Holtzhausen et al, 2006; Moore et al, 2015; Schwellnus et al, 2018; Taylor et al, 2011; Whitehouse et al, 2016). Injury epidemiology allows Scottish Rugby to understand hazards associated with professional rugby. This may identify areas for risk mitigation, fulfilling their legal duty of care of player welfare (Fuller, 1995; Fuller & Drawer, 2004; HSE, 2001), and potentially improving player availability for match selection and therefore team success (Williams et al, 2016). In order to reduce injury burden across all cohorts, preventative or therapeutic measures to reduce incidence or severity of lower limb, muscle and tendon, and joint and ligament injuries should be a priority for Scottish Rugby (Fuller & Drawer, 2004; Fuller 2007). Further investigation to understand mechanism, aetiology, and presence of/interaction of different intrinsic and extrinsic risk factors of these injuries is required to identify potential mitigation strategies. This is beyond the scope of the current PhD thesis, but is highly recommended.

Specific Diagnosis

Concussion was the most common specific match pathology for all cohorts aside from women's international rugby sevens, where it was the second most frequent. Recent studies in men's and women's international rugby, men's professional club rugby and men's and women's international rugby sevens have all reported concussion as the most frequent specific injury (Fuller et al 2017b; Fuller et al, 2017c; Fuller et al, 2020a; Fuller & Taylor, 2017; Rafferty et al, 2019; RFU, 2019; West et al, 2020). Recent studies in men's international rugby have reported match concussion injury incidences of 21.4 - 27.8/1000 player match hours, similar to the incidence of 22.5/1000 player match hours found in the current study (Cosgrave & Williams, 2019; Rafferty et al, 2019). However, other cohorts in this study report greater values than have been found previously. Concussion incidence has been reported as 14.2-15.4/1000 player match hours for women's international rugby (compared with 26.7/1000 hours in the current study) 14.8-21.4/1000 hours for men's professional club rugby (28.5/1000 hours in the current study), and 8.9-18.6/1000 hours for men's and 8.9-23.5/1000 hours for women's international rugby sevens (37.3 and 27.9/1000 hours respectively in the current study) (Cosgrave &

Williams, 2019; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Rafferty et al, 2019; RFU, 2019; RFU, 2020; Rugby Safe, 2019; Starling et al, 2020; West et al, 2020). As a specific injury, concussion also represented the greatest burden for men's professional club rugby, reflecting the statistically greater than expected severity proportion of head/neck injuries for this cohort, and was the injury with the third greatest burden for men's and women's international rugby sevens. Due to the potential negative consequences concussive injury may have on player welfare in both short- and long-term instances (Cross et al, 2016; Gouttebarge et al, 2017; McKee et al, 2009; Stern et al, 2011), and the effect it may have on player availability and team success (Drew et al, 2017; Williams et al, 2016), the concussive incidences found in the current study are of concern.

Since the introduction of the HIA system into elite rugby in 2011/2012, reported concussion incidence has dramatically increased (Best et al, 2005; Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2017; Fuller & Taylor, 2020b; Rafferty et al, 2019; RFU, 2019; West et al, 2020). Scottish Rugby have been at the forefront of improving awareness and recognition of concussion, including participating in the "If in Doubt, Sit them Out" campaign which was launched in 2015 (Sport Scotland, 2018). The current study may suggest a continuation in rise of reporting rates of concussion, in combination with medical staff within Scottish Rugby being more diligent at recognising and reporting concussion. Future studies will determine whether the concussion incidences found in the current study are representative of the true incidence of concussion in professional rugby or whether reported incidences continue to rise. Regardless, the current study suggests that concussion incidence in professional rugby in Scotland is greater than previously reported in other cohorts. With their responsibility to understand and minimise the risks to player welfare, Scottish Rugby have a responsibility to attempt reduce the incidence of concussion to protect player health and well-being, as well as minimising the risk of player time-loss and unavailability for match selection to enhance team performance (Fuller, 1995; Fuller & Drawer, 2004; HSE, 2001; Morgan, 2002; Williams et al, 2016; Zhang et al, 2003). Greater investigation into mechanism and aetiology of concussion, as well as studies to further the scientific understanding of negative implications of concussion on player welfare are required. Concussion epidemiology amongst the current cohorts will be presented and discussed in greater detail in chapter 3B.

The most frequently diagnosed match injury for women's international rugby sevens was knee sprain/ligament damage. This was similar to the findings of Fuller et al (2017c), who found knee ligament injuries as the most common match injury during the 2014/15 Women's Seven's World Series, whilst Fuller and Taylor (2020a) found knee ligament injuries (medial and anterior cruciate ligament sprains) were the second most common injury for backs, and knee medial cruciate ligament sprains the third most common injury for forwards in the Women's Sevens World Series from 2012/13 to 2019/20. Women rugby sevens players may be at greater risk of knee ligament injuries due to the effects of hormonal fluctuations during the menstrual cycle on ligament laxity (Balachandar et al, 2017; Heitz et al, 1999). Greater Q-angles found in female athletes may also contribute, causing increased knee abduction moments and knee valgus loading during landing and agility/cutting movements, increasing knee ligament injury risk (McLean, Huang, & van den Bogert, 2005; Hewett et al, 2005). Due to the more open nature and greater reliance of running and avoiding contact in rugby sevens (Higham et al, 2012), this may place women's rugby sevens players at a greater chance of knee ligament injuries in comparison with other cohorts.

Sprain/ligament injuries recorded the highest burden for men's international rugby (ankle) and women's international rugby sevens (knee), whilst posterior thigh muscle injury had the greatest burden for men's international sevens. High burden of sprain/ligament injuries have been reported in previous studies in professional rugby, whilst hamstring muscle injuries were recorded as the injury with the greatest burden for international rugby sevens backs, and the fifth greatest burden for forwards (Dallalana, Brooks, Kemp, & Williams, 2007; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2020b; Sankey, Brooks, Kemp, & Haddad, 2008). Whilst intervention recommendations for these injuries are available (Askling, Karlsson, & Thorstensson, 2003; Attwood et al, 2017; Collins et al, 2014; Crichton, Jones, & Funk, 2012; Dallalana et al, 2007; Drury, Lehman, & Rayan, 2017; Verhagen & Bay, 2010), further understanding of specific aetiology and intrinsic/extrinsic risk factors is also likely to identify further preventative or therapeutic measures to explore to potentially reduce injury burden associated with these injuries (Fuller & Drawer, 2004; Fuller, 2007). Further investigation by Scottish Rugby is recommended.

The greatest injury burden for women's international rugby was due to fracture of the foot/toe. Bone injuries in general in this cohort also had statistically greater than expected proportion of injury burden. Within the female athlete triad, lower energy availability (with or without disordered eating) has been associated with low bone mineral density, osteoporosis and increased chance of fracture (Nattiv et al, 2007; Pollock et al, 2010). This may result in bone injuries of a greater severity in women's international rugby players. Ensuring adequate energy availability and bone mineral density of players in this cohort should be a priority for Scottish Rugby in the future.

Cause and Mechanism

Contact (with another player) was the primary cause of match injury and the cause with the highest proportion of injury burden in all cohorts (aside from women's international sevens, where one non-contact trauma injury represented 72.7% of total injury burden), agreeing with previous work (Brooks et al, 2005a; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; RFU, 2019; Taylor et al, 2011). Within contact mechanisms, the tackle situation (being tackled and tackling) was responsible for the greatest proportion of injuries across all cohorts, similar with previous literature (Brooks et al, 2005a; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; RFU, 2019; RFU, 2020; Schick et al, 2008; Starling et al, 2020; Taylor et al, 2011; West et al, 2020). The tackle is the contact event which happens most frequently within matches, and being tackled and tackling are fundamentally open skills (Burger et al, 2016; Fuller et al, 2007b; Tucker et al, 2017a). As a result, they are far less predictable than other contact events such as scrummaging or mauls, and large impact forces between players are often seen (Hendricks et al, 2014a; Seminati et al, 2017). These factors may contribute to the greater proportion of injury (Fuller et al, 2007b).

Within men's professional club rugby, tackling was the mechanism associated with the greatest injury burden, followed by being tackled and ruck injuries. Similarly, West et al (2020) recorded the tackle situation as being responsible for the greatest injury burden in men's professional club rugby in England from 2002/03-2017/18, although these researchers found that being tackled had a greater burden than tackling. West et al (2020) reported that 45.3% of the injury burden over this time frame was attributed to the tackle situation, yet the current study found 59.9% of the injury burden was associated to the tackle. Whilst this may infer that other injury mechanisms have less of an impact on total injury burden in the current study than that of West et al (2020), the absolute injury burden attributed to the tackle situation in the current study (1,728.9 days absence/1000 player match hours) was far greater than that reported by West et al, (2020) (987 days absence/1000 player match hours), and reinforces the need for intervention strategies (by

Scottish Rugby as well as global stakeholders/World Rugby) to mitigate the injury risk associated with this event. Attempting to reduce the injury risk through improper technique, Kerr et al (2018) utilised a World Rugby training video to attempt to teach correct tackling technique amongst university and school-aged rugby players. However, no definite improvements were found, with some elements of technique getting worse throughout the learning process (Kerr et al, 2018). Previous studies have suggested that lowering tackle height may reduce risk of injury (Cross et al, 2019; Tierney & Simms, 2017; Tucker et al, 2017a), yet Stokes et al (2021) found that a trial to reduce the legal tackle height to below the armpit line did not reduce injury incidence to the tackler or tackled player, whilst concussion incidence to the tackler increased as a result of lowering the legal tackle height. The tackle is a dynamic, open, unpredictable event (Burger et al, 2016), and the lack of successful interventions thus far highlights the difficulty of identifying modifiable risk factors to mitigate injury risk. Whilst the primary focus of injury mitigation research literature in rugby is currently focused around concussion prevention, the current study found that the majority of injury burden whilst tackling was attributed to the upper limb, and the majority of burden whilst being tackled was to the lower limb. Whilst concussion prevention should by no means be overlooked, strategies focused on these areas may provide the greatest opportunity to reduce injury burden associated with the tackle. Further investigation of exact aetiology of these injuries, and prevalence of different intrinsic/extrinsic risk factors within the tackle situation is advised for Scottish Rugby to attempt to reduce injury risk with this event.

3A.4.2: Training Injuries

Injuries by Cohort

Training injury incidence and burden were greatly reduced for men's international (3.0/1000 player training hours and 58.8 days absence/1000 player training hours) and men's professional club rugby (4.1/1000 hours and 102.3 days absence/1000 player training hours) compared to match play (120.0 – 136.2/1000 hours and 2,887.0 – 3,745.0 days/1000 hours). Total days lost due to injury was also greater from match play (men's international: 1,498 days; men's professional club: 7,102 days) compared with training (men's international: 278 days; men's professional club: 4,795 days), suggesting match injuries provide the greatest cumulative time loss for both cohorts.

Training injury incidence in the current study for men's international rugby (3.0/1000 player training hours) was comparable with values recorded from multiple cohort studies from the previous four men's Rugby World Cups (1.0-3.5/1000 hours) yet reduced compared with single cohort studies amongst Welsh (4.7/1000 hours) and English men's international squads (4.3-6.1/1000 hours) (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Moore et al, 2015; RFU, 2017; RFU, 2019; RFU, 2020). Conversely, injury incidence for men's professional club rugby in the current study (4.1/1000 hours) was greater than that recorded in men's professional club rugby in previous studies following a multiple cohort methodology (1.5-3.0/1000 hours) (Brooks et al, 2005b; RFU, 2019; RFU, 2020; Schwellnus et al, 2018; West et al, 2019; Whitehouse et al, 2016). A potential reason for the greater training injury incidences recorded in the current study for men's professional club rugby compared with previous multiple cohort studies is that injury recognition, diagnosis and reporting may be more reliable and consistent amongst single cohort epidemiology studies due to one single medical team responsible for collecting all injury data (Moore et al, 2015). However, this would not explain that injury incidence recorded for men's international rugby in the current study was similar to previous multiple cohort studies and reduced when compared with previous single cohort studies. Varying training injury incidences between different studies may be due to time spent in different training activities. There are wide variations in training injury incidence reported in different training activities, dependent upon the content of the activity (e.g., contact versus non-contact; weight bearing versus non-weight bearing) (Brooks et al, 2005b; RFU, 2020). Training injury incidences are therefore likely to vary from team to team based on their time spent in different training activities, and also likely season-by-season if training philosophies are altered over time (West et al, 2019). Multiple cohort studies will therefore represent an average of training injury incidences from a variety of different training styles. The single cohort methodology employed here and the associated training injury incidence for men's international and men's professional club rugby therefore likely reflects the specific training style and activities undertaken of these cohorts. This provides Scottish Rugby with an accurate evaluation of the probability of injury within these cohorts over the past two seasons. Different training activities for this cohort where large incidences of injury were recorded will be evaluated later in this discussion.

Mean (19.9 days) and median training injury severity (6.0 days) for men's international rugby was similar to previous findings for this cohort (mean: 12.0 - 26.9

days; median: 6.0 - 9.0 days) (Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Moore et al, 2015; RFU, 2019; RFU, 2020). Mean (24.7 days) and median training injury severity (7.5 days) for men's professional club rugby however was reduced compared to recent studies (mean: 32-37 days; median: 9.0-17.0 days) (RFU, 2019; RFU, 2020; West et al, 2019; Whitehouse et al, 2016). West et al (2019) reported increasing mean and median training injury severity from 2007/08 to 2017/18 in men's professional club rugby in England, suggesting the number of more severe training injuries was increasing amongst this cohort over time. However, the current study does not agree with this, with reduced mean and median severity values in comparison with previous research. Without further investigation, it is not possible to determine whether this is due to a larger number of minor severity injuries in the current cohort, differing rehabilitation protocols to treat particular injuries, or whether training injuries are truly less severe in Scottish men's professional club rugby.

As a result of rising training injury severity in men's professional club rugby in England, training injury burden reported in recent seasons (2016/17: 96 days absence/1000 player training hours; 2017/18: 106 days/1000 hours) (West et al, 2019), is similar to the training injury burden reported for men's professional club rugby in the current study (102.3 days/1000 hours), despite the greater injury incidence reported by men's professional club rugby in Scotland. This illustrates how differing combinations of incidence and severity can provide similar overall quantifications of injury risk (Fuller, 2018b), and it is important to consider how this injury risk affects player availability across a season. The higher incidence yet lower severity recorded in the current study would suggest a greater proportion of total burden is attributed to shorter duration injuries, which may be less likely to cause player unavailability for match selection, compared with lower incidence/higher severities injuries (Fuller, 2018b). To establish the expected number of players unavailable for selection on any specified day, and fully understand daily injury burden, further research with Scottish Rugby should follow kinetic models outlined by Fuller (2017). This should provide greater detail on how the injury burden recorded affects player availability for match selection, and is likely to provide a greater specificity to any future injury mitigation strategy (Fuller, 2018c).

As a result of similar training injury incidence and mean severity to previous research, training injury burden in the current study for men's international rugby (58.8 days absence/1000 player training hours) was similar to what has been found previously (14.4 – 63.3 days/1000 hours at 2007, 2011, 2015 and 2019 men's Rugby World Cup

(Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a). Training injury burden for men's professional club rugby in the current study was substantially greater than that recorded for men's international rugby, which seems to be mirrored in studies from previous literature. Scottish Rugby have both a legal and financial/performance interest to fully understand the injury risk experienced by their players and to attempt reduce the risk to as low a level as practically possible (Fuller, 1995; HSE, 2001; Fuller & Drawer, 2004; HSE, 2001; Morgan, 2002; Zhang et al, 2003). Although not statistically different, injury incidence and mean injury severity were both greater amongst men's professional club rugby in the current study. Time spent in different training activities and fluctuations in training load, intensity, and frequency have all been suggested to alter training injury incidence or severity (Ball, Halaki, & Orr, 2017; Brooks et al, 2005b; Gabbett & Jenkins, 2011; Gabbett & Ullah, 2012; West et al, 2019). Due to small sample size, injury risk in different training activities was not evaluated for men's international rugby in the current research, whilst investigations around training load were beyond the scope of this PhD thesis. To attempt to reduce the injury risk reported for men's professional club rugby, further investigation is recommended by Scottish Rugby into the training practices, time in different activities, and training load of this cohort compared with men's international rugby. This may improve the comprehension of the greater injury risk in men's professional club rugby, and allow identification of potential mitigation strategies to reduce injury risk in this cohort.

Playing Position

As with previous research for men's international and men's professional club rugby, no statistical differences in injury incidence were found between forwards and backs for either cohort (Fuller et al, 2020a; Whitehouse et al, 2016), yet median injury severity was statistically greater for forwards compared with backs for men's international rugby. In men's professional club rugby, second row had the greatest injury incidence, mean severity and injury burden. Forty-five percent of the injury burden for second row players was attributed to general play/phase work training activities, whilst ten second row injuries were lower limb, soft-tissue injuries sustained whilst running or changing direction. These injuries resulted in 312 days absence across two seasons, 27.6% of the total time-loss for this position. Previous literature has demonstrated that monitoring chronic training load and time spent in different intensities of maximal velocity has been shown to protect against lower limb soft tissue injury in team sport athletes (Duhig et al, 2016; Gabbett & Ullah, 2012; Malone et al, 2018; Malone, Roe, Doran, Gabbett, & Collins, 2017). These strategies provide suggestions for Scottish Rugby for potential measures to mitigate soft-tissue injury risk in second row players.

Injury Recurrence

Incidence of new injuries was statistically greater than recurrent injuries for men's professional club rugby as has been found previously (Brooks et al, 2005b; Williams et al, 2013). The lack of statistical difference for men's international rugby may be due to the relatively small sample of injuries recorded for this cohort. Median severity of recurrent injury was statistically greater than median severity of new injuries for men' s professional club rugby, similar to previous studies (Brooks et al, 2005b; Williams et al, 2013). This highlights the need to ensure effective injury rehabilitation strategies are in place and valid return-to-play assessments are utilised to prevent further time-loss from recurrent injury. In order to further the understanding around the incidence, severity and burden of recurrent injuries however, future studies should determine between "exacerbation" and "re-injury" (Fuller et al, 2007a), as well as the severity of the recurrent injury in comparison to the original index injury (Williams et al, 2013).

Location and Type of Injury

As with match injuries, the greatest proportion of injuries and of total injury burden was due to lower limb, muscle and tendon and joint and ligament injuries across both cohorts, similar to what has been found previously (Brooks et al, 2005b; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a; Holtzhausen et al, 2006; West et al, 2019), and reflects that "running" was the primary injury mechanism in each cohort. Due to the large burden associated, lower limb, muscle and tendon and joint and ligament injuries may offer the greatest potential for reduction in overall injury risk, and should be a priority for Scottish Rugby to decrease overall injury burden in both cohorts. Injury mechanisms will be discussed below, but further investigation to understand exact aetiology, intrinsic and extrinsic risk factors for these injuries should aid in identifying potential injury mitigation strategies to be implemented by Scottish Rugby to reduce injury risk (Fuller & Drawer, 2004).

Cause and Mechanism

The primary cause of injury was contact (with another player) for both cohorts. Previous studies have found mixed results when analysing training injury by cause:

Moore et al (2015) (74%) and Brooks et al (2005b) (57%) reported that the majority of training injuries were caused in non-contact situations in men's international and men's professional club rugby respectively. However, Fuller et al (2020) reported that 70% of training injuries were caused by contact events at the 2020 men's Rugby World Cup. This difference is likely attributable to contrasts in training structure and training activities across different teams. Despite contact (with another player) causing the most injuries, running was the primary injury mechanism for both cohorts in the current study, mirroring what has been found previously in professional rugby (Brooks et al, 2005b; West et al, 2019).

Injuries caused by non-contact trauma were responsible for the greatest proportion of injury burden in both cohorts in the current study, whilst running was associated with the greatest injury burden for men's professional club rugby, as has been found previously (West et al, 2019). Whilst aetiology of any injury is likely multifactorial with differing magnitudes of relationships and associations between intrinsic and extrinsic risk factors affecting the probability of injury occurrence (Bittencourt et al, 2016; Bolling et al, 2018; Meeuwisse et al, 2007), previous research in team sport athletes has begun to suggest that chronic training load and time spent in different intensities of maximal velocity may provide indicators of probability of lower limb, non-contact soft tissue injuries (Gabbett, 2016; Gabbett, 2020; Malone et al, 2017). For men's international rugby, 11.9% of the total injury burden was attributed to soft tissue, non-contact trauma injuries to the lower limb, whilst 29.2% of the injury burden was attributed to these injuries for men's professional club rugby. Additionally for men's professional club rugby, 30.2% of the total injury burden was attributed to soft tissue injuries to the lower limb through running. Unlike match-play, training is a modifiable environment, and exposure to certain risk factors for injury can be controlled to reduce injury probability or risk. Utilising micro-technologies to monitor training load/volume and time spent in different intensities of maximal velocity for each player, and using that data to modify and prescribe future training load may provide Scottish Rugby with mitigation strategies to reduce the risk of these injuries (Gabbett, 2016; Gabbett, 2020; Malone et al, 2017).

Specific Diagnosis

Concussion, and muscle injuries to the lower leg and posterior thigh were the most common injuries for men's international, whilst posterior thigh muscle injury was the most common training injury for men's professional club rugby. Hamstring and calf muscle injuries have previously been found as the most common training injures in both men's international and men's professional club rugby (Brooks et al, 2005b; Fuller et al, 2008; RFU; 2020). Concussion was the second most common training injury for men's professional club rugby.

For men's international rugby, three of the four muscle injuries to the lower leg and posterior thigh were sustained whilst running, whilst all four muscle injuries were caused either through non-contact trauma or overuse. For men's professional club rugby, out of the 19 posterior thigh muscle injuries sustained, 17 were caused by non-contact trauma or overuse, and 12 were sustained by running mechanisms. Use of technology to monitor training load/volume and prescribe future load may prove to be an effective mitigation strategy to be implemented by Scottish Rugby to protect against these injuries (Gabbett, 2016; Gabbett, 2020; Malone et al, 2017). Interventions targeting eccentric strengthening of lower body musculature, or preventative measures such as structured movement control warm-up routines may also reduce incidence of lower limb soft tissue running injuries (Attwood et al, 2017; Askling et al, 2003). Aside from one concussion with an "unknown" mechanism, all concussions from both cohorts were caused by contact mechanisms. Further investigation of training concussion epidemiology will follow in chapter 3B of this thesis.

Shoulder/clavicula tendon injury/rupture/tendinopathy/bursitis and knee lesion of meniscus/cartilage were the two highest burden injuries in training for men's international and professional club rugby respectively. Knee and shoulder injuries have similarly been shown to have a high training injury burden across men's international and men's professional club rugby in previous studies (Brooks et al, 2005b, Fuller et al, 2008; Fuller et al, 2013). Injury prevention techniques for these injuries are available, and are based around modification of training load, taping/bracing/padding strategies, contact technique interventions and neuromuscular training (shoulder), and modification of training load and neuromuscular training interventions (knee) (Crichton et al, 2012; Dallalana et al, 2007; Headey, Brooks, & Kemp, 2007; Myklebust et al, 2003; Usman, McIntosh, & Fréchède, 2011). A further, detailed investigation by Scottish Rugby to understand mechanism, aetiology, and modifiable intrinsic/extrinsic risk factors may also highlight further preventative/therapeutic measures to reduce injury risk and is therefore highly recommended.

Training Activity

Data of injury incidence in training activities can be used by Scottish Rugby coaches and sport science staff to attempt to maximise the benefits of performance improvement, whilst minimising the probability of injury and the resulting time loss. Rucking/mauling training activities had the greatest injury incidence, median severity and injury burden of all training activities for men's professional club rugby, with a statistically greater injury incidence compared with skills, weights, rehabilitation, endurance weight-bearing and lineout activities. Whilst there were no statistical differences in injury incidence or median severity between forwards and backs for any training activity, it should be noted no backs sustained injuries in rucking/mauling training (despite 245.5 hours exposure), indicating that the probability and risk of injury was far greater for forwards. Brooks et al (2005b) similarly found rucking/mauling training activities to have a high incidence and burden in men's professional club rugby, particularly amongst forwards. This activity is likely to be full contact and potentially replicate the intensity of matches, possibly explaining the high injury incidence and burden.

Full contact training is necessary in some capacity to prepare players for match conditions (Gabbett, Jenkins, & Abernethy, 2012; Hendricks et al, 2018). However, the data presented here suggests rucking/mauling training activities present the greatest probability and risk of injury, particularly for forwards. Forwards also appeared at greater injury risk in defence training activities. Further investigation by Scottish Rugby coaches and sport science support staff is suggested to devise and implement different rucking/mauling and defence training drills and activities which may minimise injury risk whilst ensuring performance improvement and preparedness for competition is still achieved.

Conclusions

The current study found that match and training injury incidences were higher than previous multiple cohort studies in professional rugby. Whilst this may support prior suggestions that single cohort studies potentially provide a greater validity to injury recording and reporting, this single cohort approach also likely reflects playing/training tactics and styles specific to Scottish Rugby. Although data was collected over two-seasons, this still allows for inter-season variation to have a large effect on the overall injury incidence reported. These factors possibly explain the differing injury incidences presented here with previous multiple cohort studies. Whilst injury burden for men's international sevens was comparable with previous studies, burden figures were high for rugby cohorts. Whilst these were within the upper ranges previously recorded for men's international and men's professional club rugby, injury burden for women's international rugby was greater than has been recorded in previous studies. Small sample size limited the validity of burden comparison with previous research for women's international sevens

Concussion was the most frequent specific match injury across all cohorts aside from women's international rugby sevens, where it was the second most common injury. The match concussion incidences recorded were amongst the highest ever in professional rugby, and was the match injury with the greatest burden for men's professional club rugby, and the third greatest match injury burden for both men and women's international sevens. Concussion was the equal most frequent training injury for men's international rugby, and the second most frequent and represented the third largest training injury burden for men's professional club rugby.

Scottish Rugby has a legal duty of care to understand the risk to player welfare from professional rugby in Scotland, and attempt to mitigate risks to an acceptable level (Fuller, 1995, Fuller & Drawer, 2004; HSE, 2001). As the national governing body of a centrally controlled union, they also have a financial interest to maximise team performance through greater player availability for match selection (Morgan, 2002; Williams et al, 2016; Zhang et al, 2003). From the main findings, several implications were found for Scottish Rugby to potentially investigate/implement changes to improve their care of player welfare and reduce the magnitude of player time-loss from training and match-play. Data from the current study suggests injury rehabilitation protocols may be too aggressive in women's international rugby, resulting in a large incidence and burden of recurrent injury. A more conservative approach may reduce probability and risk of recurrent injury amongst players in this cohort. Across all cohorts in matches and training, the greatest proportion of injuries and injury burden was to the lower limb, and muscle and tendon, or joint and ligament injuries. Due the large number of injuries and burden, possible preventative or therapeutic interventions to mitigate risk of these injuries may offer the greatest potential for Scottish Rugby to reduce total injury burden for all cohorts. Specific injuries for each cohort which were the most common and had the greatest burden for matches and training were also identified. Whilst intervention recommendations from previous studies are available, further investigation into aetiology and interaction of intrinsic/extrinsic risk factors for these injuries is recommended to improve specificity of any potential preventative or therapeutic measure. Implementation of effective player load monitoring and methods to reduce injury probability and risk in rucking/mauling training activities whilst still achieving necessary competition preparation may also limit incidence and burden of injury in training.

The current study followed a prospective, single cohort methodology to injury surveillance. This was deemed as the most accurate approach and provides a valid report of injury incidence, severity and burden of injuries to professional players in Scotland over the past two seasons. However, there were some limitations. There was a small number of injuries in some cohorts, especially women's international rugby sevens. This may limit conclusions that can be brought. Training injury epidemiology was only possible for men's international rugby and men's professional club rugby, and training injury incidence and risk in the remaining professional cohorts is unknown. In order to investigate differences between the different cohorts studied, a large number of statistical tests were undertaken, increasing the likelihood of type I errors (Armstrong, 2014; Streiner & Norman, 2011). Rather than implement corrections such as Bonferroni or Hochberg techniques, raw *p* values were reported, allowing interpretation of the certainty of the evaluation (Rothman, 1990), as has been used in previous rugby epidemiology research (Fuller et al, 2020a).

As with previous examples in this area of research (Brooke et al, 2005b; Cosgrave & Williams, 2019; RFU, 2020; West et al, 2019; West et al, 2020), recording of injury data and monitoring of training exposure was not the responsibility of the primary researcher, yet relied upon Scottish Rugby medical staff, performance staff and players. As a result, there will always be issues around the compliance of third parties to collect data as requested. However, meetings with Scottish Rugby ahead of the 2017/18 season dictated points on how injury data and training exposure was to be recorded, and these were reinforced with meetings in summer 2018 and throughout the 2018/19 season. These meetings also provided opportunity to check and validate recent training exposure with Scottish Rugby's own records. Injury data was collected from Scottish Rugby at 3-monthly intervals, with any unclear data queried with the medical staff responsible for the data entry. At the end of each season, large data checks were performed comparing training exposure with another researcher associated with Scottish Rugby, and Scottish Rugby's own records. Equations were developed to estimate off pitch training exposure where data was lacking. It was believed this ensured training exposure data was as accurate as possible. Thorough, objective analysis of injury data to protect against duplicate data entry, incorrect cohort/scenario (match or training) injury attribution, and incorrect reporting of severity was undertaken prior to analysis. Any situation where injury data was not clear was discussed with the relevant medical staff. Future studies should attempt to implement clear, precise definitions and instructions around monitoring all forms of training exposure, whilst employing regular validation of injury data. Recording training exposure data should be the responsibility of staff rather than players. Systems and relationships should be in place to allow the primary researcher to perform regular checks with performance and medical staff over any queries on data recording/reporting.

The current PhD thesis chapter aimed to describe the incidence, severity, burden and nature of all injuries within matches and training over the 2017/18 and 2018/19 season by completing a detailed epidemiological study. This was in-line with the first step of van Mechelen's research model "The sequence of prevention of sports injuries". Concussion was the most common match injury in all cohorts, aside from women's international sevens where it was the second most frequent. Concussion also had the greatest match injury burden for men's professional club rugby, and the third greatest burden for men's and women's international sevens. In training, concussion was the equal most frequent injury for men's international rugby, and the second most frequent and had the third largest burden within men's professional club rugby. As an injury, concussion has several potential short- and long-term negative player welfare implications. Given the focus of this thesis, the duty of care Scottish Rugby has towards its players, and the interest Scottish Rugby has towards reducing injury probability and risk, further investigation of the epidemiology of concussion is warranted.

The following chapter in this thesis will aim to produce a more detailed analysis of concussion epidemiology in matches and training over the 2017/18 and 2018/19 seasons in Scottish Rugby. This will complete the first step of van Mechelen's research model.

END OF CHAPTER 3A

CHAPTER THREE (B): CONCUSSION EPIDEMIOLOGY

3B.1: Introduction

Chapter 3A demonstrated concussion was the most frequent match injury in all cohorts, aside from women's international rugby sevens where it was the second most common injury. Scottish Rugby possess a duty of care towards players, as well as a financial interest in elite teams in Scotland performing to a high standard. Due to potential short- and long-term player welfare implications (Cross et al, 2016; Gouttebarge et al, 2017; McKee et al, 2009; Stern et al, 2011), and the effect concussion may have on player availability and team success (Drew et al, 2017; Williams et al, 2016) preventative measures to reduce incidence of concussive injury in professional rugby in Scotland are of high importance.

When designing injury prevention interventions, a thorough understanding of injury incidence, severity and mechanism is first required (van Mechelen et al, 1992). Whilst some previous studies have detailed this is in other cohorts (Cosgrave & Williams, 2019; Fuller et al, 2015a), there is a paucity of scientific understanding surrounding concussive injury in professional rugby in Scotland.

The primary aim of the current chapter was to undertake a more detailed analysis of match and training concussion injuries reported in chapter 3A during the 2017/18 and 2018/19 seasons. Concussion incidence, severity, burden, cause and mechanism will be established for all cohorts. Differences in concussion incidence in playing positions, periods of matches and season will be described where possible.

3B.2: Methods

General Methodology

The current study analysed injury data collected across the 2017/18 and 2018/19 seasons in elite Scottish rugby, as described in chapter 3A. Only OSICS codes pertaining to concussion injuries (HNCA, HNCC, HNCO, HNCX, HNNX, HNXX) were included for analysis in the current chapter (Rae & Orchard, 2007).

Analysis was split into match concussions (all cohorts) and training concussions (men's international rugby and men's professional club rugby only). Several inconsistencies were found with data recording in training (missing player and session exposure data) amongst women's international rugby, men's international rugby sevens and women's international rugby sevens. This resulted in an inaccurate description of training exposure. Training concussions were therefore not analysed for these cohorts.

Concussion Diagnosis

Match concussions were diagnosed by the Head Injury Assessment (HIA) protocol. The HIA process is based upon the Sport Concussion Assessment Tool 5th edition (SCAT 5), and is a three stage process:

- Stage 1 – HIA 1 – Assessment immediately post incident
- Stage 2 – HIA 2 – Assessment 2-3 h post incident
- Stage 3 – HIA 3 – Assessment 36-48 h post incident

(Fuller et al, 2017a; Raftery et al, 2016; World Rugby, 2019b).

Players can enter the assessment process at any stage yet must continue through the rest of the process beyond that point. A player was deemed as concussed in match play due to any of the following scenarios: A player possessed any signs of concussion during on-pitch evaluation or displayed them during video review of any head impact event during HIA 1 (see table 3B.1); abnormal HIA 2 or 3; or the team doctor administering the HIA believes the player to be concussed (Fuller et al, 2017a; Raftery et al, 2016). In training, concussions were diagnosed by Scottish Rugby medical staff, supported by HIA 1. Pitch-side evaluation and the video review system of HIA 1 for identifying concussions has been shown to present sensitivity and specificity values of 77.5-84.6% and 74% respectively (Fuller et al, 2017a; Fuller et al, 2015b). Blank HIA forms are included in appendix one.

TABLE 3B.1: Criteria for immediate and permanent removal from play

Concussion Signs and Symptoms	
Confirmed loss of consciousness	Suspected loss of consciousness
Convulsion	Tonic posturing
Ataxia	Clearly dazed
Not orientated in time, place, or person	Definite confusion
Definite behavioural change	Oculomotor signs

Adapted from Raftery et al (2016).

Concussion Rehabilitation and Severity

Following concussion injury, all players followed the return to play protocol outlined by the Concussion Consensus Group and World Rugby (McCrory et al, 2017; World Rugby, 2017b). This was adapted for all cohorts by Scottish Rugby medical staff to also provide exercise intensity guidelines (table 3B.2). Concussion severity was defined as the number of days a player was unavailable for match selection and unable to take a full part in training, excluding the day of injury and the day of return, judged as the date of completing stage six of the return to play protocol (Fuller et al, 2007d). Following the return to play protocol correctly results in a minimum duration of 24 hours spent in each stage. Therefore, concussion severity should not be less than six days.

TABLE 3B.2: Scottish Rugby adapted return to play protocol for concussion injury

Stage	Aim	Activity	Stage Goal	Scottish Rugby Guidelines
1	Symptom-limited activity	No driving or exercise	Recovery	Assessment by Doctor to monitor symptoms resolution
2	Light aerobic exercise	Walking or stationary cycling	Increase heart rate	5 minute warm up to 70% MHR; 10 minute steady state at 70% MHR
3	Sport specific drill	Running drills	Add movement	15 minute straight line running – maintain HR <70%MHR
4	Non-contact training	Harder training drills	Exercise, co-ordination & thinking	Skills session; weights session up to 80% 1RM; rugby session (non-contact)
5	Full contact practice	Normal training activities	Restore confidence	Full training with contact: shield & bag tackles; 6 live tackles; 6 ball carries
6	Return to play	Normal game play		Available for selection

(HR = Heart Rate; MHR = Maximum Heart Rate)

Data Analysis

Concussion incidence for training and matches was expressed as number of concussions per 1000 player hours (match or training). Both mean concussion severity (total days absence divided by number of injuries) and median concussion severity (middle value of data set) were calculated to account for positive skew in severity data distribution caused by small numbers of high severity concussions. Due to positive skew of data, statistical comparisons were only sought between median severity values. Concussion injury burden was calculated as mean severity multiplied by injury incidence and expressed as days absence/1000 player hours (match or training) (Fuller, 2018b). Injury incidence and injury burden data were accompanied by 95% Confidence Intervals (CI) calculated by normal approximation according to the Poisson distribution:

$$\lambda \pm z(\alpha/2) \times \text{sqrt}(\lambda/n)$$

Where λ = injury incidence or burden, z = 1.96 for 95% CI, and n = total exposure (hours) (van Belle et al, 2004). To facilitate comparisons between cohorts in some instances, number of injuries were also expressed as proportions with 95% CI calculated by approximation to a normal distribution as follows:

$$p \pm (z \times (\sqrt{}(p(1-p))/n))$$

Where p = calculated proportion, z = 1.96 for 95% CI, and n = sample size (Kirkwood & Sterne, 2006). Confidence intervals for mean injury severity data were calculated as follows:

$$a \pm (z \times s/\sqrt{n})$$

Where a = mean severity, z = 1.96 for 95% CI, s = standard deviation of mean severity and n = sample size (Kirkwood & Sterne, 2006). Confidence intervals for median injury severity data were calculated as follows:

$$q = nq \pm z\sqrt{(nq(1-q))}$$

Where q = median severity, n = sample size and z = 1.96 for 95% CI (Conover, 1980). In all instances, lower 95% CIs were capped at 0.0, or at 100.0% for proportions. Data is presented by position or positional group for rugby cohorts in some instances – this is not performed for rugby sevens cohorts due to potential for interchanging between positional groups in these cohorts. Data analysis was performed using Microsoft Excel.

3.2.6: Statistical Analysis

Differences in injury incidence and median severity were assessed by incidence rate ratios (IRR) and Mann-Whitney U tests respectively. When directly comparing one cohort to another, comparisons were made as presented in table 3A.3. Chi-squared tests (Fisher's exact tests if expected counts were small) were used to determine differences in injury proportions across multiple cohorts. Effect size of chi-squared analysis was estimated by Cramer's V to estimate effect size, and post-hoc testing was performed by analysis of adjusted standardised residuals by cell-by-cell comparison (Agresti, 2018; Cohen, 1988). A statistical significance value of 0.05 was used. However, numerous statistical tests were conducted throughout this chapter, potentially causing a number of results to appear statistically significant at the $p \leq 0.05$ level by chance through type I error (Armstrong, 2014). For this reason, exact *p* values are reported to allow for evaluation certainty to be interpreted (unless $p < 0.001$), as is recommended in epidemiology research (Rothman, 1990), and with previous injury epidemiology studies in rugby union (Fuller et al, 2020a). Statistical analysis was performed using Microsoft Excel and IBM SPSS statistics for Windows Version 26 (IBM, Armonk, New York, USA).

TABLE 3B.3: Comparisons between cohorts for incidence and severity

Men's International Rugby	vs.	Women's International Rugby
Men's International Rugby	vs.	Men's Professional Club Rugby
Men's International Rugby	vs.	Men's International Rugby Sevens
Women's International Rugby	vs.	Women's International Rugby Sevens
Men's International Rugby Sevens	vs.	Women's International Rugby Sevens

3B.3: Results:

3B.3.1: Match Concussions

Concussion by Cohort

Table 3B.4 presents number of concussions for forwards and backs in each rugby cohort (total concussions for rugby sevens cohorts) during the 2017/18 and 2018/19 seasons. Across both seasons, 96 match concussions were recorded across all professional cohorts with 68 out of 208 players (see table 3A.4 Chapter 3A for players included in this chapter) sustaining at least one concussion. This resulted in 32.7% of players sustaining at least one concussion during the two seasons. Of all players who sustained a concussion, five players suffered three or more concussions, which represented 20.8% of all concussions. The maximum number of concussions sustained by a single player was six.

TABLE 3B.4: Match concussions and exposure for each professional cohort in Scotland across the 2017/18 and 2018/19 seasons.

Cohorts	Season	Concussions (n)			Match Exposure (h)		
		Forwards	Backs	All	Forwards	Backs	All
Men's International Rugby	**2017/18**	4	3	7	117.3	102.7	220.0
	2018/19	2	0	2	96.0	84.0	180.0
	All	6	3	9	213.3	186.7	400.0
Women's International Rugby	**2017/18**	4	1	5	74.7	65.3	140.0
	2018/19	3	0	3	85.3	74.7	160.0
	All	7	1	8	160.0	140.0	300.0
Men's Professional Club Rugby	**2017/18**	23	15	38	650.7	569.3	1,220.0
	2018/19	16	16	32	661.3	578.7	1,240.0
	All	39	31	70	1,312.0	1,148.0	2,460.0
Men's International Rugby Sevens	**2017/18**	-	-	3	-	-	96.4
	2018/19	-	-	4	-	-	91.5
	All	-	-	7	-	-	187.8
Women's International Rugby Sevens	**2017/18**	-	-	2	-	-	23.6
	2018/19	-	-	0	-	-	48.1
	All	-	-	2	-	-	71.6

Table 3B.5 presents concussion incidence for each cohort by season and positional group (rugby cohorts only). The greatest overall concussion incidence was found for men's international rugby sevens (37.3/1000 player match hours), followed by men's professional club rugby (28.5/1000 hours) and women's international rugby sevens (27.9/1000 hours). No statistical differences in match concussion incidence were found between cohorts.

Examining overall incidence by positional group, concussion incidence was greatest for forwards in each rugby cohort. The greatest concussion incidence was recorded for women's international forwards (43.8/1000 hours), followed by men's professional club forwards (29.7/1000 hours) and men's international forwards (28.1/1000 hours). No statistical differences were found between positional groups within cohorts, or between cohorts within positional groups.

Concussion incidence was greater in 2017/18 compared with 2018/19 for each of the three rugby cohorts. Conversely, incidence was greater in 2018/19 for men's and women's international rugby sevens. No statistical differences in concussion incidence between seasons was found for any cohort.

TABLE 3B.5: Match concussion incidence for each professional cohort in Scotland across the 2017/18 and 2018/19 seasons.

Cohorts (concussions, n)	**Season**	**Concussion Incidence (95% CI)**		
		Forwards	**Backs**	**All**
Men's International Rugby (9)	**2017/18**	34.1 (0.68-67.5)	29.2 (0.0-62.3)	31.8 (8.3-55.4)
	2018/19	20.8 (0.0-49.7)	-	11.1 (0.0-26.5)
	All	28.1 (5.6-50.6)	16.1 (0.0-34.3)	22.5 (78-37.2)
Women's International Rugby (8)	**2017/18**	53.6 (1.1-106.1)	15.3 (0.0-45.3)	35.7 (4.4-67.0)
	2018/19	35.2 (0.0-74.9)	-	18.8 (0.0-40.0)
	All	43.8 (11.3-76.2)	7.1 (0.0-21.1)	26.7 (8.2-45.2)
Men's Professional Club Rugby (70)	**2017/18**	35.3 (20.9-49.8)	26.3 (13.0-39.7)	31.1 (21.2-41.1)
	2018/19	24.2 (12.3-36.1)	27.6 (14.1-41.2)	25.8 (16.9-34.8)
	All	29.7 (20.4-39.1)	27.0 (17.5-36.5)	28.5 (21.8-35.1)
Men's International Rugby Sevens (7)	**2017/18**	-	-	31.1 (0.0-66.3)
	2018/19	-	-	43.7 (0.87-86.6)
	All	-	-	37.3 (9.7-64.9)
Women's International Rugby Sevens (2)	**2017/18**	-	-	84.7 (0.0-202.2)
	2018/19	-	-	-
	All	-	-	27.9 (0.0-66.7)

Table 3B.6 presents match concussion severity and burden by cohort. Men’s professional club rugby had the greatest mean severity (17.6 days), followed by women’s international rugby (15.5 days) and men’s international rugby (9.8 days). Women’s international rugby had the greatest median injury severity (13.0 days), followed by men’s international rugby (10.0 days) and men’s international rugby sevens (8.0 days). Due to non-normal distribution of severity data, differences between cohorts were only assessed by comparison of median severity. No statistical differences were found.

Men’s professional club rugby had the greatest concussion injury burden (501.6 days absence/1000 player match hours), followed by women’s international rugby (413.3 days/1000 hours) and women’s international rugby sevens (293.3 days/1000 hours). This indicates that for each game across the study period, it could be expected that 10.0 days would be lost for men’s professional club rugby due to concussion injury, followed by 8.3 for women’s international and 4.4 days for men’s international rugby. For men’s international rugby sevens 0.47 days were lost to concussion injury per game, and 0.48 days for women’s international rugby sevens.

TABLE 3B.6: Match concussion severity and burden for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons

Cohort	Concussions (n)	Severity (days)		Burden (95% CI)
		Mean (95% CI)	Median (95% CI)	
Men's International Rugby	9	9.8 (7.0-12.5)	10.0 (5.0-13.0)	220.0 (174.0-266.0)
Women's International Rugby	8	15.5 (6.7-24.3)	13.0 (5.0-45.0)	413.3 (340.6-486.1)
Men's Professional Club Rugby	70	17.6 (11.0-24.3)	7.0 (6.0-9.0)	501.6 (473.6-529.6)
Men's International Rugby Sevens	7	7.7 (5.9-9.6)	8.0 (4.0-12.0)	287.5 (210.9-364.2)
Women's International Rugby Sevens	2	(n = 2)	(n = 2)	293.3 (167.9-418.7)

Figure 3B.1 presents the cumulative percentage return to play with severity of match concussions for all cohorts (data combined). Almost two-thirds (64.6%; n = 62) of concussions returned to play by 10 days. Ten percent of concussions (n = 10) took longer than 28 days before return to play. Across all cohorts 29 concussions (30.2%) were returned to play within the minimum recommendation of 6 days.

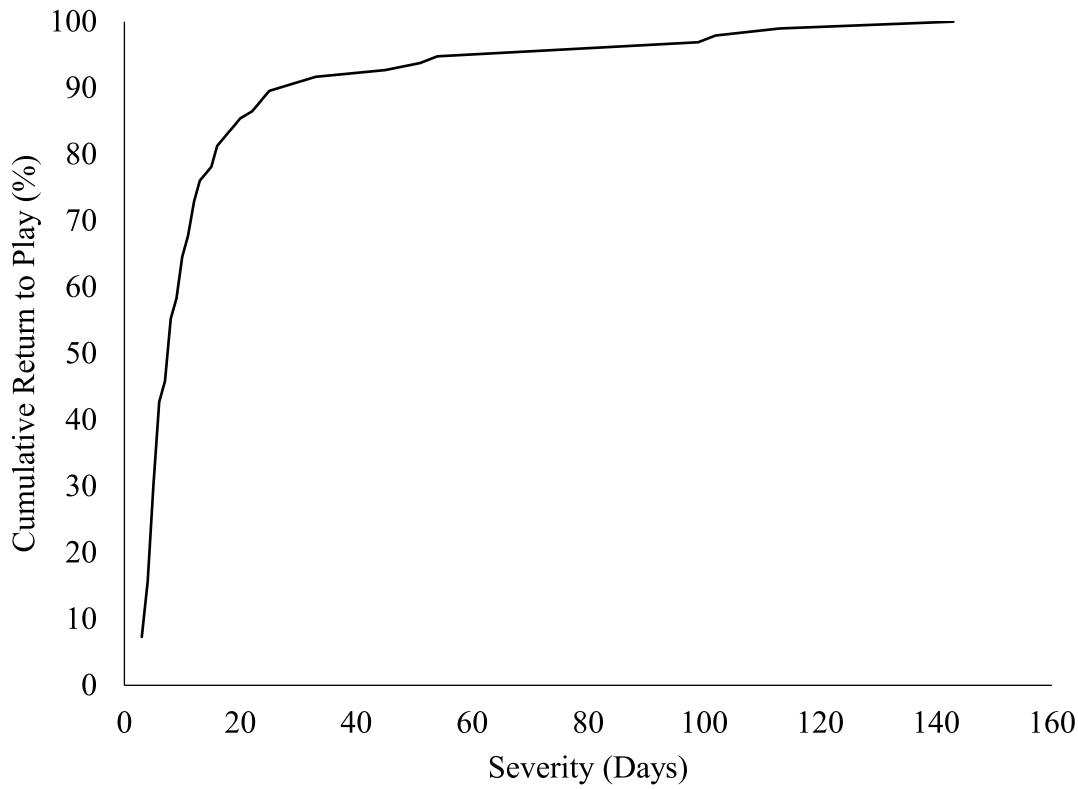

FIGURE 3B.1: Combined cumulative return to play from match concussive injury for all professional rugby cohorts in Scotland across the 2017/18 and 2018/19 seasons.

Repeat Concussions

Table 3B.7 presents new and repeat concussions across all cohorts. Incidence of new concussions was greater than repeat concussions in all cohorts. Excluding women's international rugby sevens due to small sample size, men's international rugby sevens had the greatest incidence of new concussions (26.6/1000 player match hours), followed by men's professional club rugby (22.0/1000 hours) and men's international rugby (17.5/1000 hours). Incidence of new concussions was statistically greater for men's professional club rugby compared with repeat concussions (IRR: 3.6; 95% CI: 2.0-6.4; $p < 0.001$). Women's international rugby had the greatest proportion of repeat concussions (37.5%), followed by men's professional club rugby (21.4%) and men's international rugby sevens (14.3%). Proportion of new and repeat concussions was not statistically different across all cohorts (Fisher's exact: $p = 0.180$).

Women's international rugby had the greatest median severity for new concussions (13.5 days), followed by men's international (10.0 days) and men's international rugby sevens (8.0 days). The greatest median severity for repeat concussions was found for women's international rugby (14.0 days), followed by men's professional club rugby (13.0 days). No statistical differences in median severity between cohorts were found. Statistical differences in median severity between new and repeat concussions were only sought in men's professional club rugby – no differences were found.

Burden of new concussions was greater than repeat concussions in all cohorts. Excluding women's international rugby sevens (both concussions were new), burden of new concussions was greatest for men's professional club rugby (348.4 days absence/1000 player match hours), followed by women's international rugby (256.7 days/1000 hours) and men's international rugby sevens (229.0 days/1000 hours). Repeat concussion burden was greatest for men's professional club rugby (132.5 days/1000 hours), followed by women's (116.7 days/1000 hours) and men's international rugby (25.0 days/1000 hours).

TABLE 3B.7: New and repeat match concussion injury proportion, incidence, median severity, and burden for professional cohorts in Scotland across 2017/18 and 2018/19.

Cohort	Concussion (n)	Proportion (95% CI)	Incidence (95% CI)	Median Severity (95% CI)	Burden (95% CI)
Men's International Rugby	**New** (7)	77.8 (506-100.0)	17.5 (4.5-30.5)	10.0 (5.0-18.0)	162.5 (123.0-202.0)
	Repeat (1)	11.1 (0.0-31.6)	2.5 (0.0-7.4)	(n = 1)	25.0 (9.5-40.5)
Women's International Rugby	**New** (4)	50.0 (15.4-84.7)	13.3 (0.27-26.4)	13.5 (5.0-45.0)	256.7 (199.3-314.0)
	Repeat (3)	37.5 (4.0-71.0)	10.0 (0.0-21.3)	14.0 (6.0-15.0)	116.7 (78.0-155.3)
Men's Professional Club Rugby	**New** (54)	77.1 (67.3-87.0)	22.0 (16.1-27.8)*	6.0 (5.0-8.0)	348.4 (325.1-371.7)
	Repeat (15)	21.4 (11.8-31.0)	6.1 (3.0-9.2)	13.0 (5.0-29.0)	132.5 (118.1-146.9)
Men's International Rugby Sevens	**New** (5)	71.4 (37.0-100.0)	26.6 (3.3-50.0)	8.0 (6.0-12.0)	229.0 (160.5-297.4)
	Repeat (1)	14.3 (0.0-40.2)	5.3 (0.0-15.8)	(n = 1)	21.3 (160.5-297.4)
Women's International Rugby Sevens	**New** (2)	100.0	27.9 (0.0-66.7)	(n = 2)	293.3 (167.9-418.7)
	Repeat (-)	-	-	-	-

Proportion reported as a percentage of all concussions for each cohort, including those of an unknown repeat status. New or repeat concussion injury status unknown for one concussion each for men's international, women's international, men's professional club, and men's international rugby sevens. *($p < 0.001$) new to repeat concussion incidence within cohort.

Playing Position

Table 3B.8 presents concussion injury proportion, median severity and burden by positional group for the three rugby cohorts. Proportion of concussions was highest for forwards across all three cohorts: 66.7% (women's international); 55.8% (men's international); and 52.5% (men's professional club). The proportion of concussions sustained by forwards and backs did not differ across cohorts (Fisher's exact: $p = 0.238$).

The greatest median severity was found for women's international forwards (12.0 days), followed by men's international backs (11.0 days) and men's international forwards and men's professional club rugby backs (both 8.0 days). No statistical differences in median severity were found between positional groups within cohorts, or within positional groups between cohorts.

Women's international forwards had the greatest concussion burden (681.3 days absence/1000 player match hours), followed by men's professional club backs (618.5 days/1000 hours) and forwards (399.4 days/1000 hours).

TABLE 3B.8: Match concussion injury proportion, median severity and burden for forwards and backs within three professional rugby cohorts in Scotland during the 2017/18 and 2018/19 seasons

Positional Group	Concussions (n)	Proportion (95% CI)	Median Severity (95% CI)	Burden (95% CI)
Men's International Rugby				
Forwards	6	66.7 (35.9-97.5)	8.0 (5.0-18.0)	253.1 (185.6-320.6)
Backs	3	33.3 (2.5-64.1)	11.0 (10.0-13.0)	182.1 (120.1-243.4)
Women's International Rugby				
Forwards	7	87.5 (64.6-110.4)	12.0 (5.0-45.0)	681.3 (553.4-809.1)
Backs	1	12.5 (0.0-35.4)	(n = 1)	107.1 (53.0-161.4)
Men's Professional Club Rugby				
Forwards	54	55.7 (44.1-67.4)	6.0 (5.0-10.0)	399.4 (365.2-433.6)
Backs	15	44.3 (32.7-55.9)	8.0 (6.0-16.0)	618.5 (573.0-664.0)

Figure 3B.2 presents concussion injury incidence, mean injury severity and concussion burden by individual playing position for men's professional club rugby (men's and women's international rugby not shown due to small sample size). Hooker had the greatest concussion incidence (61.0/1000 player match hours; 95% CI: 23.2-98.8), followed by centre (45.7/1000 hours; 95% CI: 22.6-68.9) and back row (28.5/1000 hours; 95% CI: 13.5-43.4). Concussion incidence for hooker was statistically greater than second row (IRR: 3.3; 95% CI: 1.2-9.2; $p = 0.020$) and back three positions (IRR: 3.3; 95% CI: 1.4-8.2; $p = 0.009$).

The greatest mean severity was for the scrum half position (31.5 days; 95% CI: 0.0-75.9), followed by back three (24.7 days; 95% CI: 2.1-47.2) and centre (22.7 days; 95% CI: 3.9-41.5). The greatest concussion injury burden was to the centre position (1,036.6 days absence/1000 player match hours; 95% CI: 926.4-1,146.8), followed by hooker (1,012.2 days/1000 hours; 95% CI: 858.2-1,166.2) and scrum half (768.3 days/1000 hours; 95% CI: 634.1-902.4). Burden figures suggest that concussion injuries would result in 1.4 days absence for each centre per match across the 2017/18 and 2018/19 seasons, followed by 1.3 days for hookers, and 1.0 days for scrum halves.

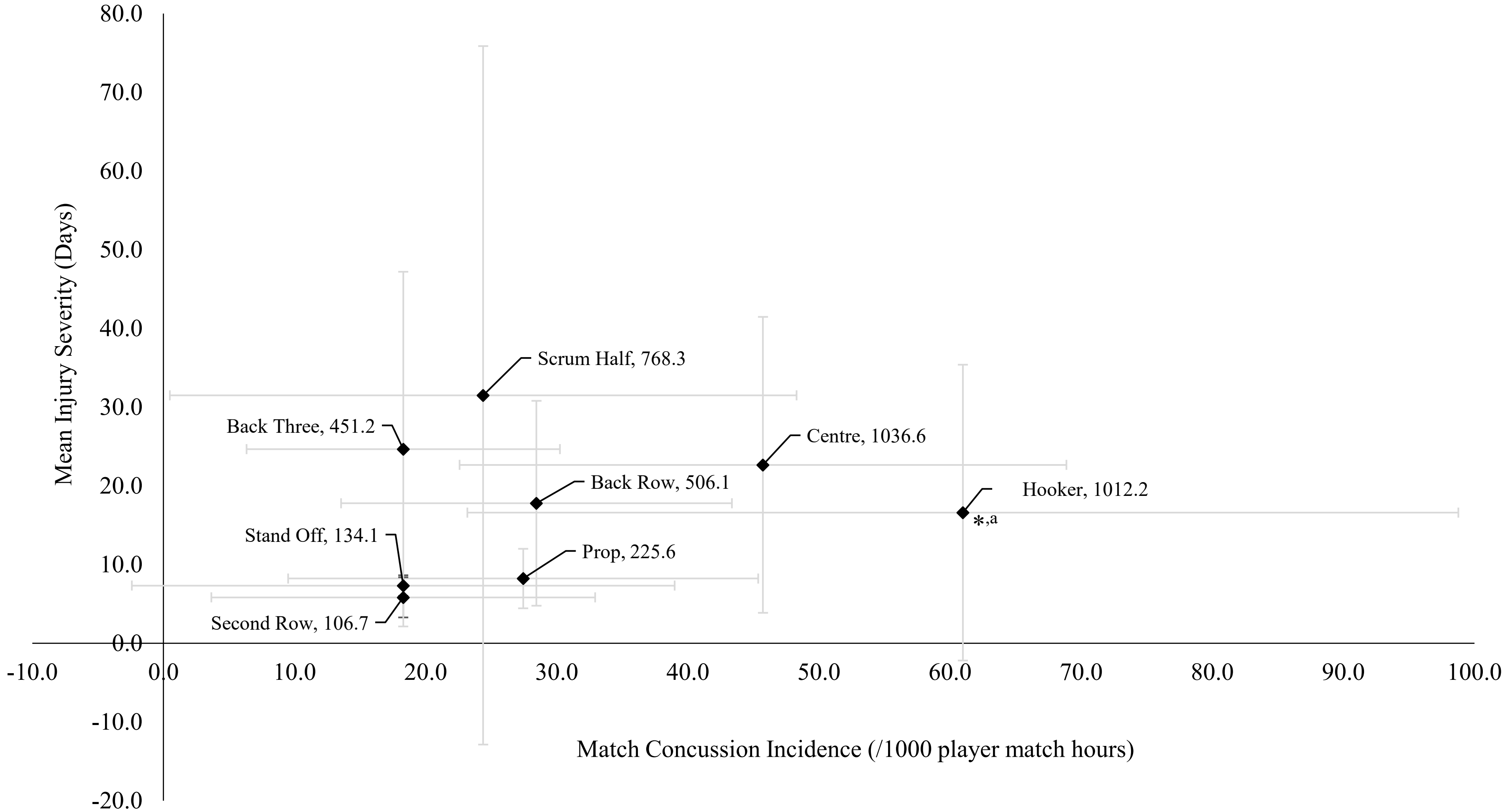

FIGURE 3B.2: Match concussion incidence (with 95% CI), mean severity (with 95% CI) and injury burden (data label; days absence/1000 player match hours) for each playing position for men's professional club rugby in Scotland across 2017/18 and 2018/19. *($p = 0.020$) Hooker concussion incidence to second row. [a]($p = 0.009$) Hooker concussion incidence to back three.

Due to non-normal distribution, differences were not sought in mean severity data between positions. Back three had the greatest median severity (13.0 days; 95% CI: 5.0-29.0), followed by scrum half (11.0 days; 95% CI: 5.0-99.0), and back row (9.0 days; 95% CI: 5.0-23.0). Compared with back three, no statistical differences in median severity were found.

Cause and Mechanism

Across all cohorts 95.8% of concussions (n = 66) were caused by contact (with another player). The remaining 4.2% of concussions (n = 4) were attributed to an unknown cause. Figure 3B.3 present concussive mechanism for each cohort (severity and burden data for each mechanism are not presented due to a small number of data points and skewed distribution in some instances. Women's international rugby sevens not shown due to only two concussions recorded, both attributed to collision mechanism). Tackling was the most common concussive mechanism for men's international sevens (100.0%), men's professional club (47.1%) and women's international rugby (37.5%). Collision was the most common mechanism for men's international rugby (55.6%). Proportion of concussion mechanisms across cohorts was not statistically different (Fisher's exact p = 0.135; women's international rugby sevens excluded due to small sample size).

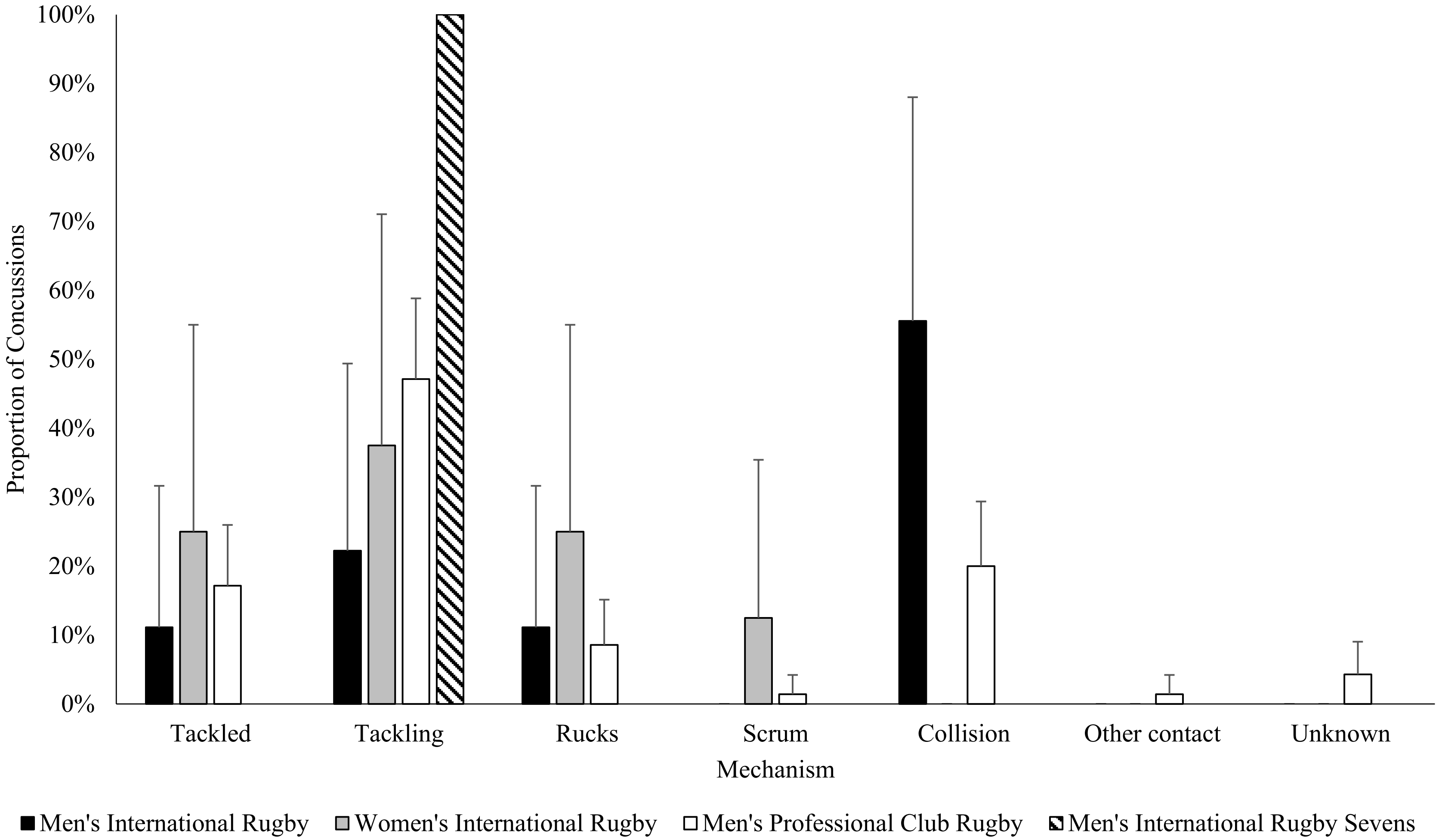

FIGURE 3B.3: Proportion (with 95% CI) of match concussion by mechanism for professional cohorts in Scotland during the 2017/18 and 2018/19 seasons.

Due to larger sample sizes available for analysis, table 3B.9 presents concussion incidence, median severity, and burden by mechanism for men's professional club rugby. Tackling concussions had the greatest incidence (13.4/1000 player match hours), followed by collision (5.7/1000 hours) and tackled concussions (4.9/1000 hours). Incidence of tackling concussions was statistically greater than all other mechanisms: collision IRR 2.4 (95% CI: 1.3-4.4; $p = 0.007$), tackled IRR: 2.8 (95% CI: 1.4-5.3; $p = 0.003$), rucks IRR 5.5 (95% CI: 2.3-13.1; $p < 0.001$), scrums and other contact both IRR 33.0 (95% CI: 4.5-241.3; $p = 0.001$).

Concussions from being tackled had the greatest median severity (11.0 days), followed by rucks (9.0 days) and collision (8.0 days). No statistical differences in median severity were found. Concussions from tackling had the greatest burden (206.9 days absence/1000 player match hours), followed by being tackled (143.1 days/1000 hours) and rucks (78.0 days/1000 hours).

TABLE 3B.9: Concussion incidence, median severity and burden by mechanism for men's professional club rugby across the 2017/18 and 2018/19 seasons.

Mechanism (n)	**Incidence (95% CI)**	**Median Severity (95% CI)**	**Burden (95% CI)**
Tackled (12)	4.9 (2.1-7.6)	11.0 (5.0-25.0)	143.1 (128.1-158.0)
Tackling (33)	13.4 (8.8-18.0)*[,a,b,c]	6.0 (5.0-10.0)	206.9 (188.9-224.9)
Rucks (6)	2.4 (0.49-4.4)	9.0 (3.0-113.0)	78.0 (67.0-89.1)
Scrum (1)	0.4 (0.0-1.2)	(n = 1)	3.3 (1.0-5.5)
Collision (14)	5.7 (2.7-8.7)	8.0 (5.0-16.0)	55.7 (46.4-65.0)
Other Contact (1)	0.4 (0.0-1.2)	(n = 1)	2.0 (0.25-3.8)
Unknown (3)	1.2 (0.0-2.6)	6.0 (5.0-20.0)	12.6 (8.2-17.0)

*($p < 0.001$) to Rucks; [a]($p = 0.001$) to Scrums and Other Contact; [b]($p = 0.003$) to Tackled; [c]($p = 0.007$) to Collision.

Time in Match

Figure 3B.4 presents concussion proportion by match quarter for the three rugby cohorts. The greatest proportion of concussion was in the third match quarter for all cohorts (men's international: 33.3%, 95% CI 2.5-64.1, [n = 3, equal with fourth quarter]; women's international: 37.5%, 95% CI 4.0-71.1 [n = 3]; and men's professional club rugby: 34.3%, 95% CI 23.2-45.4 [n = 24]). Proportion of concussions by match quarters was not statistically different between cohorts (Fisher's exact $p = 0.960$).

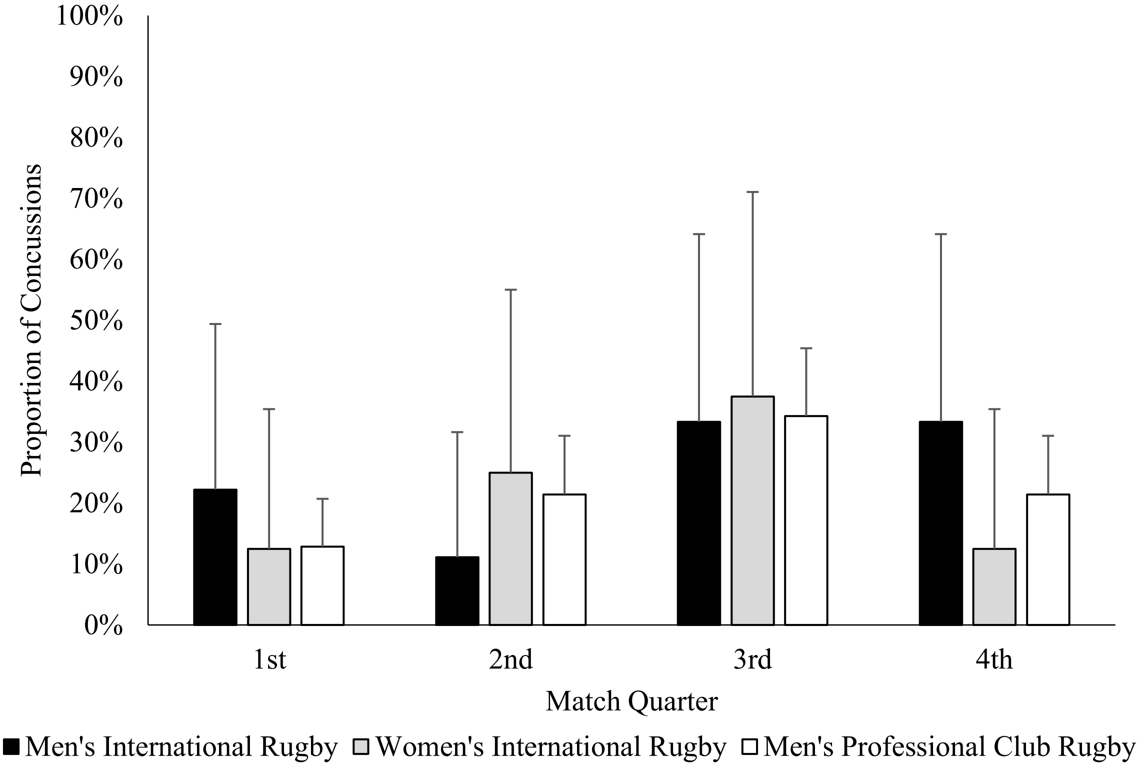

FIGURE 3B.4: Concussion proportion by match quarter for men's international, women's international, and men's professional club rugby in Scotland during the 2017/18 and 2018/19 seasons. 1st Quarter (0-20 mins); 2nd Quarter (21-40+ mins), 3rd Quarter (40-60 mins); 4th Quarter (61-80+ mins). One concussion for women's international and seven concussions for men's professional club rugby were not attributed to any match quarter.

Figure 3B.5 presents concussion incidence, mean severity, and concussion burden by match quarter for men's professional club rugby (men's international and women's international not shown due to small sample sizes). Concussion incidence was greatest in the third match quarter (39.0/1000 player match hours; 95% CI: 23.4-54.6, n = 24), which was statistically greater than the first match quarter (IRR: 2.7; 95% CI: 1.2-5.7; $p = 0.012$). Mean severity was greatest in the first match quarter (23.8 days; 95% CI: 0.0-48.0, n = 9), whilst concussion burden was greatest in the third match quarter (613.0 days absence/1000 player match hours; 95% CI: 551.1-674.9).

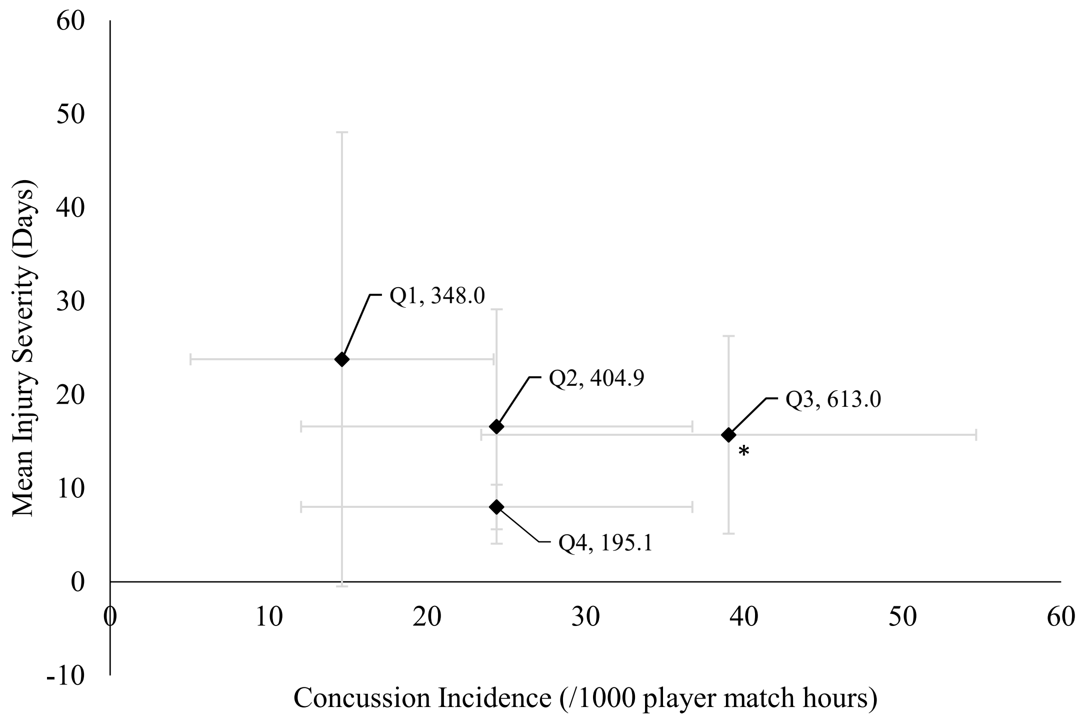

FIGURE 3B.5: Concussion incidence (with 95% CI), mean severity (with 95% CI), and burden (data labels; days absence/1000 player match hours) by match quarter for men's professional club rugby. Q1 (0-20 mins); Q2 (21-40+ mins), Q3 (40-60 mins); Q4 (61-80+ mins). Seven concussions not attributed to any match quarter and excluded. *(p = 0.012) Incidence to Q1.

Differences in mean concussion severity were not sought due to positive skew of data. The greatest median injury severity was in the second (8.0 days; 95% CI: 4.0-19.0) and fourth match quarter (8.0 days; 95% CI: 5.0-10.0), followed by the first (6.0 days; 95% CI: 4.0-54.0) and third match quarter (6.0 days; 95% CI: 5.0-12.0). No differences in median concussion severity were found between match quarters.

Time in Season

Table 3B.10 presents concussion incidence, median severity and burden by month for men's professional club rugby. Matches in August had the greatest concussion incidence (50.0/1000 player match hours), followed by October (37.5/1000 hours) and February (35.0/1000 hours). Concussion incidence in August was statistically greater than December (IRR: 3.2; 95% CI: 1.1-8.9; p = 0.029).

Concussions in March had the greatest median severity (16.0 days), followed by April (10.5 days) and December (9.5 days). There were no differences in median severity compared with August. March had the greatest concussion burden (795.0 days absence/1000 player match hours), followed by January (764.3 days/1000 hours) and August (738.9 days/1000 hours).

TABLE 3B.10: Concussion incidence, median severity and burden by month for men's professional club rugby

Month (concussions, n)	**Incidence (95% CI)**	**Median Severity (95% CI)**	**Burden (95% CI)**
August (9)	50.0 (17.3-82.7)*	8.0 (5.0-29.0)	738.9 (613.3-864.5)
September (10)	26.3 (10.0-42.6)	8.0 (5.0-9.0)	223.7 (176.1-271.2)
October (12)	37.5 (16.3-58.7)	6.0 (4.0-10.0)	690.6 (599.6-781.7)
November (4)	22.2 (0.44-44.0)	6.0 (3.0-7.0)	122.2 (71.2-173.3)
December (6)	15.8 (3.2-28.4)	9.5 (4.0-99.0)	376.3 (314.6-438.0)
January (8)	28.6 (8.8-48.4)	9.0 (3.0-113.0)	764.3 (661.9-866.7)
February (7)	35.0 (9.1-60.9)	5.0 (4.0-25.0)	340.0 (259.2-420.8)
March (5)	25.0 (3.1-46.9)	16.0 (3.0-102.0)	795.0 (671.4-918.6)
April (8)	30.8 (9.5-52.1)	10.5 (3.0-99.0)	642.3 (544.9-739.7)
May (1)	12.5 (0.0-37.0)	(n = 1)	275.0 (160.1-389.2)

*(p = 0.029) to December.

3B.3.2: Training Concussions

Concussion by Cohort

Table 3B.11 presents number of concussions for forwards and backs in each cohort during the 2017/18 and 2018/19 seasons. Across both seasons, 16 training concussions were recorded across men's international and men's professional club rugby cohorts with 14 of 203 players (see table 3A.16 Chapter 3A for players included in this chapter) sustaining at least one concussion. This equated to 6.9% of all players sustaining at least one concussion across the two seasons. Two players sustained two concussions, which was the maximum number of concussions sustained by singe players across both seasons.

TABLE 3B.11: Training concussions and exposure for each professional cohort in Scotland across the 2017/18 and 2018/19 seasons.

Cohorts	Season	Concussions (n)			Training Exposure (h)		
		Forwards	Backs	All	Forwards	Backs	All
Men's International Rugby	2017/18	-	2	2	1,497.6	1,090.2	2,587.8
	2018/19	-	-	-	1,215.5	925.2	2,140.7
	All	-	2	2	2,713.1	2,015.3	4,728.5
Men's Professional Club Rugby	2017/18	3	2	5	13,508.8	10,608.3	24,117.1
	2018/19	6	3	9	12,896.0	9,869.3	22,765.3
	All	9	5	14	26,404.8	20,477.6	46,882.3

Table 3B.12 presents training concussion incidence for each cohort by season and positional group. Men's international rugby had the greatest overall concussion incidence, with both concussions sustained by backs. For men's professional club rugby, forwards had the greatest overall concussion incidence and overall incidence was greater in 2018/19 compared with 2017/18. No statistical differences in overall concussion incidence between cohorts, or in overall incidence between positional groups or seasons for men's professional club rugby were found.

TABLE 3B.12: Training injury incidence for each professional cohort in Scotland across the 2017/18 and 2018/19 seasons.

Cohort (concussions, n)	**Season**	**Concussion Incidence (95% CI)**		
		Forwards	**Backs**	**All**
Men's International Rugby (2)	**2017/18**	-	1.8 (0.0-4.4)	0.77 (0.0-1.8)
	2018/19	-	-	-
	All	-	0.99 (0.0-2.4)	0.42 (0.0-1.0)
Men's Professional Club Rugby (14)	**2017/18**	0.22 (0.0-0.47)	0.19 (0.0-0.45)	0.21 (0.03-0.39)
	2018/19	0.47 (0.09-0.84)	0.30 (0.0-0.65)	0.40 (0.14-0.65)
	All	0.34 (0.12-0.56)	0.24 (0.03-0.46)	0.30 (0.14-0.46)

Table 3B.13 presents training concussion severity and burden for each cohort. Concussion burden was greater for men's professional club rugby compared with men's international. Across both cohorts, four concussions were returned to play with a reduced severity (3 days: n = 1; 4 days: n = 2; 5 days n = 1) compared to the minimum recommendation of six days signified by the Concussion Consensus Group and World Rugby (McCrory et al, 2017; World Rugby, 2017).

TABLE 3B.13: Training concussion mean and median severity and injury burden for men's professional rugby cohorts in Scotland during the 2017/18 and 2018/19 seasons

Cohort	Concussions (n)	Severity (days)		Burden (95% CI)
		Mean (95% CI)	Median (95% CI)	
Men's International Rugby	2	(n = 2)	(n = 2)	1.9 (0.66-3.2)
Men's Professional Club Rugby	16	28.4 (0.0-62.4)	7.0 (5.0-35.0)	8.5 (7.6-9.3)

Repeat Concussions

One new and one repeat concussion was recorded for men's international rugby. Table 3B.14 presents new and repeat concussion incidence, proportion, median severity and burden for men's professional club rugby. A statistically greater incidence was found for new concussions compared with repeat concussions (IRR: 3.7; 95% CI: 1.0 - 13.1; p = 0.046). No statistical difference in median severity was found for new concussions compared with repeat concussions. Burden of repeat concussions was greater than new concussions, yet this was influenced by one concussion with a severity of 251 days.

TABLE 3B.14: New and repeat concussion proportion, incidence, median severity and burden for men's professional club rugby in Scotland during the 2017/18 and 2018/19 seasons

Concussion (n)	**Proportion (95% CI)**	**Incidence (95% CI)**	**Median Severity (95% CI)**	**Burden (95% CI)**
New (11)	78.6 (57.1-100.0)	0.23 (0.10-0.37)*	7.0 (4.0-9.0)	2.9 (2.4-3.4)
Repeat (3)	21.4 (0.0-42.9)	0.06 (0.0-0.14)	6.0 (5.0-251.0)	5.6 (4.9-6.3)

*(p = 0.046) to repeat concussions.

Playing Position

Both concussions for men's international rugby were sustained by backs. Table 3B.15 presents concussion proportion, median severity and burden by positional group for men's professional club rugby. Forwards had a greater proportion of total concussions and a greater burden, yet burden was influenced by one concussion with a severity of 251 days. Backs had the greater median severity, yet no statistical difference compared with forwards.

TABLE 3B.15: Concussion proportion, median severity, and burden by position group men's professional club rugby in Scotland during the 2017/18 and 2018/19 seasons

Positional Group (Concussions, n)	**Proportion (95% CI)**	**Median Severity (95% CI)**	**Burden (95% CI)**
Forwards (9)	64.3 (39.2-89.4)	6.0 (4.0-36.0)	13.6 (12.2-15.0)
Backs (5)	35.7 (10.6-60.8)	7.0 (7.0-9.0)	1.9 (1.3-2.5)

Cause and Mechanism

Across both cohorts, 93.8% (n=15) were caused by contact (with another player). The remaining one concussion was attributed to an "unknown" cause. Both concussions for men's international rugby were caused by collision mechanisms. Figure 3B.6 presents training concussions by mechanism for men's professional club rugby. The primary mechanism was tackling (n = 5; 35.7%; 95% CI: 10.6-60.8), followed by collisions (n = 4; 28.6%; 95% CI: 4.9-52.2). All other mechanisms recorded a similar frequency (n = 1; 7.1%; 95% CI: 0.0-20.6). Severity and burden data by mechanism not reported due to a small number of data points and skewed distribution in some instances.

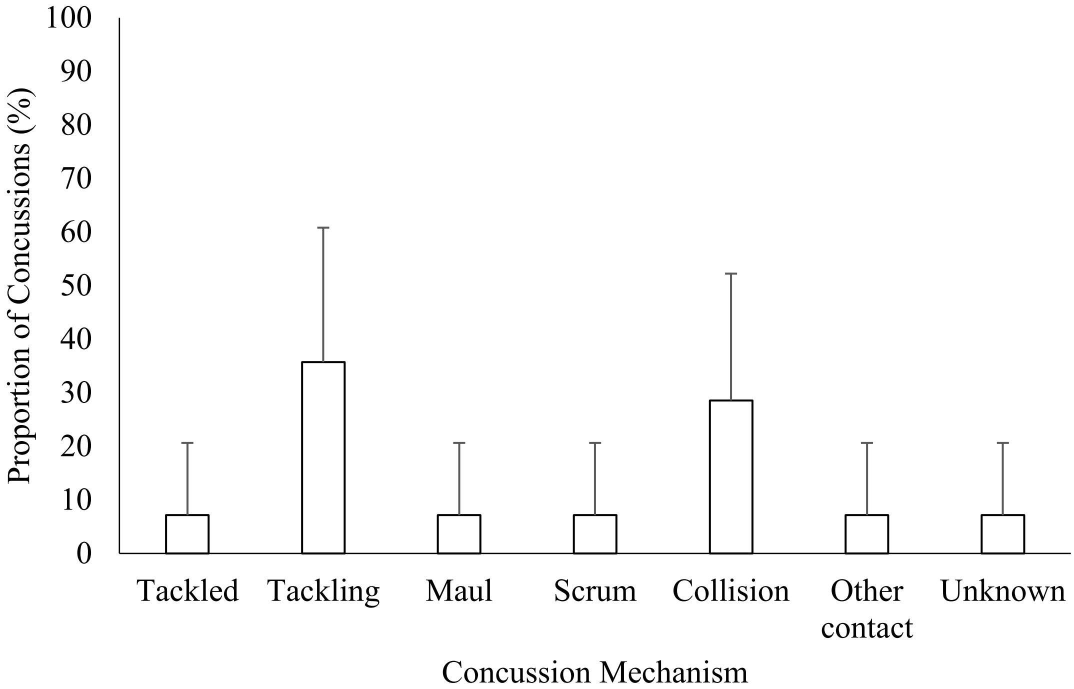

FIGURE 3B.6: Proportion (with 95% CI) of training concussion by mechanism for men's professional club rugby during the 2017/18 and 2018/19 seasons.

Training Activity

Table 3B.16 presents concussion incidence, median severity, and burden by training activity for men's professional club rugby. Only training activities where there was a minimum of 100 hours training exposure are included. Rucking/mauling training activities had the greatest concussion incidence (2.4/1000 player training hours), followed by defence (1.7/1000 hours) and scrum activities (1.2/1000 hours). Concussion incidence in rucking/mauling (IRR: 6.0; 95% CI: 1.1-32.7; $p = 0.039$) and defence training activities

(IRR: 4.2; 95% CI: 1.1-15.5; p = 0.034) were both statistically greater than general play/phase work.

Defence training activities had the greatest median severity (9.0 days) and the greatest concussion burden (31.3 days absence/1000 player training hours), followed by general play/phase work (26.7 days/1000 hours) and rucking/mauling (21.6 days/1000 hours). This indicates that during the 2017/18 and 2018/19 seasons, each hour in these activities with forty players would result in 1.3 (defence), 1.1 (general play/phase work) and 0.86 player days (rucking/mauling) lost to concussion injury.

TABLE 3B.16: Concussion incidence, median severity and burden by training activity for men's professional club rugby in Scotland during the 2017/18 and 2018/19 seasons

Training Activity (concussions, n)	**Incidence (95% CI)**	**Median Severity (95% CI)**	**Burden (95% CI)**
Defence (5)	1.7 (0.21-3.1)[a]	9.0 (7.0-36.0)	31.3 (24.9-37.6)
Endurance NWB (-)	-	-	-
Endurance WB (-)	-	-	-
Fitness testing (-)	-	-	-
General play/phase work (4)	0.40 (0.01-0.79)	6.0 (4.0-251.0)	26.7 (23.5-29.9)
Lineouts (1)	0.49 (0.0-1.5)	(n = 1)	2.0 (0.04-3.9)
Rehabilitation (-)	-	-	-
Rucking/mauling (2)	2.4 (0.0-5.7)*	(n = 2)	21.6 (11.6-31.5)
Scrum (1)	1.2 (0.0-3.5)	(n = 1)	7.1 (1.4-12.7)
Skills (-)	-	-	-
Speed & Agility (-)	-	-	-
Weights (-)	-	-	-
Other/Unclassified (1)	N/A	(n =1)	N/A

WB = Weight Bearing; NWB = Non-Weight Bearing. *(p = 0.039) to general play/phase work. [a](p = 0.034) to general play/phase work.

Time in Season

Table 3B.17 presents concussion incidence, median severity and burden by season phase. Concussion incidence was greater in-season (September-May) compared with pre-season (June-August), but this did not reach statistical significance. Median severity and burden were greater in pre-season than in-season. The high burden figure for pre-season is skewed by one concussion with a severity of 251 days. Other concussions in pre-season had severities of 4 and 12 days.

TABLE 3B.17: Concussion proportion, median severity, and burden by season phase in men's professional club rugby in Scotland during the 2017/18 and 2018/19 seasons

Season Phase (Concussions, n)	**Incidence (95% CI)**	**Median Severity (95% CI)**	**Burden (95% CI)**
Pre-Season (3)	0.21 (0.0-0.45)	12.0 (4.0-251.0)	18.9 (16.7-21.2)
In-Season (11)	0.34 (0.14-0.53)	7.0 (5.0-35.0)	4.0 (3.3-4.7)

Figure 3B.7 presents training concussion incidence by month of the season. Concussion incidence in the final four months of the season (February, March, April, and May: 0.69/1000 player training hours, 95% CI: 0.24-1.1; median severity: 7.0 days; 95% CI: 5.0 - 35.0, burden: 8.9 days absence/1000 player training hours, 95% CI: 7.3-10.5), was statistically greater compared with the rest of the season (0.15/1000 hours, 95% CI: 0.02-0.28; median severity: 7.0 days; 95% CI: 4.0 - 251.0; burden: 8.3 days/1000 hours, 95% CI: 7.3-9.3) (IRR: 4.7; 95% CI: 1.6-13.9; p = 0.006). Out of individual months, March had the greatest concussion incidence (1.2/1000 hours; 95% CI: 0.02-2.3). This was followed by May (0.99/1000 hours; 95% CI: 0.0-2.4) and February (0.89/1000 hours; 95% CI: 0.0-1.9).

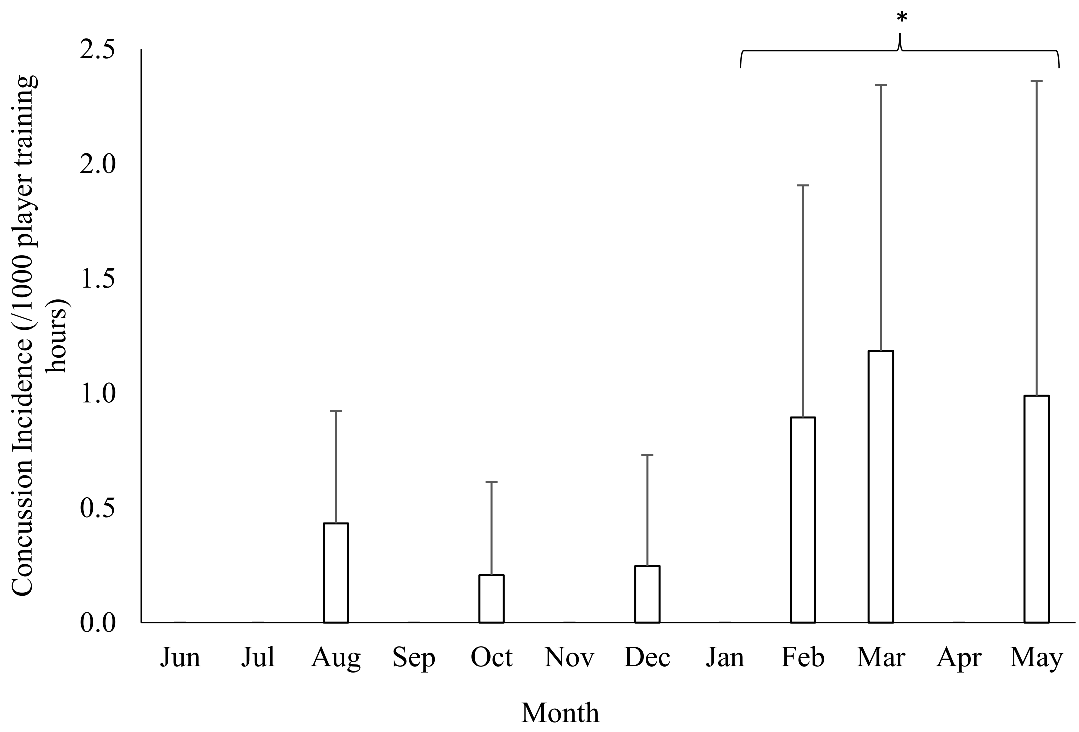

FIGURE 3B.7: Training concussion incidence by month for men's professional club rugby in Scotland during the 2017/18 and 2018/19 seasons. *(p = 0.006) February, March, April, and May to rest of season.

3B.4: Discussion

The primary aim of the current chapter was to undertake a more detailed analysis of match and training concussion injuries reported in chapter 3A during the 2017/18 and 2018/19 seasons. Concussion incidences ranged from 22.5 - 37.3/1000 player match hours, and 0.30 - 0.42/1000 player training hours. Severity ranged from 7.7-28.4 (mean) and 7.0-13.0 days (median) across match play and training. Burden values ranged from 220.0-501.6 days absence/1000 player match hours, and 2.3-8.5 days absence/1000 player training hours. The primary cause of concussion for matches and training was contact with another player, primarily due to the mechanism of tackling.

3B.4.1: Match Concussions

Concussions by Cohort

The incidences of match concussion found in the current chapter were higher than have been reported previously, aside from men's international rugby. Contemporary studies within men's international rugby have demonstrated match concussion incidences of 12.2 - 27.8/1000 player match hours (Cosgrave & Williams, 2019; Fuller et al, 2020a; Rafferty et al, 2019), similar to the incidence of 22.5/1000 player match hours found in the current work. However, other cohorts in this chapter all report concussion incidences greater than previous studies. Recent studies have found concussion incidences of 4.2-15.4/1000 player match hours for women's international (compared with 26.7/1000 hours in the current study), 14.8-21.4/1000 hours for men's professional club rugby (28.5/1000 hours in the current study), and 8.9-18.6/1000 hours for men's and 8.9-23.5/1000 hours for women's international rugby sevens (37.3 and 27.9/1000 hours respectively in the current study) (Cosgrave & Williams, 2019; Fuller et al, 2017b; Fuller et al, 2017c; Fuller & Taylor, 2017; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Rafferty et al, 2019; RFU, 2019; RFU, 2020; Rugby Safe, 2019; Rugby Safe, 2020; Schick et al, 2008; Starling et al, 2020; Taylor et al, 2011; West et al, 2020). Concussion burden recorded in the current study was also greater than previous literature for women's international (413.3 days absence/1000 player match hours compared with 88-285 days/1000 hours); men's professional club (501.6 days/1000 hours compared with 109-455 days/1000 hours); and men's international rugby sevens (287.5 days/1000 hours compared with 238.7 days/1000 hours) (Fuller & Taylor, 2020b; RFU, 2020; Rugby Safe, 2019; Rugby Safe, 2020; Starling et al, 2020). However, concussion burden was similar for men's international rugby (220.0 days/1000 hours) and women's international rugby sevens (293.3 days/1000 hours) when compared with previous research (men's international: 201.3-228.2 days/1000 hours; women's international sevens: 321.8 days/1000 hours) (Cosgrave & Williams, 2019; Fuller et al, 2020a; Fuller & Taylor, 2020a). Similar mean severity values across all cohorts when compared with previous research (current study: 7.7-17.6 days; previous research: 7.7-22 days) (Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2013; Fuller et al, 2015a; Fuller et al, 2017b; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a; Moore et al, 2015; Rafferty et al, 2019; RFU, 2020; Rugby Safe, 2019; Rugby Safe, 2020; Starling et al, 2020) suggests that the greater burden reported for women's international, men's professional club, and men's international rugby sevens is due to the greater concussion incidence reported.

Several short- and long-term implications of sustaining a concussion injury have been reported, such as increased susceptibility of further concussion or musculoskeletal injury, and increased likelihood of common mental disorders and neurocognitive degeneration (Cross et al, 2016; Decq et al, 2016; Gouttebarge et al, 2017; Hollis et al, 2009; Hume et al, 2016; McKee et al, 2009; Nordström et al, 2014). Player absence due to concussive injury may also have a negative impact on chances of team success (Drew et al, 2017; Williams et al, 2016). Scottish Rugby have a legal duty of care to protect player welfare (Fuller, 1995; HSE, 2001) and a financial interest to enhance team performance through greater player availability for match selection (Morgan, 2002; Zhang et al, 2003). The high concussion incidence and burden values reported in the current study should therefore be of concern to Scottish Rugby.

Since the introduction of the HIA system into elite rugby in 2011/2012, and the significant input from World Rugby on best practices for concussion recognition & awareness (Fuller et al, 2015b; McCrory et al, 2009; McCrory et al, 2013; Raftery & Falvey, 2021; Raftery et al, 2016) reported concussion incidence and burden has increased (Best et al, 2005; Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2017; Fuller et al, 2020a; Rafferty et al, 2019; RFU, 2019; RFU, 2020; West et al, 2020). Evolutions to the HIA protocol since its inception, including increased number of symptoms for immediate removal and increased number of diagnostic tests during HIA 1, introduction of assessments 2-3 hours post-incident (HIA 2) and 48 hours post-match (HIA 3), and a video review system to identify potential concussive incidents may also have lowered the diagnostic threshold for concussion across this time frame (Fuller et al, 2020b; Raftery et al, 2016; Raftery & Tucker, 2016; West et al, 2020). Therefore, rather than a true increase in concussion incidence, it has been suggested that the work to improve the diagnosis and recognition of the injury has contributed to an increased rate of reported concussions and the subsequent burden associated with this (Cosgrave & Williams, 2019; Cross et al, 2017; Emery et al, 2017; Lincoln et al, 2011; West et al, 2020). Scottish Rugby have also been at the forefront of driving increased awareness of concussion, including participating in the “If in Doubt, Sit Them Out” campaign which was launched in 2015 (Sport Scotland, 2018). The increased awareness of concussion in rugby in Scotland specifically, alongside an improvement in concussion diagnostic ability and recognition and diagnostic in general, may explain the greater concussion incidence and burden values reported in the current research: as the most contemporary study of concussion epidemiology, greater incidence rates reported here may be a continuation of improved concussion recognition and diagnostic ability. Future concussion epidemiology studies in professional rugby will demonstrate whether a plateau has now been reached with reported match concussion incidence and burden, or whether these continue to rise beyond what has been found in the current work.

However, as a single cohort study of injury epidemiology, results from the current chapter may also reflect playing styles and risk factors for concussion injury present amongst professional Scottish teams (Alexander et al, 1980; Bolling et al, 2018; Fuller et al, 2010; Gissane et al, 1998; Quarrie & Hopkins, 2008). Whilst improved ability to recognise, diagnose, and report concussion may have contributed to the greater incidences found, it is also possible that these results suggest concussion genuinely occurs at a greater frequency in professional rugby in Scotland compared with other professional cohorts. The legal duty of care bestowed upon Scottish Rugby as employer of professional players necessitates that they understand the risks to player welfare, and attempt to reduce these risks to a level as low as possible (Fuller, 1995; HSE, 2001). In order to further the understanding of concussion occurrence amongst Scottish professional players, additional investigation of exact aetiology and mechanism of concussion injury would be required (van Mechelen et al, 1992). The subsequent chapter of this thesis (Chapter 4) will study concussion aetiology, considering various intrinsic and extrinsic factors as suggested by previous injury investigation frameworks (Fuller & Drawer, 2004; Meeuwisse, 1994; Meeuwisse et al, 2007). This may identify potential modifiable risk factors which could indicate potential mitigation strategies to reduce concussion risk.

As reported in previous studies (Fuller et al, 2015a), men's international rugby sevens had a greater match concussion incidence than men's international rugby. In the current study, all concussions in men's international rugby sevens were caused by tackling. Tackling is an open skill (Burger et al, 2016), and likely to be more open in rugby sevens due to greater space to defend and more evasive manoeuvres by ball carriers. This may increase the likelihood of improper technique and the head of the tackler being impacted (Burger et al, 2016; Davidow et al, 2018), which may lead to an increased chance of concussion (Tucker et al, 2017a). Rugby sevens matches are played at a greater relative intensity, with greater volumes of high intensity running compared with rugby (Higham et al, 2012; Ross et al, 2014). As a result, ball carriers and tacklers may approach the tackle at a higher velocity, causing greater peak impact force in tackle situations (Hendricks et al, 2014a; Seminati et al, 2017). A combination of greater peak impact forces and increased likelihood of the tackler's head being impacted may explain the greater concussive incidence recorded in men's international rugby sevens, both in the current study and previous research.

Potentially due to the stepwise return to play protocol outlined by the concussion consensus group and World Rugby, the majority of previous research (mean: 7.7 – 22 days; and median: 9.0 - 11.0 days) reports similar concussion severities across all formats compared with the current study (mean: 7.7-17.6 days; median: 7.0-13.0 days) (Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2013; Fuller et al, 2015a; Fuller et al, 2017b; Fuller & Taylor, 2020a; Fuller & Taylor, 2020b; Fuller et al, 2020a; Moore et al, 2015; Rafferty et al, 2019; RFU, 2020; Rugby Safe, 2019; Rugby Safe, 2020; Starling et al, 2020). The median severity value of 13.0 days for women's international rugby was the only value greater than has been recorded previously across all professional rugby formats, however to this researcher's best knowledge, no previous study has reported median concussion severity in women's international rugby specifically (Fuller & Taylor, 2014; Fuller & Taylor, 2017; Rugby Safe, 2019; Rugby Safe, 2020; Taylor et al, 2011). Although no statistical differences, mean (15.5 days) and median concussion severity for women's international rugby were both greater than men's international rugby in the current study (mean: 9.8 days; median: 10.0 days). These greater values suggest a greater number of more severe concussions amongst women's international players compared with male counterparts. As all cohorts in the current study follow the return to play protocol outlined by the Concussion Consensus Group and World Rugby (McCrory et al, 2017; World Rugby, 2017b), greater severity here suggests genuine greater injury severity, rather than more conservative rehabilitation practices in women's international compared with men's international rugby. Studies have noted reduced neck strength of female athletes compared with male athletes, with negative correlations between neck strength and resultant head velocity following impact (Gutierrez et al, 2014; Tierney et al, 2005; Viano et al, 2007). Greater resultant head velocity post concussive collision may produce a greater magnitude of trauma (Viano et al, 2005). This phenomenon may have resulted in concussions of a greater severity in women's international rugby in the current study. Training interventions based around neck strengthening for women's international players may reduce the severity of concussions experienced (Hrysomallis, 2016).

Across all cohorts, 64.6% of match concussions returned to play within 10 days. Fuller et al (2015a) reported that 72% of concussions in professional senior and elite junior rugby returned to play within ten days. A more recent study of Irish male professional and international players reported 53.3% of concussions returned to play within 10 days (Cosgrave & Williams, 2019). The reduced value reported by Cosgrave and Williams (2019) compared with Fuller et al (2015a) is potentially due to a greater awareness of concussion injury due to work implemented by World Rugby over the past decade (McCrory et al, 2009; McCrory et al, 2013; Raftery & Falvey, 2021; Raftery et al, 2016), resulting in a more cautious rehabilitation approach, or a reflection of a greater number of more severe concussion injuries. When compared with Cosgrave & Williams (2019), the value of 64.6% of match concussions returning to play within 10 days in the current study may be due to less severe concussions sustained, but may also reflect that a substantial proportion of concussion cases in the current study (30.2%) were returned to play within the minimum recommendation of six days. Returning within 6 days causes a greater chance of neuropsychological deficits and chance of further injury, and should be avoided (Barkhoudrian et al, 2011; McCrory et al, 2013; McCrory et al, 2017). The number of players returning within this timeframe is therefore of a large concern, and potentially contravenes the duty of care Scottish Rugby have towards their players (Fuller, 1995; HSE, 2001). However, Scottish Rugby have been at the forefront of concussion management across all levels of rugby, including launching the "If in Doubt, Sit Them Out" campaign in 2015 (Sport Scotland, 2018). Rigorous concussion guidelines are in place within Scottish Rugby, and the instances recorded here of early return to play are likely as a result of errors in data recording, rather than returning players too soon. Nonetheless, further investigation of this may be required within Scottish Rugby, to ensure safety of players and accuracy of injury surveillance systems.

Only 10% of match concussions lasted beyond 28 days. This reflects the recent international concussion consensus statement, which specified that a large majority of concussed individuals recover within the first month of injury (McCrory et al, 2017). From this large group analysis, concussion recovery follows what has been indicated in other recent studies (Cosgrave & Williams, 2019). However, this may hide individual athletes or sub-groups of athletes who are more likely to suffer from persistent symptoms (McCrory et al, 2017). In the current study, seven match concussion cases (7.3%) took over 50 days to return to play post-concussion, with a maximum severity of 144 days. As a combined total, these seven match concussions presented with a total severity of 668 days and caused 51 rugby matches to be missed (these concussions were all in rugby cohorts rather than rugby sevens). Considering the duty of care Scottish Rugby has towards its players, and the financial interest in enhancing team performance through maximising player availability for match selection (Fuller 1995, HSE, 2001; Morgan, 2002; Zhang et al, 2003), these concussion injuries may require further investigation to understand possible reasons for persistent symptoms. In order to mitigate the burden of these injuries, therapeutic interventions such as less aggressive, individualised rehabilitation protocols may reduce overall injury severity. Recent studies have begun to develop predictive formulae based on symptomology at concussion diagnosis to predict recovery duration (Meehan, Mannix, Mounteaux, Stein, & Bachur, 2014; Resch et al, 2015). Further work in rugby should focus on whether any symptom(s) reported during HIA 2 and 3 are associated with a longer recovery period, and propose therapeutic interventions to treat these symptoms directly in an attempt to reduce the severity/burden of these concussions.

Repeat Concussions

Incidence of new concussions were greater than repeat concussions in all cohorts - however, this difference only reached statistical significance for men's professional club rugby. Proportion of repeat concussions were 11.1% (men's international), 37.5% (women's international), 21.4% (men's professional club), and 14.3% (men's international rugby sevens). Kemp et al (2008) reported a repeat concussion proportion of 10% in men's professional club rugby over three seasons. Whilst the high proportion of repeat concussions in women's international rugby may be offset by the small sample size, repeat concussions in men's professional club rugby appear to occur twice as frequently as has been previously reported (Kemp et al, 2008).

Previous studies have highlighted that one concussion injury statistically increases the risk of sustaining a future concussion (Hollis et al, 2009; McGuine et al, 2014). This may be due to inadequate recovery from previous concussion resulting in heightened neuronal vulnerability (Barrett et al, 2014; Hollis et al, 2009; Howell et al, 2018). Neurobiological deficits may be present beyond clinical recovery, reducing co-ordination and contact skill proficiency, including diminished feed-forward control of neck muscles to stabilise the head during cranial impact (Bussey et al, 2019; Hides et al, 2016). These factors may increase the probability of repeat concussion. Further work investigating how previous concussion contributes to future concussive risk is required, especially within Scottish Rugby based on the current data. Future investigations in Chapter four of this thesis will take into consideration how concussive history acts as an intrinsic risk factor for future concussion, examining concussion aetiology within the context of each individual's concussion history (Fuller & Drawer, 2004; Fuller, 2007; Fuller & Vassie, 2004; Meeuwisse, 1994; Meeuwisse et al, 2007). The greater proportion of repeat concussion in the current chapter may also suggest concussion rehabilitation and return to sport protocols in professional rugby may be too aggressive. Further investigations into the validity of the current return to play protocol recommended by the international concussion consensus group may also be required.

Playing Position

No statistical differences were found in concussion incidence or median severity between forwards and backs for the three rugby cohorts, similar to previous findings in professional rugby (Brooks et al, 2005a; Cosgrave & Williams, 2019; Holtzhausen et al, 2006; Kemp et al, 2008; Rafferty et al, 2019). For men's professional club rugby, hookers had the greatest incidence of concussion followed by the centre position, whilst the greatest concussion burden was associated with centres followed by hookers. Tucker et al (2017a) similarly reported that hookers had a high rate of HIAs per match across men's professional club and international rugby, whilst Kemp et al (2008) found that centres had the greatest incidence and burden of concussion across three seasons of men's professional club rugby in England. In the current study, incidence of concussion to players in the hooker position was statistically greater than that of back three and second row players. Similarly, Kemp et al (2008) found back three and second row players had the lowest incidence of concussion in the English Premiership, whilst Tucker et al (2017a) also found wingers to have the lowest rate of HIAs per match. Positional differences in concussion incidence is likely due to differing roles and therefore differing extrinsic risk factors experienced around contact events by each position (Kemp et al, 2008; Tucker et al, 2017a; Tucker et al, 2017b). Assuming the tackle as the contact mechanism responsible for the majority of concussions (as shown here and in previous work) (Cosgrave & Williams, 2019; Fuller et al, 2015a; Tucker et al 2017a), extrinsic risk factors such as active shoulder tackles, front-on tackles, and acceleration into tackles have all been shown to increase chance of concussion to both the tackler and tackled player (Cross et al, 2019; Tucker et al, 2017b). Hookers and centres in the current study may have engaged in these actions more frequently than other positions. However, as a single cohort study, these findings may also reflect that particular players in these positions in Scotland have a pre-determined increased chance of concussion due to certain intrinsic risk factors such as contact technique or concussion history (Hollis et al, 2009; Sobue et al, 2017). To fully comprehend concussion aetiology, these intrinsic risk factors also need to be considered (Meeuswisse, 1994; Meeuwisse et al, 2007). The study of concussion aetiology and risk factors in Chapter four of this thesis will attempt to illustrate the effect of different intrinsic and extrinsic factors on chances of sustaining a concussion.

Cause and Mechanism

Aside from four concussions with an unknown cause, the remaining concussions were all caused by contact (with another player) across all cohorts. As with previous research in professional rugby (Cosgrave & Williams, 2019; Tucker et al, 2017b), tackling was the most frequent mechanism of concussion for women's international, men's international rugby sevens, and men's professional club rugby, where incidence of concussion from tackling was statistically greater than all other mechanisms. Tackling is an open skill, and the tackler is always reacting to the actions of the ball carrier. Whilst the majority of the time the tackler should be attempting to make contact with their shoulder, a failure to react to the ball carrier, or an element of technical deficiency results in increased likelihood of the head of the tackler being impacted (Burger et al, 2016; Davidow et al, 2018; Rugby AU, 2017; Rugby Smart, 2018; Sobue et al, 2017; Suzuki et al, 2019). This has been shown to increase the chance of concussion for the tackler (Tucker et al, 2017a). Other factors such as active shoulder tackles, front-on tackles, and accelerating into tackles have also been shown to increase likelihood of concussion (Cross et al, 2019; Tucker et al, 2017b). However, these are behaviours which are often encouraged in professional rugby, in an attempt to dominate tackle situations and provide a competitive advantage (Hendricks et al, 2014b; van Rooyen, Yasin, & Viljoen, 2014). Establishing a balance between competition advantage and player welfare in this area is a quandary for all rugby stakeholders.

All seven concussions sustained by men's international rugby sevens in the current study were attributed to tackling. This greater proportion of tackling concussions may be due to more open space in match play and greater opportunities for ball carriers to be evasive, resulting in tackling becoming more of an open skill. This may increase the likelihood of the head of the tackler being impacted. Greater volumes of high intensity running are also seen in rugby sevens compared with rugby (Higham et al, 2012; Ross et al, 2014). As a result, ball carriers and tacklers may approach the tackle at a higher velocity, causing greater peak impact force in tackle situations (Hendricks et al, 2014a; Seminati et al, 2017). A combination of greater peak impact forces and increased likelihood of the tackler's head being impacted may explain the greater proportion recorded in men's international rugby sevens (Burger et al, 2016; Davidow et al, 2018; Tucker et al, 2017a). However, it may also be due to tackles occurring more frequently than other contact events in rugby sevens compared to rugby. Future studies comparing concussion propensity per 1000 contact events in rugby and rugby sevens would further the understanding of any differences between the two formats.

Collision was the most common concussion mechanism for men's international rugby and women's international rugby sevens, and has also been shown to be a frequent mechanism of concussion in professional rugby in previous studies (Cosgrave & Williams, 2019; Fuller et al, 2015a). As with previous work however, the current study was not able to distinguish whether collisions were intentional or accidental off the ball collisions or kick contests. Intentional collisions (attempting to "charge or knock down an opponent carrying the ball without attempting to grasp that player") are against the laws of the game, and have been shown to statistically increase concussion risk compared with legal tackles (Suzuki et al, 2019; World Rugby, 2019c). Kick contests also have a high propensity for causing concussion (Tucker et al, 2017a), yet other accidental collisions such as those occurring off the ball are yet to be investigated in rugby. Distinguishing between legal and illegal collision mechanisms for concussion is a requirement for future work.

Men's professional club rugby in the current study demonstrated that tackling was the mechanism with the greatest associated concussion burden. Scottish Rugby have a legal requirement of duty of care towards their players, and must attempt to reduce the risk associated with professional rugby to as low a level as practically possible, which may also aid with chances of competitive success (Fuller, 1995; Drew et al, 2017; HSE, 2001; Williams et al, 2016). The large burden associated with tackling potentially identifies a particular area to focus mitigation strategies to reduce the risk of concussion. However, previous attempts have been unsuccessful in this aim. Stokes et al (2021) investigated whether lowering the maximum height of legal tackles to the armpit line (from the line of the shoulders) would reduce the incidence of concussion in men's elite club rugby. Whilst prevalence of extrinsic risk factors such as proportion of upright tacklers and ball carriers, tacklers making first contact with the ball carrier's head/neck, and tackles where the initial contact was above the armpit line were all statistically reduced, concussion incidence and propensity for the tackler did not decrease pre- to post-policy change. Conversely, incidence and propensity of tackler concussion statistically increased as a result of the change in policy (Stokes et al, 2021). The failure of this study to reduce concussion incidence indicates the open, unpredictable nature of the tackle in professional rugby, the likely multifactorial aetiology of concussion occurrence (Bolling et al, 2018; McGuine et al, 2014; Meeuwisse et al, 2007), and therefore the difficulty in reducing concussion incidence/risk. Yet this should not discourage attempts to reduce the burden of concussion associated with tackling specifically, or across rugby in general. Increased understanding of concussion mechanism and aetiology is required to identify further potentially modifiable risk factors which may indicate potential mitigation strategies to reduce the probability or risk of concussion injury.

Aside from tackle height and tackler body position, recent studies have identified other extrinsic risk factors around the tackle situation such as players accelerating into the tackle, front-on tackles, and tackle impact force statistically increasing the probability of the tackler sustaining a concussion (Cross et al, 2019; Suzuki et al, 2019; Tucker et al, 2017a; Tucker et al, 2017b). However, these studies have potentially neglected the specific context in which concussion injuries occur, and have not considered intrinsic risk factors such as the concussion history specific to each player (Fuller & Drawer, 2004, Fuller & Vassie, 2004). The current chapter has found that repeat concussions are occurring more frequently within the current cohort than reported in previous research, and previous concussion has been identified as an intrinsic risk factor for future concussion injury (Bussey et al, 2019; Hides et al, 2016; Hollis et al, 2009; McGuine et al, 2014). Chapter four of this thesis will examine concussion aetiology in the context of each individual's concussion history, and by extrinsic risk factors experienced in different contact events by following the dynamic, recursive model of injury aetiology proposed by Meeuwisse et al (2007). This will ensure the context and complexity of concussion aetiology is considered (Bolling et al, 2018; Fuller & Drawer, 2004; Fuller & Vassie, 2004). Any potentially modifiable risk factors which may allow for mitigation strategies to reduce concussion incidence or propensity will subsequently be identified and debated in the discussion section of chapter four of this thesis.

Time in Match

For all three rugby cohorts, the greatest proportion of concussions occurred in the third quarter of matches. For men's professional club rugby, the incidence of concussion in the third match quarter was statistically greater than the first match quarter. The third match quarter also had the greatest concussion burden for men's professional club rugby. Previous studies have debated the effect that fatigue may have on concussion incidence. Gabbett (2008) demonstrated an association between fatigue and a decrement in tackling technique in rugby league players. A decrement in tackling technique may increase the likelihood of the head being impacted, increasing probability of tackler concussion

(Davidow et al, 2018; Tucker et al, 2017a). Assuming substitutes are introduced into the game around the start of the fourth quarter (Lacome, Piscione, Hager, & Carling, 2016), the third quarter in matches may be the time where there is a greater proportion of fatigued players who started the match still on the pitch. This may suggest player fatigue increases concussion incidence by diminished contact skill proficiency.

However, a recent video analysis study of professional rugby demonstrated that tackling and ball carrying proficiency did not statistically deteriorate as player time in game increased (Tierney et al, 2018). Tierney et al (2018) also found a statistical difference in the number of tackles in the latter periods of the game, suggesting an increase in concussion incidence and/or burden in this period may be explained by exposure to a greater number of tackles or contact events such as rucks and mauls. This is supported by the fact that no statistical difference was found in concussion propensity per 1000 tackles between any match quarters in men's professional rugby (Tucker et al, 2017a). Greater concussion incidence and burden in the third match quarter in the current study may therefore be due to a greater number of tackles or contact events occurring in this period.

Training Concussions

Training concussion incidence and burden were greatly reduced for men's international (0.42/1000 player training hours and 2.3 days absence/1000 player training hours) and men's professional club rugby (0.30/1000 hours and 8.5 days/1000 hours) compared to match play (22.5 - 28.5/1000 hours and 220.0 – 501.6 days/1000 hours). Training concussions resulted in a total absence of 9 and 397 days for men's international and professional club rugby respectively, compared with 88 and 1,234 days in matches. The total time loss from concussion injury was substantially greater in match play compared with training for both cohorts.

Training concussion incidences found in the current chapter were higher than previous studies have reported. Previous studies have found values of 0.02 - 0.21/1000 player training hours for men's international and men's professional club rugby, compared with 0.42 and 0.30/1000 hours for these cohorts respectively in the current study (Brooks et al, 2005b; Fuller et al, 2008; Fuller et al, 2017b; Fuller et al, 2020a; RFU, 2019; West et al, 2019). Two possible reasons exist for the greater reported incidence of training concussion in the current study. Firstly, there has been an increase in incidence of reported concussion in training in recent years (West et al, 2019). It is likely this rise in reported incidence is due to the work from World Rugby on recognition and management of concussion, and introduction of the HIA protocol for concussion diagnosis (and its subsequent evolution lowering the diagnostic threshold) (Cross et al, 2017; McCrory et al, 2009; McCrory et al, 2013; Rafferty et al, 2019; Raftery & Falvey, 2021; Raftery et al, 2016). These factors may have improved the reporting rate of concussions in training, similar to increasing incidences of reported concussions in matches in the past decade (Brooks et al, 2005a; Cosgrave & Williams, 2019; Cross et al, 2017; Emery et al, 2017; Lincoln et al, 2011; Fuller et al, 2015a; RFU, 2019; West et al, 2019; West et al, 2020). Scottish Rugby specifically have also been at the forefront of driving increased awareness of concussion, including participating in the "If in Doubt, Sit Them Out" campaign which was launched in 2015 (Sport Scotland, 2018). As the most contemporary study on concussion epidemiology, the greater incidences reported here may reflect the continuing rise in concussion awareness, and a resultant increase in reported concussion incidence. Secondly, unlike match play, training is largely under the influence of coaches and sport science staff. Differing incidences of training concussion in previous literature may be due to time spent in different training activities. Non-contact activities such as weight training, fitness training, speed/agility and non-contact skills activities are likely to have a low concussion incidence, compared with training activities which may mimic contact attributes of match-play such as defence and rucking/mauling, which may represent a higher chance of concussion occurrence (Kemp et al, 2008). As a single cohort study which accurately reflects the training activities and patterns of men's international and men's professional club rugby in Scotland, the current data may suggest a greater training volume spent in more hazardous activities where concussions may be more likely. Future concussion epidemiology studies should include concussion incidence in different training activities to further the understanding of concussion occurrence.

Median concussion severity for men's professional club rugby was similar in the current study (7.0 days) to what has been reported previously in men's international and professional club rugby in training (10.0 days) (Cosgrave & Williams, 2019), yet the mean severity value reported in the current study (28.4 days) was greater than previous studies (11-14 days) (Brooks et al, 2005b; Cosgrave & Williams, 2019; West et al, 2019). This reflects the fact that one concussion had a severity of 251 days in the current study. If this injury were excluded, mean concussion severity would be 11.2 days. Interestingly, whilst West et al (2019) reported a mean concussion severity of 14 days in training from

2007/08-2017/18 in the English Premiership, recent seasons have seen increased mean severity of concussion injury: 17.1 days (2016/17 season) and 35.2 days (2018/19 season) (RFU, 2020), suggesting training concussion injuries of a greater severity may be becoming more frequent in men's professional club rugby. Whether this may be due to more conservative rehabilitation, or genuine increases in severity of concussion injury is currently unknown.

As a result of a greater concussion incidence and mean severity than previous research for men's professional club rugby, concussion burden in the current study of 8.5 days absence/1000 player training hours was greater than has been reported previously (1.3 days/1000 hours in the English Premiership from 2007/08 – 2017/18) (West et al, 2019). However, this mean value reported by West et al (2019) ignores recent increases in reported concussion incidence and severity amongst this cohort. Concussion burden in recent seasons has been reported as 2.4 (2016/17) and 7.4 days/1000 hours (2018/19) in the English Premiership (RFU, 2020). Despite this recent increase, concussion burden in the current study remains greater than has been reported previously. As a single cohort study, the burden reported here accurately reflects the concussion risk professional club players in Scotland are exposed to. Whilst this may be heavily influenced by one concussion of large severity, Scottish Rugby should continue to monitor concussion risk in training through continuous epidemiology and injury surveillance strategies, to fulfil their duty of care and to attempt to identify strategies to mitigate the concussion risk players are exposed to (Fuller, 1995; Fuller & Drawer, 2004). Concussion burden for men's international rugby was reported as 2.3 days absence/1000 player training hours. Only one other study has reported concussion injury burden in training for men's international rugby, with Fuller et al 2008 reporting a value of 0.90 from the 2007 men's Rugby World Cup. However, the small sample size of concussions in the current study for this cohort (n = 2) and Fuller et al (2008) (n = 1) limits the validity of comparisons that can be made.

Four concussions were returned to play under the minimum recommendation of six days across both cohorts. Due to potential damage caused during concussion injury, returning to play within six days increases the risk of long-term neuropsychological issues and risks further cerebral injury, and should therefore be avoided (Barkhoudrian et al, 2011; McCrory et al, 2013; McCrory et al, 2017). Scottish Rugby have a legal duty of care to reduce threats to player welfare, and the number of players returning within this six day recommended timeframe is therefore of a large concern (Fuller, 1995; HSE, 2001). However, stringent guidelines are in place throughout Scottish Rugby in terms of player welfare following concussion injury. Instances of players being returned to play early are likely a result of errors in recording injury severity, rather than players being returned to normal training/match play too soon. Regardless, investigation of this will be advised within Scottish Rugby, to ensure player welfare remains a priority as well as improving validity of injury surveillance systems.

Repeat Concussions

New concussions had a statistically greater incidence compared with repeat concussions in training for men's professional club rugby. Proportions of new (78.6%) and repeat (21.4%) training concussions were recorded. This was similar to proportions of repeat concussions found in matches within the same cohort. As discussed with match concussions, it appears repeat concussions occurred more frequently in the current cohort compared to previous work, (new: 90%; repeat: 10%; albeit recorded in matches opposed to training) (Kemp et al, 2008). Prior concussion has been proved to be a risk factor for future concussive injury (Hollis et al, 2009; McGuine et al, 2014). This may be due to incomplete recovery from prior concussion and may suggest current return to play protocols lack sensitivity (Barrett et al, 2014; Bussey et al, 2019; Hides et al, 2016; Hollis et al, 2009; Howell et al, 2018). Further work investigating how previous concussion may influence chance of future concussion in professional rugby in Scotland is required. Chapter four of this thesis will investigate concussion aetiology in the context of each individual's concussion history, and by extrinsic risk factors experienced in different contact events in an attempt to further this understanding.

Cause and Mechanism

Across both cohorts, 93.8% of training concussions were caused by contact (with another player). The single remaining concussion was attributed to an unknown cause. Within men's professional club rugby the primary concussive mechanism was tackling, followed by collision. Tackling as the primary mechanism of concussion is in agreement with mechanism in matches and previous research (Cosgrave & Williams, 2019). As an open skill, tackling relies on the tackling player to react to the movement and decisions of the ball carrier (Burger et al, 2016). Tacklers should be initially aiming to make contact with the ball carrier with their shoulder (Rugby AU, 2017; Rugby Smart, 2018). Technical deficiency or failure to react to the ball carrier may result in increased likelihood of the head of the tackler being impacted (Davidow et al, 2018). This has been shown to increase the risk of concussion to the tackler (Tucker et al, 2017a).

Collision was the second most common mechanism for concussion within men's professional club rugby, and was the mechanism attributed to both training concussions for men's international rugby. Cosgrave and Williams (2019) also illustrated collision as a frequent mechanism for concussion (~22%) across matches and training in men's professional rugby. As described earlier, the current research did not consider whether the collisions recorded here were intentional or accidental. Intentional collisions have been found to statistically increase the risk of concussion compared with legal tackling (Suzuki et al, 2019). It is hoped coaches would not permit intentional collisions in training, as they are against the laws of rugby. Future studies should distinguish between intentional and accidental collisions in training when describing concussive mechanisms.

Training Activity

Data of concussion incidence in training activities can be used by Scottish Rugby coaches and sport science support staff to attempt to maximise the benefits of performance improvement, whilst minimising the risks of concussive injury. The greatest concussion incidence and burden for men's professional club rugby was found in rucking/mauling and defence activities respectively. Both these activities showed a statistically greater incidence of concussion than general play/phase work. The current study has demonstrated that concussion primarily occurs in contact situations in matches and training, and it is not surprising that two training activities where full-contact activities are likely to occur show the greatest incidence and burden of concussion. Similarly, the only concussions sustained across three seasons of training for English Premiership clubs occurred in defence training activities (Kemp et al, 2008), whilst concussion was the most common training injury in full contact training sessions in the English Premiership in the 2018/19 season (RFU, 2020). Full contact training is necessary in some capacity to prepare players effectively for match conditions (Gabbett et al, 2012; Hendricks et al, 2016). However, Scottish Rugby must balance this with the potential negative influence that player absence through concussion injuries sustained in training may have on team performance (Drew et al, 2017; Williams et al, 2016). Scottish Rugby also have a duty of care to protect player welfare and minimise the risk of injury (Fuller, 1995; Fuller & Drawer, 2004; HSE, 2001), particularly when considering the potential adverse short- and long-term effects of concussion around further injury, common mental disorders and neurocognitive degeneration (Cross et al, 2016; Gouttebarge et al, 2017;

Hollis et al, 2009; Hume et al, 2016; McKee et al, 2009; Nordström et al, 2014). A challenge for Scottish Rugby staff should be to attempt to identify preventative measures to mitigate concussion injury incidence and risk in defence and rucking/mauling training activities, whilst also ensuring adequate preparation is completed for match performance (Fuller & Drawer, 2004).

Season Phase

There was no statistical difference between concussion incidence in pre-season training compared with in-season for men's professional club rugby. There was however a statistical increase in training concussion incidence in the final four months of the season compared with the rest of the year. This rise in concussive incidence may be due to player fatigue towards the end of the season, resulting in diminished technical proficiency and increased reaction times, increasing the likelihood of head impacts and concussive injury (Davidow et al, 2018; Tucker et al, 2017a). Scottish Rugby coaches may need to reduce full-contact training activities with high concussion incidence (rucking/mauling and defence) towards the end of the season to attempt to minimise concussion occurrence whilst still maximising performance benefits.

Conclusions

Match and training concussion incidence and burden figures reported in the current study were amongst the highest ever recorded in professional rugby. Proportion of repeat concussion was greater in some cohorts than has been previously reported, suggesting possible ineffective rehabilitation strategies. Tackling and collision mechanisms were responsible for the majority of concussions in matches and training, whilst tackling was associated with the greatest concussion burden in match play for men's professional club rugby. Defence and rucking/mauling training activities had the greatest incidence and concussion risk, likely due to the player contact element of these training types. As advised by several injury investigation models (Fuller & Drawer, 2004; van Mechelen et al, 1992), the next step to further the understanding of concussion occurrence and to identify potential modifiable risk factors which may reduce concussion incidence or risk is to investigate concussion aetiology. By examining this in the context of each individual's concussion history and by the extrinsic risk factors experienced in different contact events, a valid understanding of concussion occurrence will be achieved (Bolling et al, 2018; Fuller & Drawer, 2004; Fuller & Vassie, 2004; Meeuwisse, 1994; Meeuwisse et a, 2007). This will take place in the subsequent chapter of this thesis.

Scottish Rugby have a legal duty of care towards their players and must understand the risk of concussion their players are exposed to, and attempt to reduce this risk to as low a level as practically possible (Fuller, 1995; HSE, 2001). Scottish Rugby also have a financial interest in enhancing team performance by attempting to reduce player unavailability for match selection through concussion injury (Williams et al, 2016). The current work has highlighted several areas for Scottish Rugby to possibly improve their management of concussion, enhance their care of player welfare, and potentially take steps to mitigate concussion risk and therefore improve player availability for match selection. Match and training concussion incidence and burden figures reported in the current study were amongst the highest ever recorded in professional rugby. Tackling and collisions were the most common concussion mechanisms, whilst tackling also had the greatest concussion burden for men's professional club rugby. Paired with this was a greater proportion of repeat concussions than had been found previously. Greater comprehension of the aetiology of concussion, in the context of each individual's concussion history and by the extrinsic risk factors experienced in these contact events may provide Scottish Rugby with potential modifiable risk factors to base mitigation strategies to reduce concussion risk. Data also demonstrated there were several instances of players being returned within the minimum recommendation of six days from concussion. Greater care should be taken by Scottish Rugby to ensure players are not returned to full training/match play within the minimum recommendation of six days, and that injury surveillance data accurately reflects this. There were also instances of certain individuals witnessing prolonged concussion severity. A therapeutic intervention of individualised concussion rehabilitation protocols by considering immediate and evolving symptomology may improve care of player welfare, reduce concussion severity and therefore lessen the concussion risk experienced by these players. Finally, rucking/mauling and defence training activities were shown to have high incidence and burden of concussion for men's professional club rugby. Alteration of these activities to reduce the risk of concussion whilst still preparing effectively for competition should be considered.

The current study followed a prospective, single cohort methodology to concussion injury surveillance. This was deemed as the most accurate approach and provides a valid study of concussion incidence, severity and burden experienced by professional players in Scotland over the past two seasons. However, there were some limitations. There was a small number of concussions recorded within some cohorts. This potentially limits conclusions which can be brought. Future studies may continue this epidemiological work in Scottish Rugby to provide a larger data set, as well allowing researchers to track patterns over time. Due to poor validity and accuracy of the recording of training exposure for women's international rugby, and men and women's international rugby sevens, it was not possible to study training concussion epidemiology for these cohorts, and therefore this remains unknown. In order to investigate differences between the different cohorts studied, a large number of statistical tests were undertaken, increasing the likelihood of type I errors (Armstrong, 2014; Streiner & Norman, 2011). Rather than implement corrections such as Bonferroni or Hochberg techniques, raw *p* values were reported, allowing interpretation of the certainty of the evaluation (Rothman, 1990), as has been used in previous rugby epidemiology research (Fuller et al, 2020a).

As with previous examples in this area of research (Brooke et al, 2005b; Cosgrave & Williams, 2019; RFU, 2020; West et al, 2019; West et al, 2020), recording of injury data and monitoring of training exposure was not the responsibility of the primary researcher, yet relied upon Scottish Rugby medical staff, performance staff and players. As a result, there will always be issues around the compliance of third parties to collect data as requested. However, meetings with Scottish Rugby ahead of the 2017/18 season dictated points on how injury data and training exposure was to be recorded, and these were reinforced with meetings in summer 2018 and throughout the 2018/19 season. These meetings also provided opportunity to check and validate recent training exposure with Scottish Rugby's own records. Injury data was collected from Scottish Rugby at 3-monthly intervals, with any unclear data queried with the medical staff responsible for the data entry. At the end of each season, large data checks were performed comparing training exposure with another researcher associated with Scottish Rugby, and Scottish Rugby's own records. Predictive equations were developed to estimate off pitch training exposure where data was lacking. It was believed this ensured training exposure data was as accurate as possible. Thorough, objective validation of injury data to protect against duplicate data entry, incorrect cohort/scenario (match or training) injury attribution, and incorrect reporting of severity was undertaken prior to analysis. Any situation where injury data was not clear was discussed with the relevant medical staff. Future studies should attempt to implement clear, precise definitions and instructions around monitoring all forms of training exposure, whilst employing regular validation of injury data. Recording training exposure data should be the responsibility of staff rather than players. Systems and relationships should be in place to allow the primary researcher to perform regular checks with performance and medical staff over any queries on data recording/reporting.

The current PhD thesis chapter aimed to undertake a detailed analysis of match and training concussions during the 2017/18 and 2018/19 seasons. This was to complete the first step of van Mechelen's research model "The sequence of prevention of sports injuries". The majority of concussions were caused by tackling or collision mechanism, and further investigation of extrinsic risk factors around different contact types is warranted to increase comprehension of concussion mechanism and aetiology. The current chapter also illustrated that repeat concussions were occurring more frequently in some cohorts than previous research suggests. Whilst previous concussion is known to increase risk of subsequent concussion, how this interacts with different extrinsic risks in contact situations is currently unknown in professional rugby.

The current PhD thesis follows the framework laid out by van Mechelen et al (1992), and the subsequent step in this framework is to investigate the mechanism and aetiology of injury. This will be the intention of the following chapter of this thesis (Chapter 4). In order to ensure the context and complexity of concussion aetiology is considered, the dynamic, recursive model of injury aetiology proposed by Meeuwisse et al (2007) will be followed to investigate concussion occurrence. This model allows consideration of how a predisposed athlete (defined by their intrinsic risk factors) interacts with extrinsic risk factors in the game environment to describe the probability of either injury or continued participation, and also allows for injury history to become an intrinsic risk factor for future injury (Meeuwisse et al, 2007). Concussion aetiology can therefore be examined in the context of each individual's concussion history, and by extrinsic risk factors experienced in different contact events (Fuller & Drawer, 2004; Fuller, 2007). This will be in line with the second step of van Mechelen's research model "The sequence of prevention of sports injuries", as well as considering the stipulations of context and complexity of injury aetiology debated by other researchers (Bolling et al, 2018; Fuller, 2007; Fuller, 2020; Fuller & Drawer, 2004; Fuller & Vassie, 2004; Meeuwisse et al, 2007).

END OF CHAPTER 3B

CHAPTER 4: CONCUSSION RISK FACTORS

4.1: Introduction

The previous two chapters of this thesis illustrated that concussion was the most frequent match injury for all but one cohort (where it was the second most frequent) in professional rugby in Scotland. Scottish Rugby have a legal duty of care towards their players to attempt to reduce the frequency of concussion to as low a level as practically possible (Fuller, 1995; HSE, 2001), as well as a financial interest in enhancing team performance by attempting to reduce player unavailability for match selection through concussion injury (Morgan, 2002; Zhang et al, 2003; Williams et al, 2016). The second step of van Mechelen's research model "The sequence of prevention of sports injuries" states that aetiology and mechanism of injury need to be understood, in order to potentially identify modifiable risk factors which may provide possible mitigation strategies to reduce the frequency of concussion (Fuller & Drawer, 2004; van Mechelen et al, 1992). Injury occurrence in sport can be described by the exposure to and interaction of various risk factors (Meeuwisse, 1994; Meeuwisse et al, 2007). Risk factors are placed into two distinct categories: "Intrinsic" and "Extrinsic" (van Mechelen et al, 1992). Intrinsic factors are particular to each individual, and may include physical and psychological fitness/strength, skill level/ability, and prior injury history (Hollis et al, 2009; van Mechelen et al, 1992; Witchalls et al, 2012). Extrinsic factors are those which are experienced by individuals during competition or training such as equipment, rules of the sport (i.e. contact versus non-contact), actions of opponents/team-mates, and weather conditions (Lawrence et al, 2016; van Mechelen et al, 1992).

Previous literature has suggested aspects of concussion history may be intrinsic risk factors which alter the probability of subsequent concussion. In their systematic review of sports related concussion, Abrahams et al (2014) stated that "a history of previous concussion increases concussion risk with a high level of certainty". Previous research has shown that in non-professional rugby the incidence of concussion of those who had been concussed in the previous 3 months and those who had been concussed twice in the past 12 months were both 3 times higher than those who did not have a recent history of concussion (Hollis et al, 2009). Prior concussion symptoms have also been reported to influence future concussion susceptibility (Delaney et al, 2000; Delaney et al, 2002; McCrory, 2004; Schneider et al, 2013). Chapter 3B demonstrated that men's professional club rugby had a greater rate of repeat concussion than had been reported in previous literature (Kemp et al, 2008). However, quantification of how previous concussion influences odds of future concussion in professional rugby in Scotland is currently unknown, as is any link between prior concussion symptoms and chances of a future concussion.

Previous studies of extrinsic risks for concussion in rugby union have investigated characteristics of different contact events. Whilst chapter 3B suggested tackling and collisions were the mechanisms responsible for the majority of concussions in professional rugby in Scotland, this does not take into account rate of occurrence of these events, or risk factors within these contact types which further increase the propensity of concussion. Measurement of the exposure to the contact event and each risk factor is required before a proper calculation of incidence or propensity can be completed (Bahr et al, 2020; De Loës, 1997). Tucker et al, (2017a) demonstrated that tackling, being tackled, and kick contests were the contact events with the highest propensity for causing a player to leave the field for a head injury assessment (HIA) per 1000 events. Within the tackle situation, certain factors such as tackler head position, active shoulder tackles, illegal tackles, players approaching tackles at high speed or accelerating into contact, and tackler and ball carrier body positions have all been shown to statistically alter the propensity of concussion or being removed for HIA for those tackling or being tackled (Cross et al, 2019; Sobue et al, 2017; Suzuki et al, 2019; Tierney et al, 2019; Tucker et al, 2017a; Tucker et al, 2017b). From this understanding of extrinsic risk factors around the tackle, World Rugby have begun to initiate trial changes to the laws of rugby to reduce concussion propensity in the tackle (Stokes et al, 2021; Tucker et al, 2017b; World Rugby, 2019a; World Rugby, 2019e). However, no previous study has investigated concussion occurrence and extrinsic risk factors for concussion in the context of each individual's concussion history.

Concussion aetiology is likely extremely complex and context specific, dependent upon numerous interactions between intrinsic and extrinsic factors (Bolling et al, 2018; Fuller & Drawer, 2004; Fuller, 2007; Fuller & Vassie, 2004; Meeuwisse, 1994; Meeuwisse et al, 2007). To this researcher's best knowledge, it appears no study in professional rugby has investigated how concussion aetiology is affected by considering intrinsic risk factors such as concussion history and extrinsic risks in contact events simultaneously. By following the dynamic, recursive model of injury aetiology (Meeuwisse et al, 2007), examining concussion occurrence by different extrinsic risk factors in contact events in the context of each individual's concussion history should result in a greater understanding of concussion aetiology (Bolling et al, 2018; Fuller & Drawer, 2004; Fuller & Vassie, 2004; Meeuwisse, 1994; Meeuwisse et al, 2007).

The aims of the current chapter were two-fold. Firstly, this chapter aims to identify intrinsic (concussion history) and extrinsic (contact event specific) risk factors which statistically increase the probability of match-play concussions in men's professional rugby in Scotland. Secondly, the chapter aims to develop explanatory regression models to demonstrate whether any interaction effect on concussion outcome exists when intrinsic concussion history and extrinsic contact event specific risk factors are studied simultaneously. From these results, future preventative measures and interventions to possibly reduce concussion propensity will be discussed. This will provide greater detail on the aetiology and mechanism of concussion, answering the second stage of van Mechelen's model "The sequence of prevention of sports injuries" (van Mechelen et al, 1992), yet also considering the context and complexity of concussion aetiology (Bahr & Krosshaug, 2005; Bolling et al, 2018; Fuller & Drawer, 2004; Fuller & Vassie, 2004; Fuller, 2020; Meeuwisse et al, 2007; Quatman et al, 2009).

4.2: Methods

4.2.1: Participants

A cohort of 120 players participated in match play for Scotland men's international rugby and/or men's professional club rugby across the 2017/18 and 2018/19 seasons (excluding pre-season), totalling 2,700 hours of match exposure. Of these players, match and training concussion history information since August 2014 was successfully collected for 78, who participated in 2,079.7 hours of match exposure (77.0% of total). These 78 players participated in the study (table 4.1). No statistical differences in positional group, age or body mass between players included and excluded in the study were found.

TABLE 4.1: Anthropometrics of players included and excluded in the current study

	n (%Forwards; %Backs)	Age (years)	Body Mass (kg)
Included Players	78 (57.7; 42.3)	26.8 ± 3.6	103.8 ± 12.2
Excluded Players	42 (59.5; 40.5)	26.3 ± 3.7	108.1 ± 12.1

For players who had exclusively played within Scotland since August 2014, consent to access concussive history data is implied by virtue that these players have signed professional contracts with Scottish Rugby. These contracts state that player injury data is owned by Scottish Rugby and can be used for research if deemed necessary (appendix 2). All concussions sustained (match and training), return to play dates, and Head Injury Assessment (HIA) 2 forms since August 2014 were stored by Scottish Rugby. Players who had not exclusively played within Scotland since August 2014 were approached and verbally explained the aims of the study. Informed consent was obtained for permission to contact medical staff at previous teams and ask for necessary concussion history information (date of all match and training concussions sustained, date of return to play, and HIA 2 forms) to be shared with the primary researcher only (appendix 4). Edinburgh Napier University Ethics Committee provided ethical approval for the study.

4.2.2: Procedures

Prospective univariate analysis of intrinsic and extrinsic risks for concussion occurence in match play in the cohort of 78 players from Scotland men's international rugby and men's professional club rugby was conducted across the 2017/18 and 2018/19 seasons. Extrinsic risks were broken down by contact event type. Due to lack of video footage and irregular playing time/squad size, match exposure from pre-season matches were not included. Any concussions sustained in these matches were not analysed prospectively for the occurrence of risk factors. However, if a player sustained a concussion in these matches (n = 2), this was included as part of their concussion history. Training concussions over the 2017/18 and 2018/19 seasons (n = 8) similarly were not analysed for the occurrence of risk factors, but also contributed towards player concussive histories.

Based on the results of the univariate analysis, the two contact event types responsible for the most concussions were described by explanatory regression models aiming to identify risk factors that are potent influencers on a concussion outcome. Extrinsic (from that particular contact type) and intrinsic factors which were shown to statistically increase probability of concussion from univariate analysis were entered into the regression models.

Concussion Diagnosis

Prospective match concussions throughout the 2017/18 and 2018/19 seasons were diagnosed by match/team doctors by aid of the HIA protocol. The HIA process is based upon the Sport Concussion Assessment Tool 5th edition (SCAT 5), and is a three-stage process:

- Stage 1: HIA 1 – Assessment immediately post incident
- Stage 2: HIA 2 – Assessment 2-3 h post incident
- Stage 3: HIA 3 – Assessment 36-48 h post incident

(Fuller et al, 2017a; Raftery et al, 2016; World Rugby, 2019b).

Players can enter the assessment process at any stage yet must continue through the rest of the process beyond that point. A player was deemed as concussed in match play due to any of the following scenarios: A player possessed any signs of concussion during on-pitch evaluation or displayed them during video review of any head impact event during HIA 1 (see table 4.2) abnormal HIA 2 or 3; or the team doctor administering the HIA believes the player to be concussed (Fuller et al, 2017a; Raftery et al, 2016). On-pitch evaluation and the video review system of HIA 1 for identifying concussions has been shown to present sensitivity and specificity values of 77.5-84.6% and 74% respectively (Fuller et al, 2015b; Fuller et al, 2017d). Blank HIA forms are included in appendix one.

TABLE 4.2: Criteria for immediate and permanent removal from play

Concussion Signs and Symptoms	
Confirmed loss of consciousness	Suspected loss of consciousness
Convulsion	Tonic posturing
Ataxia	Clearly dazed
Not orientated in time, place, or person	Definite confusion
Definite behavioural change	Oculomotor signs

The HIA process has been developed from its original inception in 2012 to the protocol's followed in the current study, including increased number of symptoms for immediate removal and increased number of diagnostic tests during HIA 1, introduction of assessments 2-3 hours post-incident (HIA 2) and 48 hours post-match (HIA 3), and a video review system to identify potential concussive incidents (Fuller et al, 2020b; Raftery et al, 2016; Raftery & Tucker, 2016). These changes may have lowered the diagnostic threshold for concussion across this time frame. In addition to increased awareness of concussion (Cross et al, 2017; World Rugby, 2017b), this may result the potential for a greater incidence of concussion to be reported in the current study compared with previous work.

Intrinsic Risk Factors

Concussion history information collected for each of the 78 players as potential risk factors are presented in table 4.3 below. Concussion history was collected from August 2014 onwards, and therefore does not represent a lifetime history. These were split into categorical variables. The occurrence of each categorical variable was described by match exposure. Match exposure for each player throughout the 2017/18 and 2018/19 seasons was attributed to each of the categorical variables for each risk factor in table 4.3 dependent on each players' concussive history information. Player match exposure for each player throughout the 2017/18 and 2018/19 seasons was calculated as described in chapter 3A. Scotland men's international rugby and one men's professional club (Edinburgh Rugby) used Catapult Optimeye S5 Global Positioning System (GPS) devices (Catapult; Melbourne, Australia) for the entire study duration. The other men's professional club (Glasgow Warriors) used GPSports Evo GPS devices (GPSports; Canberra, Australia) for the 2017/18 season, and Catapult Optimeye S5 GPS devices for the 2018/19 season. Match exposure for each player was represented as a proportion (in hours) of the total team exposure, calculated as recommended by Fuller et al (2007d):

$$N_M P_M D_M/60$$

With N_M representing the number of matches played, P_M the number of players in a team, and D_M as match duration.

TABLE 4.3: Intrinsic risk factors collected from August 2014 onwards for future concussion included in univariate analysis.

Risk Factor	Categorical Variables
Number of previous concussions	No prior concussion 1 2-3 4-5 Greater than 5
Age at time of prospective concussion	Under 18 18-21 years 22-25 years 26-30 years Greater than 30 years
Severity of most-recent concussion	No prior concussion 0-7 days 8-14 days 15-21 days Greater than 21 days
Time since most-recent concussion	No prior concussion Less than 1 month 1-6 months 7-12 months 13-24 months Greater than 24 months
HIA 2 symptom score (most-recent concussion)	No prior concussion 0-5 6-10 11-15 Greater than 15
HIA 2 symptom severity (most-recent concussion)	No prior concussion 0-10 11-20 21-30 31-40 Greater than 40

Exposure for each categorical variable was updated on a match-by-match basis throughout the 2017/18 and 2018/19 seasons, ensuring participation in every match was described by each players' concussive history correct at the time of that match. Each concussion sustained during the 2017/18 and 2018/19 season was attributed to the category the concussed player's concussion history information placed him in at the time of that match.

Concussion incidence for each categorical variable for each risk factor was expressed as number of concussions/1000 player match hours with 95% confidence intervals (CI) calculated for incidence by the same formula stated in Chapters 3A and 3B (van Belle et al, 2004). Univariate analysis within each risk factor were completed by incidence rate ratios (IRR) and 95% confidence intervals (CI). Aside from age, the variable used as the reference value was "No prior concussion" (Kirkwood & Sterne, 2006). For age, the categorical variable with the largest exposure was used as the reference value.

Extrinsic Risk Factors

Univariate extrinsic risk factor analysis was performed by video coding (Nac Sport Scout Plus; Las Palmas de Gran Canaria, Spain). Match videos of all Scotland men's international and men's professional club rugby fixtures across the 2017/18 and 2018/19 seasons were obtained as broadcasted footage. Based on previous literature, coding templates were developed for each contact type using Nac Sport Scout Plus video analysis software. Each template was designed to describe each contact type by categorical variables within factors which may alter concussion propensity. The different contact types analysed are presented in table 4.4. A list of all categorical variables in each coding template and the definition used for each variable are provided in appendix five.

TABLE 4.4: Definitions of different contact types analysed by video analysis.

Contact Type	Example	Definition
Being Tackled		Any event where a Scottish Rugby ball carrier experiences contact with an opponent, regardless of whether the ball carrier is stopped or brought to ground.
Tackling		Any event where a Scottish Rugby player attempts to tackle an opposing player with the ball, regardless of whether the ball carrier is stopped or brought to ground.
Ruck		Attacking Ruck: When a Scottish Rugby ball carrier has been tackled to the ground. At least one player from each team are in contact on their feet and over the ball. Defensive Ruck: When an opponent ball carrier has been tackled to the ground. At least one player from each team are in contact on their feet and over the ball.
Maul		Attacking Maul: When a Scottish Rugby ball carrier has been tackled and remains on their feet. At least one player from each team are bound together around the ball carrier and remain on their feet. Defensive Maul: When an opponent ball carrier has been tackled and remains on their feet. At least one player from each team are bound together around the ball carrier and remain on their feet.

TABLE 4.4 Continued: Definitions of different contact types analysed by video analysis.

Contact Type	Example	Definition
Lineout		A parallel line of players from each team preparing to compete for ball as it is thrown in to restart play.
Scrum		From the referee's command "set" and ball put-in until the ball is played out of the scrum.
Kick Contest		Contact between two players, both of whom were making a reasonable attempt to catch/win the ball after it has been kicked
Off the Ball Collision		Contact between two players away from the ball and not involved in any of the above contact scenarios. Did not include fighting/brawling.

All match concussion events from the 2017/18 and 2018/19 seasons (excluding pre-season) for the 78 players involved in the study were analysed by the template for the contact type which the concussion occurred in. Concussions were reported into the injury database system as described in Chapter 3A and 3B. From here, the corresponding match and contact incident where the concussion occurred was found for video analysis.

In addition to this, 32 matches were randomly selected from Scotland men's international rugby and men's professional club rugby from the 2017/18 and 2018/19 seasons. Every contact type listed in table 4.4 in these matches experienced by one of the 78 players with full concussion history was analysed using the same coding templates as used to analyse the concussion events. This sample of matches was used to represent frequency of each contact type and frequency of categorical variables within contact types for players with a full concussion history across all 135 matches in the 2017/18 and 2018/19 seasons. This was achieved by extrapolating the number of occurrences of all contact types and categorical variables by the ratio of 135 matches/32 matches (4.21875). This allowed for estimated concussion propensity per 1000 contact events to be calculated across the 2017/18 and 2018/19 seasons. Concussion propensity per 1000 events due to the occurrence of different categorical variables within different contact types were also calculated, with 95% CI calculated as described in Chapters 3A and 3B (van Belle et al, 2004). Concussion propensity for different categorical variables were compared by IRR and 95% CI for univariate analysis. The reference value was the variable which occurred most frequently (Cross et al, 2019).

As many matches as was practically feasible within time constraints were analysed for the representative sample. Thirty-two matches represent a slightly larger sample than has been used in previous research: Cross et al (2019) and Tucker et al (2017a) used 28 and 20 matches respectively. A larger representative sample maximises the accuracy of estimates of occurrences of contact events across the 2017/18 and 2018/19 seasons.

All video analysis was performed by the primary researcher. Once all video analysis was completed, a random match was selected to be coded a second time to observe reliability of the primary researcher. As the contact events which were expected to happen most frequently (Fuller et al, 2007b; Tucker et al, 2017a), only reliability of coding for tackling and being tackled were calculated. Reliability was assessed by calculation of the kappa (κ) statistic (Kirkwood & Sterne, 2006). Kappa statistic values less than 0.4 were regarded as poor, 0.40 - 0.75 as fair to good, and greater than 0.75 as excellent (Kirkwood & Sterne, 2006). The κ values obtained are presented in table 4.5. All values were either "fair to good" or "excellent".

TABLE 4.5: Kappa statistics for reliability analysis of Tackling and Being Tackled contact types

Risk Factor	Kappa Statistic
Tackling	
Tackler Playing Position	0.97
Tackler Scrum Cap	1.00
Tackler Speed	0.69
Ball Carrier Speed	0.68
Accelerating Player	0.65
Direction of Tackle	0.78
Ball Carrier Fend	0.47
Tackler Body Region Used	0.49
Ball Carrier Body Region Struck	0.58
Tackle Type	0.73
Tackle Sequence	0.78
Tackler Head Position	0.78
Tackler and Ball Carrier Impact Force	0.71
Tackler Body Position	0.81
Ball Carrier Body Position	0.76
Tackler First Body Region to Strike Ground	0.67
Being Tackled	
Ball Carrier Playing Position	0.96
Ball Carrier Scrum Cap	1.00
Ball Carrier Speed	0.81
Tackler Speed	0.55 - 0.89
Accelerating Player	0.62
Direction of Tackle	0.82 - 0.88
Ball Carrier Body Region Struck	0.73 - 0.76
Tackler Body Region Used	0.68 - 0.82
Tackle Type	0.69 - 0.73
Ball Carrier and Tackler Impact Force	0.71 - 0.89
Ball Carrier Body Position	0.74
Tackler Body Position	0.71 - 0.83

4.2.3: Data Analysis

Calculation of κ statistics and univariate analysis for intrinsic and extrinsic risks was performed using Microsoft Excel (Microsoft, Redmond, Washington, USA). The incidence or propensity of concussion between different categorical variables was compared by IRR and 95% CI according to the Poisson distribution (Kirkwood & Sterne, 2006). Statistical findings were assumed if 95% CIs did not include 1.00.

Regression models for the two contact types that were shown through univariate extrinsic risk analysis to be responsible for the most concussions across the 2017/18 and 2018/19 seasons were developed. These were intended to be explanatory models, identifying the effect of potent risk factors on concussion outcome (Kirkwood & Sterne, 2006). Risk factors within each contact event type that were shown to statistically alter concussive propensity from univariate extrinsic risk analysis were included in each model. The reference value was the variable which occurred most frequently. Intrinsic factors which were shown to alter concussion incidence through univariate analysis were also entered into each model, with the reference value "no prior concussion".

For each regression model, Poisson regression was first attempted. In any case of overdispersion, as assessed by Pearson chi-square divided by degrees of freedom (χ^2/df), negative binomial regression with both default and estimated ancillary parameters were attempted (Ismail & Jemain, 2007; Yang & Berdine, 2015). Final model selection was based upon log likelihood, Akaike's and Bayesian information criterion and likelihood ratio chi-square (χ^2) statistics. The number of concussions sustained was the outcome variable. The number of contact events was the exposure variable, offset by a log-link function. Interaction between exposures (risk factors) entered into the regression model were assumed, with data entered using interaction parameters to allow for the effect of exposure from each categorical variable within each risk factor to be different amongst each categorical variable for all other risk factors. Multicollinearity was assessed by variance inflation factor (VIF) of all variables entered into the model. A VIF value of $\geq$ 10.0 was taken as indication of multicollinearity between variables (Kutner, Nachtsheim, & Neter, 2004). Resultant IRRs and 95% CIs were reported. Statistical findings were assumed if 95% CIs did not include 1.00. A statistical software package (IBM SPSS statistics for Windows Version 26) (IBM, Armonk, New York, USA) was used for construction of generalised linear models and assessment of multicollinearity of variables.

Numerous statistical tests were conducted throughout this chapter, potentially causing a number of results to appear statistically significant at the $p \leq 0.05$ level by chance through type I error (Armstrong, 2014). For this reason, exact p values are reported to allow for evaluation certainty to be interpreted (unless $p < 0.001$), as is recommended in epidemiology research (Rothman, 1990).

4.3: Results

Excluding pre-season matches, 73 concussions occurred for Scotland men's international and men's professional club rugby across the 2017/18 and 2018/19 seasons. For players with a full concussion history who participated in the study, 57 concussions were recorded amongst 38 different players, suggesting 48.7% of players sustained at least one concussion. Players participating in the study recorded 2,079.7 hours of match play, resulting in a concussion incidence of 27.4 (95% CI: 20.4 - 34.4)/1000 player match hours.

4.3.1 Univariate Analysis

Intrinsic Risks

Table 4.6 presents concussion incidence stratified by number of previous concussions since August 2014. The greatest concussion incidence was recorded for players who had sustained greater than five previous concussions (102.8/1000 player match hours), followed by four-five previous concussions (37.5/1000 hours) and two-three previous concussions (22.1/1000 hours). Concussion incidence for the greater than five previous concussions category was statistically greater than the no prior concussion category (IRR: 4.8; 95% CI: 1.9 - 12.0; $p < 0.001$).

TABLE 4.6: Concussion incidence by number of prior concussions since Aug 2014

Previous Concussion	Exposure (h)	Concussions (n)	Incidence (95% CI)
No Prior Concussion	328.6	7	21.3 (5.7-36.9)
1	614.2	11	17.9 (7.4-28.4)
2-3	814.1	18	22.1 (12.0-32.2)
4-5	186.5	7	37.5 (10.3-64.8)
Greater than 5	136.2	14	102.8 (51.8-153.7)*

*($p < 0.001$) Greater than 5 to No Prior Concussion

Table 4.7 presents concussion incidence by age at prospective concussion. The greatest incidence was found for 26-30 (32.2/1000 hours), followed by 22-25 (27.1/1000 hours) and greater than 30 years of age (14.3/1000 hours). Compared with concussion incidence for 26-30 years, no statistical differences in concussion incidence were found to other ages.

TABLE 4.7: Concussion incidence by player age at prospective concussion.

Age (years)	Exposure (h)	Concussions (n)	Incidence (95% CI)
18-21	93.3	1	10.7 (-10.2-31.6)
22-25	590.7	16	27.1 (14.0-40.2)
26-30	1,116.5	36	32.2 (21.9-42.6)
Greater than 30	279.3	4	14.3 (0.4-28.3)

Table 4.8 presents concussion incidence by severity of most-recent concussion. The greatest incidence was found for a most-recent concussion severity of 8-14 days (54.9/1000 hours), followed by 15-21 days (31.8/1000 hours) and those who had never experienced a concussion (21.3/1000 hours). Incidence for those with a most-recent concussion severity of 8-14 days was statistically greater than the no prior concussion category (IRR: 2.6; 95% CI: 1.1 - 6.1; $p = 0.031$).

TABLE 4.8: Concussion incidence by severity of most-recent concussion

Severity of Most-Recent Concussion	Exposure (h)	Concussions (n)	Incidence (95% CI)
No Prior Concussion	328.6	7	21.3 (5.7-36.9)
0-7 days	733.9	15	20.4 (10.2-30.7)
8-14 days	364.2	20	54.9 (31.5-78.3)*
15-21 days	188.5	6	31.8 (6.8-56.9)
Greater than 21 days	196.3	4	20.4 (0.6-40.1)
No HIA Info	268.2	5	18.6 (2.5-34.8)

*($p = 0.031$) 8-14 days to No Prior Concussion.

Table 4.9 presents concussion incidence by time since most-recent concussion. The greatest incidence was found for one month (58.9/1000 hours), followed by 2-6 months (40.3/1000 hours) and 7-12 months (29.7/1000 hours). No statistical differences were found between categories.

TABLE 4.9: Concussion incidence by time since most-recent concussion

Time Since Most-Recent Concussion	**Exposure (h)**	**Concussions (n)**	**Incidence (95% CI)**
No Prior Concussion	328.6	7	21.3 (5.7-36.9)
1 month	101.9	6	58.9 (13.2-104.6)
2-6 months	297.8	12	40.3 (18.0-62.6)
7-12 months	437.0	13	29.7 (13.8-45.7)
13-24 months	476.8	9	18.9 (6.7-31.1)
Greater than 24 months	437.5	10	22.9 (8.9-36.9)

Table 4.10 presents concussion incidence by Head Injury Assessment (HIA) 2 symptom score from the most-recent concussion sustained. The greatest incidence was found for 11-15 HIA 2 symptoms (78.6/1000 hours), followed by 6-10 HIA 2 symptoms (57.6/1000 hours) and 0-5 symptoms (23.9/1000 hours) (excluding No HIA Information category). Concussion incidence for 11-15 HIA 2 symptoms (IRR: 3.7; 95% CI: 1.1-12.6; $p = 0.037$) and 6-10 HIA 2 symptoms (IRR: 2.7; 95% CI: 1.0 - 7.3; $p = 0.048$) from the most-recent concussion were statistically greater than concussion incidence for the no prior concussion category.

TABLE 4.10: Concussion incidence by recent concussion HIA 2 symptom score

Recent HIA 2 Symptom Score	**Exposure (h)**	**Concussions (n)**	**Incidence (95% CI)**
No Prior Concussion	328.6	7	21.3 (5.7-36.9)
0-5	1,002.9	24	23.9 (14.5-33.4)
6-10	156.3	9	57.6 (21.1-94.1)[a]
11-15	50.9	4	78.6 (4.7-152.6)*
15-22	60.4	-	-
No HIA Information	480.6	13	27.1 (12.5-41.6)

*($p = 0.037$) to No Prior Concussion. [a]($p = 0.048$) to No Prior Concussion.

Table 4.11 presents concussion incidence by HIA 2 symptom severity from the most-recent concussion sustained. The greatest incidence was found for symptom severity of 31-40 (155.9/1000 hours), followed by 21-30 (50.2/1000 hours) and 11-20 (40.3/1000 hours). The incidence of concussion for the most-recent HIA 2 symptom severity category of 31-40 was statistically greater than the no prior concussion category (IRR: 7.3; 95% CI: 1.5 - 35.2; $p = 0.013$).

TABLE 4.11: Concussion incidence by recent concussion HIA 2 symptom severity

Recent HIA 2 Symptom Severity	Exposure (h)	Concussions (n)	Incidence (95% CI)
No Prior Concussion	328.6	7	21.3 (5.7-36.9)
0-10	1,077.1	28	26.0 (16.5-35.5)
11-20	74.5	3	40.3 (-4.4-84.9)
21-30	39.8	2	50.2 (-17.6-118.0)
31-40	12.8	2	155.9 (-42.6-354.5)*
Greater than 40	66.3	2	30.2 (-11.0-71.3)
No HIA Info	480.6	13	27.1 (12.5-41.6)

*($p = 0.013$) 31-40 symptom severity to No Prior Concussion.

Extrinsic Risks

Forty-eight concussions were included in extrinsic risk analysis. Nine of the 57 concussions sustained by players involved in the study were excluded due to either inadequate video footage to identify concussive impact, or players reporting concussion symptoms post-match with no singular mechanism.

Table 4.12 presents the number of contact events analysed across the representative sample of 32 matches for players involved in the study, and the extrapolated value representing the number of contact events estimated to have occurred across all matches during the 2017/18 and 2018/19 seasons.

TABLE 4.12: Number of analysed contact events and their estimated number of occurrences across the 2017/18 and 2018/19 seasons for players with a full concussion history.

Contact Event	Analysed from Representative Sample (n)	Estimation of Occurrences across 2017/18 and 2018/19 seasons (n)	Events per match for 2017/18 and 2018/19 seasons
Being Tackled	5,711	24,093	178.5
Tackling	5,335	22,507	166.7
Attacking Ruck	3,214	13,559	100.4
Defensive Ruck	2,399	10,121	75.0
Attacking Maul	247	1,042	7.7
Defensive Maul	183	772	5.7
Lineout	705	2,974	22.0
Scrum	472	1,991	14.8
Kick Contest	145	612	4.5
Off the Ball Collision	586	2,472	18.3

Defensive Ruck only counted when a Scottish Rugby player participated in the ruck.

Table 4.13 presents contact events responsible for each concussion. Concussion propensity is expressed per 1000 events and incidence per match, both based from estimation of number of events across the whole 2017/18 and 2018/19 season. Kick contests presented the greatest propensity of concussion (3.3/1000 events), followed by tackling (0.93/1000 events) and being tackled (0.62/1000 events). When frequency of events within each match is considered, concussions caused by tackling occurred the most frequently (6.4 matches/concussion) followed by being tackled (9.0 matches/concussion) and attacking ruck (19.3 matches/concussion). Due to the contact events that were responsible for the most concussions, tackling and being tackled have been investigated further in the subsequent section.

TABLE 4.13: Concussion propensity by contact event

Contact Event	Concussions (n)	Concussion Propensity (/1000 events) (95% CI)	Matches per Concussion (95% CI)
Tackling	21	0.93 (0.53 - 1.3)	6.4 (3.9 - 9.0)
Being Tackled	15	0.62 (0.31 - 0.94)	9.0 (4.7 - 13.3)
Attacking Ruck	7	0.52 (0.13 - 0.90)	19.3 (5.4 - 33.2)
Defensive Ruck	2	0.20 (-0.08 - 0.47)	67.5 (-25.4 - 160.4)
Attacking Maul	0	-	-
Defensive Maul	0	-	-
Lineout	0	-	-
Scrum	1	0.50 (-0.48 - 1.49)	135.0 (-128.6 - 398.6)
Kick Contest	2	3.3 (-1.3 - 7.8)	67.5 (-25.4 - 160.4)
Off the Ball Collision	0	-	-

Extrinsic Risks: Tackling

For the tackling player, the following factors demonstrated statistical differences in concussion propensity between variables: initial body region struck on the ball carrier, initial body region used by the tackler to strike the ball carrier, tackler head position and tackle impact force.

Table 4.14 presents tackler concussion propensity by the initial body region struck on the ball carrier. Excluding inconclusive body regions, the greatest propensity of concussion for the tackler was making contact with the ball carrier's head (3.5/1000 tackles), followed by the shoulder/arm (1.3/1000 tackles) and the lower limb (1.2/1000 tackles). Compared with initial contact with the ball carrier's torso, contacting the ball carrier's head (IRR: 10.8; 95% CI: 1.8 - 64.6; p = 0.009) and shoulder/arm (IRR: 4.0; 95% CI: 1.1 - 14.4; p = 0.036) statistically increased concussion propensity for the tackler.

TABLE 4.14: Tackler concussion propensity by body region struck on the ball carrier

Ball Carrier Body Region Struck	Tackles (n)	Concussions (n)	Propensity (95% CI)
Head	578	2	3.5 (-1.3 - 8.3)*
Neck	55	-	-
Shoulder/Arm	7,864	10	1.3 (0.48 - 2.1)[a]
Torso	9,361	3	0.3 (-0.04 - 0.68)
Lower Limb	4,210	5	1.2 (0.15 - 2.2)
Inconclusive	439	1	2.3 (-2.2 - 6.7)

*(p = 0.009) to Torso. [a](p = 0.036) to Torso.

Table 4.15 presents tackler concussion propensity by the initial body region the tackler used to strike the ball carrier. Excluding inconclusive body regions, the greatest propensity of concussion for the tackler was by making initial contact with their head (20.7/1000 tackles), followed by shoulder/arm (0.39/1000 tackles). Concussion was not recorded when making initial contact with any other body region. Compared with the shoulder/arm region, making initial contact with their head statistically increased the propensity of concussion for the tackler (IRR: 53.4; 95% CI: 21.3 - 133.9; $p < 0.001$).

TABLE 4.15: Tackler concussion propensity by body region used by the tackler to strike ball carrier

Tackler Body Region Used	Tackles (n)	Concussions (n)	Propensity (95% CI)
Head	629	13	20.7 (9.6 - 31.8)*
Neck	38	-	-
Shoulder/Arm	18,082	7	0.39 (0.10 - 0.67)
Torso	3,113	-	-
Lower Limb	219	-	-
Inconclusive	426	1	2.4 (-2.3 - 6.9)

*($p < 0.001$) Head to Shoulder/Arm

Table 4.16 presents tackler concussion propensity by the tackler's head position relative to the ball carrier. The greatest concussion propensity was found for the tackler's head in front of the ball carrier (4.4/1000 tackles), followed by beside (0.71/1000 tackles) and behind (0.45/1000 tackles). Compared with the tackler's head beside the ball carrier, the tackler's head in front of the ball carrier statistically increased the propensity of concussion (IRR: 6.3; 95% CI: 2.4 - 16.2; $p < 0.001$).

TABLE 4.16: Tackler concussion propensity by tackler head position relative to ball carrier.

Tackler Head Position	Tackles (n)	Concussions (n)	Propensity (95% CI)
Beside	11,327	8	0.70 (0.22 - 1.2)
Above	4,733	2	0.42 (-0.16 - 1.0)
Behind	4,413	2	0.45 (-0.17 - 1.1)
In front	2,033	9	4.4 (1.5 - 7.3)*

*($p < 0.001$) to Beside.

Table 4.17 presents tackler concussion propensity by impact force between the tackler and ball carrier. The greatest concussion propensity was reported for high impact tackles (3.6/1000 tackles), followed by moderate impact (1.4/1000 tackles) and low impact (0.24/1000 tackles). Compared with low impact tackles, both high (IRR: 15.1; 95% CI: 3.9 - 58.5; $p < 0.001$) and moderate impact tackles (IRR: 5.7; 95% CI: 1.6 - 20.5; $p = 0.007$) statistically increased the propensity of concussion to the tackler.

TABLE 4.17: Tackler concussion propensity by tackle impact force.

Tackle Impact Force	Tackles (n)	Concussions (n)	Propensity (95% CI)
Low	12,534	3	0.24 (-0.03 - 0.51)
Moderate	8,041	11	1.4 (0.56 - 2.2)[a]
High	1,932	7	3.6 (0.94 - 6.3)*

*($p < 0.001$) to Low. [a]($p = 0.007$) to Low.

Remaining risk factors which did not statistically alter concussion propensity are presented in table 4.18 below.

TABLE 4.18: Statistically non-significant risk factors for concussion whilst tackling.

Variable	Tackles (n)	Concussions (n)	Propensity (95% CI)
Playing Position			
Forwards	15,107	13	0.86 (0.39 - 1.3)
Backs	7,400	8	1.1 (0.33 - 1.8)
Match Quarter			
0 - 20 mins	5,375	4	0.74 (0.02 - 1.5)
21 - 40 mins	4,843	4	0.83 (0.02 - 1.6)
41 - 60 mins	5,674	6	1.1 (0.21 - 1.9)
61 - 80 mins	6,615	7	1.1 (0.27 - 1.8)
Scrum Cap			
No	20,031	20	1.0 (0.56 - 1.4)
Yes	2,476	1	0.40 (-0.39 - 1.2)
Ball Carrier Speed			
Slow	13,403	11	0.82 (0.34 - 1.3)
Medium	6,400	7	1.1 (0.28 - 1.9)
Fast	2,704	3	1.1 (-0.15 - 2.4)
Tackler Speed			
Slow	19,465	19	0.98 (0.54 - 1.4)
Medium	2,274	2	0.88 (-0.34 - 2.1)
Fast	768	-	-
Accelerating Player			
Ball Carrier	7,332	8	1.1 (0.34 - 1.9)
Tackler	2,603	-	-
Both	3,447	6	1.7 (0.35 - 3.1)
Neither	9,125	7	0.77 (0.20 - 1.3)
Direction of Tackle			
Front-On	14,563	17	1.2 (0.61 - 1.7)
Side-On	6,438	4	0.62 (0.01 - 1.2)
Behind	1,506	-	-

TABLE 4.18 Continued:

Variable	Tackles (n)	Concussions (n)	Propensity (95% CI)
Ball Carrier Fend			
None	21,309	21	0.99 (0.56 - 1.4)
Moderate	835	-	-
Strong	363	-	-
Tackle Type			
Shoulder	10,201	15	1.5 (0.73 - 2.2)
Smother	5,780	5	0.87 (0.11 - 1.6)
Arm	4,641	1	0.22 (-0.21 - 0.64)
Tap	51	-	-
Jersey	835	-	-
Collision	835	-	-
High	135	-	-
Lift	30	-	-
Tackle Sequence			
One on One	7,990	10	1.3 (0.48 - 2.0)
Two on One Sequential	8,075	9	1.1 (0.4 - 1.8)
Two on One Simultaneous	6,442	2	0.31 (-0.12 - 0.74)
Ball Carrier Body Position			
Low	3,236	-	-
Medium	10,859	14	1.3 (0.61 - 2.0)
Upright	8,412	7	0.83 (0.22 - 1.5)
Tackler Body Position			
Low	5,742	7	1.2 (0.32 - 2.1)
Medium	12,028	12	1.0 (0.43 - 1.6)
Upright	4,738	2	0.42 (-0.16 - 1.0)
Tackler Legality			
Legal	22,431	21	0.94 (0.54 - 1.3)
Illegal	76	-	-
First Body Region to Strike Ground			
Head	21	-	-
Neck	-	-	-
Shoulder/Arm	1,278	2	1.6 (-0.60 - 3.7)
Torso	2,160	-	-
Lower Limb	1,2310	17	1.4 (0.72 - 2.0)
Stayed on Feet	6,185	1	0.16 (-0.16 - 0.48)
Inconclusive	553	1	1.8 (-1.7 - 5.4)

Extrinsic Risks: Being Tackled

For the tackled player, the following factors demonstrated statistical differences in concussion propensity between variables: body region struck, tackle impact force, and tackle legality.

Table 4.19 presents concussion propensity for the tackled player by the initial body region struck by the tackler. The greatest concussion propensity was recorded from initially being struck on the head (5.0/1000 tackles), followed by shoulder/arm (0.80/1000 tackles) and torso (0.29/1000 tackles). Compared with being initially struck by the tackler on the torso, being first impacted on the head statistically increased the propensity of concussion (IRR: 17.4; 95% CI: 3.9 - 77.6; $p < 0.001$).

TABLE 4.19: Concussion propensity for the tackled player by initial body region struck.

Body Region Struck	Tackles (n)	Concussions (n)	Propensity (95% CI)
Head	793	4	5.0 (0.11 - 10.0)*
Neck	63	-	-
Shoulder/Arm	8,745	7	0.80 (0.21 - 1.4)
Torso	10,328	3	0.29 (-0.04 - 0.62)
Lower Limb	3,675	1	0.27 (-0.26 - 0.81)
Inconclusive	489	-	-

*($p < 0.001$) to Torso.

Table 4.20 presents concussion propensity for the tackled player by tackle impact force. The greatest concussion propensity was found for a moderate impact force tackle (1.4/1000 tackles), followed by high impact (1.1/1000 tackles) and low impact (0.20/1000 tackles). Compared with low impact, propensity of concussion to the tackled player was statistically greater in moderate impact tackles (IRR: 6.7 95% CI: 1.8 - 24.3; $p = 0.004$).

TABLE 4.20: Concussion propensity for the tackled player by tackle impact force.

Tackle Impact Force	Tackles (n)	Concussions (n)	Propensity (95% CI)
Low	14,846	3	0.20 (-0.03 - 0.43)
Moderate	7,412	10	1.35 (0.51 - 2.2)*
High	1,835	2	1.1 (-0.42 - 2.6)

*($p = 0.004$) to Low.

Table 4.21 presents concussion propensity for the tackled player by legality of the tackler. Tackles where the tackling player was penalised resulted in the greatest concussion propensity (36.5/1000 tackles). The propensity of concussion to the tackled player when the tackler was penalised was statistically greater when compared to legal tackles (IRR: 67.4; 95% CI: 15.2 - 298.8; $p < 0.001$).

TABLE 4.21: Concussion propensity for the tackled player by tackler legality.

Tackler Penalised	Tackles (n)	Concussions (n)	Propensity (95% CI)
No	24,038	13	0.54 (0.25 - 0.83)
Yes	55	2	36.5 (-13.4 - 86.1)*

*($p < 0.001$) to No.

Remaining risk factors which did not statistically alter concussion propensity for the tackled player are presented in table 4.22 below.

TABLE 4.22: Statistically non-significant concussion risk factors for the tackled player

Variable	Tackles (n)	Concussions (n)	Propensity (95% CI)
Playing Position			
Forwards	14,061	8	0.57 (0.17 - 0.96)
Backs	10,032	7	0.70 (0.18 - 1.2)
Match Quarter			
0 - 20 mins	5,333	3	0.56 (-0.07 - 1.2)
21 - 40 mins	6,197	8	1.3 (0.40 - 2.2)
41 - 60 mins	6,598	3	0.45 (-0.06 - 0.97)
61 - 80 mins	5,965	1	0.17 (-0.16 - 0.50)
Scrum Cap			
No	21,866	14	0.64 (0.30 - 0.98)
Yes	2,228	1	0.45 (-0.43 - 1.3)
Ball Carrier Speed			
Slow	13,390	5	0.37 (0.05 - 0.70)
Medium	7,619	8	1.1 (0.32 - 1.8)
Fast	3,084	2	0.65 (-0.25 - 1.6)
Tackler Speed			
Slow	20,870	15	0.72 (0.36 - 1.1)
Medium	2,413	-	-
Fast	810	-	-
Accelerating Player			
Ball Carrier	9,644	6	0.62 (0.12 - 1.1)
Tackler	2,822	-	-
Both	4,383	5	1.1 (0.14 - 2.1)
Neither	7,244	4	0.55 (0.01 - 1.1)

TABLE 4.21 Continued

Variable	Tackles (n)	Concussions (n)	Propensity (95% CI)
Direction of Tackle			
Front-On	15,251	12	0.79 (0.34 - 1.2)
Side-On	7,066	3	0.42 (-0.06 - 0.90)
Behind	1,776	-	-
Tackle Type			
Shoulder	9,138	7	0.77 (0.20 - 1.3)
Smother	7,024	4	0.57 (0.01 - 1.1)
Arm	5,501	-	-
Jersey	983	-	-
Tap	38	-	-
Collision	1,173	3	2.6 (-0.33 - 5.5)
High	198	1	5.0 (-4.8 - 14.9)
Lift	38	-	-
Tackle Sequence			
One on One	8,484	4	0.47 (0.01 - 0.93)
Two on One Sequential	9,669	6	0.62 (0.12 - 1.1)
Two on One Simultaneous	5,940	5	0.84 (0.10 - 1.6)
Tackler Body Region Used			
Head	397	-	-
Neck	21	-	-
Shoulder/Arm	19,145	13	0.68 (0.31 - 1.05)
Torso	3,780	1	0.26 (-0.25 - 0.78)
Lower Limb	321	1	3.1 (-3.0 - 9.2)
Inconclusive	430	-	-
Ball Carrier Body Position			
Low	3,679	2	0.54 (-0.21 - 1.3)
Medium	10,167	4	0.39 (0.01 - 0.78)
Upright	10,247	9	0.88 (0.30 - 1.5)
Tackler Body Position			
Low	5,269	2	0.38 (-0.15 - 0.91)
Medium	13,449	8	0.59 (0.18 - 1.0)
Upright	5,375	5	0.93 (0.12 - 1.8)

4.3.2: Regression Analysis

As the contact events which caused most concussions, regression models were developed for tackling and being tackled. All intrinsic and extrinsic factors pertaining to each contact type which had previously been shown to increase the probability of concussion were included in each model.

Tackling

The following factors were entered into the tackling regression model: Number of prior concussions, severity of most-recent concussion, most-recent concussion HIA 2 symptom score, body region struck on the ball carrier, body region used to strike ball carrier, tackler head position and tackle impact force. Despite univariate analysis suggesting most-recent concussion HIA 2 symptom severity was a statistically significant intrinsic risk factor for concussion, this variable was left out of the regression model due to a small sample of concussions within the statistically significant variable (Agresti, 2018).

Data reduction was applied to two factors in order to reduce standard errors of estimated effects (Agresti, 2018; Kirkwood & Sterne, 2006). Number of prior concussions was changed to the following variables: "No Prior Concussion"; "One to Five Previous Concussions"; and "Greater than Five Previous Concussions". Tackler head position variables were altered to "Correct" (Beside, Behind, and Above) and "Incorrect" (in front) (Rugby AU, 2017; Rugby Smart, 2018; Sobue et al, 2017).

All variables were entered into a Poisson regression model. This displayed overdispersion (χ^2/df = 2.241). Negative binomial regression with both a default parameter and estimated ancillary parameter were then attempted. Log likelihood and Akaike's and Bayesian information criterion statistics suggested negative binomial regression with a default parameter was the model with the best fit (Lagrange multiplier test: χ^2 (1) = 0.938; p = 0.333). Likelihood ratio χ^2 statistic reported a statistically significant model (χ^2 (23) = 108.886; $p < 0.001$). Variance inflation factors demonstrated no multicollinearity between variables in the model.

Table 4.23 presents the factors entered in the negative binomial regression model. After allowing for interactions between variables, severity of most-recent concussion, body region struck on the ball carrier, body region used to strike ball carrier and tackle impact force remained factors which statistically altered propensity for concussion whilst tackling. The largest statistical increase in concussion propensity was due to the tackler using their head to strike the ball carrier, compared with shoulder/arm (IRR: 48.7; 95% CI: 15.0 - 157.6; $p < 0.001$). This was followed by high impact force tackles when compared with low impact (IRR: 13.2; 95% CI: 3.0 - 57.1; p = 0.001) and initially striking the ball carrier on the head as opposed to the torso (IRR: 9.3; 95% CI: 1.1 - 76.6; p = 0.038). Most-recent concussion severity of 8-14 days compared with no prior concussion (IRR: 8.4; 95% CI: 2.2 - 31.4; p = 0.002), initially striking the ball carrier on the shoulder/arm compared with torso (IRR: 4.3; 95% CI: 1.1 - 17.1; p = 0.037), and moderate impact force tackles compared with low impact (IRR: 4.0; 95% CI: 1.0 - 15.5; p = 0.047) were the remaining variables which statistically increased propensity of concussion to the tackler.

TABLE 4.23: Regression predictors of tackler concussion

Risk Factor	Variables	Regression Coefficient	IRR (95% CI)	*p* value
Number of Previous Concussions	No Prior Concussion (R)	-	1.0	-
	One to Five	-1.6	0.20 (0.04 - 1.1)	0.068
	Greater than Five	-1.0	0.35 (0.05 - 2.4)	0.292
Severity of most-recent concussion	No Prior Concussion (R)	-	1.0	-
	0-7 days		*Redundant Variable*	
	8-14 days	2.1	8.4 (2.2 - 31.4)	0.002*
	15-21 days	-0.15	0.86 (0.09 - 8.7)	0.901
	> 21 days	0.295	1.3 (0.14 - 13.4)	0.802
HIA 2 symptom score of most-recent concussion	No Prior Concussion (R)	-	1.0	-
	0-5 Symptoms		*Redundant Variable*	
	6-10 Symptoms	0.84	2.3 (0.43 - 12.5)	0.332
	11-15 Symptoms		*No Concussions Reported*	
	> 15 Symptoms		*No Concussions Reported*	
Body region struck on ball carrier	Torso (R)	-	1.0	-
	Shoulder/Arm	1.5	4.3 (1.1 - 17.1)	0.037*
	Lower Limb	1.2	3.3 (0.70 - 15.6)	0.131
	Head	2.2	9.3 (1.1 - 76.6)	0.038*
	Neck		*No Concussions Reported*	
Body region used to strike ball carrier	Shoulder/Arm (R)	-	1.0	-
	Torso		*No Concussions Reported*	
	Head	3.9	48.7 (15.0 - 157.6)	<0.001*
	Lower Limb	1.3	3.8 (0.00 - 4,731.1)	0.713
	Neck		*No Concussions Reported*	
Tackler head position	Correct (R)	-	1.0	-
	Incorrect	-0.1	0.9 (0.29 - 2.9)	0.870
Tackle Impact Force	Low (R)	-	1.0	-
	Moderate	1.4	4.0 (1.0 - 15.5)	0.047*
	High	2.6	13.2 (3.0 - 57.1)	0.001*

(R) indicates reference variable within each risk factor. Exposure variable was tackles.
*(p < 0.05) to reference variable.

Being Tackled

The following factors were entered into the regression model for the tackled player: Number of prior concussions, severity of most-recent concussion, most-recent concussion HIA 2 symptom score, body region struck on the tackled player, tackle impact force, and legality of the tackler. Despite univariate analysis suggesting most-recent concussion HIA 2 symptom severity was a statistically significant intrinsic risk factor for concussion, this variable was left out of the regression model due to a small sample of concussions within the statistically significant variable (Agresti, 2018). Number of prior concussions was reduced to the following variables: "No Prior Concussion"; "One to Five Previous Concussions"; and "Greater than Five Previous Concussions" in order to reduce standard errors of estimated effects (Agresti, 2018; Kirkwood & Sterne, 2006).

All variables were entered into a Poisson regression model. This displayed overdispersion (χ^2/df = 6.016). Negative binomial regression with both a default parameter and estimated ancillary parameter were then attempted. Log likelihood and Akaike's and Bayesian information criterion statistics suggested negative binomial regression with a default parameter was the model with the best fit (Lagrange multiplier test: χ^2 (1) = -16.149; p = 1.000). Likelihood ratio χ^2 statistic indicated a statistically significant model (χ^2 (18) = 60.382; $p < 0.001$). Variance inflation factors recorded no multicollinearity between variables that were included.

Table 4.24 presents the factors entered into the negative binomial regression model. After allowing for interactions between variables, severity of most-recent concussion, body region struck on the tackled player, tackle impact force and tackle legality remained factors which statistically altered propensity for concussion to the tackled player. The largest statistical increase in concussion propensity was due to an illegal tackle compared with legal (IRR: 54.4; 95% CI: 7.1 - 415.1; $p < 0.001$), followed by most-recent concussion severity of 8-14 days compared with no prior concussion (IRR: 18.6; 95% CI: 2.3 - 151.6; p = 0.006) and the tackled player being initially struck on the head compared with the torso (IRR: 8.3; 95% CI: 1.4 - 47.8; p = 0.018). Moderate tackle impact force compared with low impact was the remaining variable which statistically increased propensity of concussion to the tackled player (IRR: 6.4; 95% CI: 1.5 - 26.5; p = 0.010).

TABLE 4.24: Regression predictors of concussion for the tackled player

Risk Factor	Variables	Regression Coefficient	IRR (95% CI)	*p* value
Number of Previous Concussions	No Prior Concussion (R)	-	1.0	-
	One to Five	-2.0	0.14 (0.01 - 2.9)	0.203
	Greater than Five	1.6	4.9 (0.32 - 75.4)	0.257
Severity of most-recent concussion	No Prior Concussion (R)	-	1.0	-
	0-7 days	*Redundant Variable*		
	8-14 days	2.9	18.6 (2.3 - 151.6)	0.006*
	15-21 days	1.7	5.5 (0.70 - 43.4)	0.106
	> 21 days	1.5	4.2 (0.44 - 41.1)	0.213
HIA 2 symptom score of most-recent concussion	No Prior Concussion (R)	-	1.0	-
	0-5 Symptoms	*Redundant Variable*		
	6-10 Symptoms	-0.3	0.73 (0.06 - 8.4)	0.800
	11-15 Symptoms	1.3	3.6 (0.52 - 24.4)	0.196
	> 15 Symptoms	*No Concussions Reported*		
Body region struck on tackled player	Torso (R)	-	1.0	-
	Shoulder/Arm	0.73	2.1 (0.46 - 9.3)	0.341
	Lower Limb	0.28	1.3 (0.12 - 14.1)	0.820
	Head	2.1	8.3 (1.4 - 47.8)	0.018*
	Neck	*No Concussions Reported*		
Tackle Impact Force	Low (R)	-	1.0	-
	Moderate	1.9	6.4 (1.5 - 26.5)	0.010*
	High	1.4	3.9 (0.48 - 32.3)	0.202
Tackle Legality	Legal (R)	-	1.0	-
	Illegal	4.0	54.4 (7.1 - 415.1)	<0.001*

(R) indicates reference variable within each risk factor. Exposure variable was tackles.
*($p < 0.05$) to reference variable.

4.4: Discussion

The current chapter aimed to first identify intrinsic (concussion history) and extrinsic (contact event specific) risk factors which statistically increased probability of match concussion in professional rugby in Scotland. The number of previous concussions and most-recent concussion severity, head injury assessment (HIA) 2 symptom score and HIA 2 symptom severity were identified as intrinsic risk factors for future concussion. Tackling and being tackled were the two contact types where concussion occurred most frequently. Body region struck on the ball carrier, body region used by the tackler to strike the ball carrier, head position and tackle impact force were identified as extrinsic risk factors for concussion to the tackler. For the tackled player, body region struck, tackle impact force and tackler legality were found as extrinsic risk factors.

Secondly, the chapter aimed to develop explanatory regression models to demonstrate whether any interaction effect on concussion outcome exists when intrinsic concussion history and extrinsic contact event specific risk factors are studied simultaneously, in-line with the dynamic, recursive injury aetiology model proposed by Meeuwisse et al (2007), and investigating risk factors as recommended by Fuller and Drawer (2004). Regression analysis for the tackler found that severity of most-recent concussion, region of the body used to strike the ball carrier, the body region struck on the ball carrier, and tackle impact force remained statistical risk factors for concussion. For the tackled player, regression analysis found severity of most-recent concussion, body region struck by the tackler, tackle impact force and tackler legality remained as statistical risk factors for concussion.

Intrinsic Risks

It was found that players who had sustained greater than five previous concussions in the three years preceding the start of the 2017/18 season reported a statistically increased concussion incidence compared with those who had not been concussed. Non statistical increases in concussion incidence were also seen for those players who had sustained 2-3 and 4-5 previous concussions from those who had no prior concussion. These findings concur with previous studies in both rugby (Hollis et al, 2009) and other sports (Abrahams et al, 2014; Emery et al, 2010; Guskiewicz et al, 2003; Schneider et al, 2013; Zemper, 2003) describing the increased concussion incidence which is associated with a history of previous concussion.

Reasons for previous concussion increasing future incidence have been based on the theory that there is inadequate recovery from prior concussion. This may result in heightened neuronal vulnerability leaving cells more vulnerable to further injury (Barrett et al, 2014; Hollis et al, 2009; Howell et al, 2018). Neurobiological deficits may also be present beyond clinical recovery of concussion, reducing co-ordination and contact skill proficiency, subsequently increasing future concussive incidence. Increased corticomotor inhibition and altered motor unit recruitment strategies have been recorded in participants post-concussion injury (Di Virgilio et al, 2019; Hides et al, 2016). Bussey et al (2019) demonstrated diminished feed-forward control of neck muscles in those who had been concussed in the previous 12 months. Neck musculature appears to play a role in reducing concussive incidence through limiting cranial acceleration (Broglio et al, 2012; Collins et al, 2014; Vanio et al, 2007) and impaired feed-forward control may increase future concussion incidence. Neurobiological deficits appear to persist beyond clinical recovery as assessed by current return to sport tests (Howell et al, 2018). It appears current concussion rehabilitation protocols do not allow for complete recovery, whilst return to sport tests may lack the necessary validity to determine whether a player is fit to return to full training and match play.

Higher HIA 2 symptom scores and symptom severities from the most-recent concussion were also shown to statistically increase the concussion incidence compared with players who had never previously been concussed. Previous studies have suggested that the number and severity of symptoms reported at concussion diagnoses are positively associated with a prolonged recovery and more severe concussive injury (Cosgrave & Williams, 2019; Meehan et al, 2014; Meehan, Mannix, Stracciolini, Elbin, & Collins, 2013). The greater number or severity of concussion symptoms reported at the most-recent HIA 2 in the current study may suggest a greater magnitude of tissue damage at initial injury. Assuming possible inadequate recovery from previous concussion (Barrett et al, 2014; Bussey et al, 2019; DiVirgilio et al, 2019; Hides et al, 2016; Hollis et al, 2009; Howell et al, 2018), a greater magnitude of damage may result in greater incidence of concussion in the future, explaining the current findings.

A most-recent concussion severity of 8-14 days was found to statistically increase the incidence of subsequent concussion. To the best of the author’s knowledge, this is the first study which has investigated the severity of the most-recent concussion as a potential risk-factor for future concussion. A most-recent concussion severity of 0-7 days had a similar incidence for future concussion compared with those who had never been concussed. After a statistical increase for a most-recent severity of 8-14 days, a most-recent concussion severity of 15-21 days demonstrated a non-statistically significant increase in concussion incidence compared with no prior concussion. Beyond this, a most-recent concussion severity of greater than 21 days illustrated a concussion incidence similar to those who had never been concussed.

Assuming no exacerbation or re-emergence of concussive symptoms, a player may return to sport in less than one week (although not less than 6 days if current guidelines are followed correctly) (McCrory et al, 2017). The current data suggests that players who recover in this manner experience no alteration in future concussion incidence compared with those who have never been concussed. For concussion recovery to last into a second week, there has to be evidence of prolonged or re-emergence of concussive symptoms during the recovery period (McCrory et al, 2017). Due to the number and severity of symptoms reported at concussion diagnosis being positively associated with a prolonged recovery and more severe injury, it is possible that prolonged or exacerbated symptoms during recovery may also be indicative of greater magnitude of tissue damage and more severe concussion. Players who then return at the earliest stage having experienced prolonged/exacerbated symptoms (8-14 days) may therefore be at a greater incidence of future concussion. As longer recovery time from prolonged symptoms is observed (15-21 days; greater than 21 days) future concussive incidence decreases and returns to similar as those with no prior concussion.

From both a player welfare and team performance perspective, the influence that previous concussion may have on future concussion incidence is concerning (Fuller, 1995; Williams et al, 2016). Scottish Rugby have a legal duty of care to protect player welfare (Fuller, 1995), and individuals who have sustained multiple concussions have been associated with cognitive impairments and common mental disorder symptoms in later life, and neurodegeneration possibly leading to chronic traumatic encephalopathy (Baugh et al, 2012; de Beaumont et al, 2007; Gouttebarge et al, 2017; Guskiewicz et al, 2005; Lewis et al, 2007; McKee et al, 2009; Stern et al, 2011). Reduced player availability through repetitive concussive injury, or a resulting enhanced incidence of subsequent musculoskeletal injury may also negatively affect team performance across a competitive season (Cross et al, 2016; Drew et al, 2017; Hägglund et al, 2013b; Herman et al, 2016; Nordström et al, 2014; Williams et al, 2016). Understanding the effects and reducing the impact that different elements of concussion history may have on future concussion should therefore be of a high priority to all rugby stakeholders.

Current concussion rehabilitation protocols used by Scottish Rugby and throughout the elite game across the world differ vastly from almost any other type of injury (McCrory et al, 2017). The current system is based around rest, before general exercise intensity is increased with the hope that concussion symptoms do not rematerialize (McCrory et al, 2017). Despite evidence to suggest that co-ordination and neuromuscular control may be impaired post concussive injury (Bussey et al, 2019; Cross et al, 2016; Di Virgilio et al, 2019; Hides et al, 2016; Nordström et al, 2014), no functional co-ordination re-training is offered as part of the return to play process. The fact that neuromuscular deficits from previous concussion may be present beyond a player's return to training and competition (Bussey et al, 2019; Hides et al, 2016; Howell et al, 2018) suggests that either return to play tests, or the rehabilitation process requires reviewing and possible change.

Previous studies have attempted to use various medical technologies to assess recovery from concussion, including serum biomarkers (Shahim et al, 2016; Zetterberg, Morris, Hardy, & Blenow, 2016) electroencephalography (Broglio et al, 2017) and functional magnetic resonance imaging (Arfanakis et al, 2002; Hammeke et al, 2013). However, these methods currently do not possess the necessary sensitivity and specificity to accurately deduce when a player may be completely recovered from concussion (Makdissi et al, 2017). With this in mind, it is suggested that different rehabilitation processes are explored. The current study indicates that individualised concussion recovery protocols may be required. Data suggests that the current return to play protocol may be suitable for players that have experienced zero or one prior concussion, who are diagnosed with minimal symptom score and severity at HIA 2, and who progress through recovery with no exacerbation of symptoms. Data from this study suggests these players would not experience an increased incidence of future concussion by following current recovery protocols. However, as number of prior concussions increases, number/severity of symptoms at HIA 2 increases, and/or prolonged occurrence of symptoms during the recovery period manifest, the data suggests that a longer minimum rehabilitation protocol may be required. From the data presented here, allowing recovery/rehabilitation protocols to extend beyond 14 days in these instances appears to reduce the incidence of subsequent concussion. It is also recommended that all future rehabilitation protocols should include an element of co-ordination re-training, especially under tasks of divided attention to assess neuromuscular deficiency (Cross et al, 2016; Howell et al, 2018).

Extrinsic Risks

Tackling and being tackled were the contact events where match concussions occurred most frequently. Whilst kick contests had the highest propensity of concussion of any contact event, the comparatively fewer occurrences of kick contests compared with tackles resulted in this contact event being responsible for a small number of concussions in this cohort over the 2017/18 and 2018/19 seasons (n = 2).

Similar to previous research, the tackler had a greater propensity of concussion compared to the tackled player (Cross et al, 2019; Tucker et al, 2017a). Tackling is fundamentally an open skill, and the tackling player is almost always reacting to the actions and movement of the ball carrier (Burger et al, 2016; Hendricks & Lambert, 2010). This open nature may increase the likelihood of technical deficiency, which may increase the likelihood of concussion for the tackler compared to the tackled player (Davidow et al, 2018).

Univariate analysis of extrinsic risks to the tackler indicated that the greatest propensity of concussion occurred when the head of the tackling player made initial contact with the ball carrier. Similarly, the propensity of concussion to the tackled player statistically increased if they were initially struck on the head compared to being struck on the torso. These phenomena were expected and agree with previous findings (Cross et al, 2019; Sobue et al, 2017; Suzuki et al, 2019; Tucker et al, 2017a). Correct tackle technique suggests that the tackler should be attempting to make contact with their shoulder between the ball carrier's hips and sternum from a bent at the waist body position, with their head placed beside the ball carrier (Burger et al, 2016; Rugby AU, 2017; Rugby Smart, 2018; Sobue et al, 2017; Tucker et al, 2017b). Previous studies have illustrated tackling in this manner reduces concussive propensity for both tackler and tackled player (Sobue et al, 2017; Suzuki et al, 2019; Tucker et al, 2017b). The data found in the current study reinforces this suggestion. The lowest propensity of concussion for the tackler occurred when they made contact with the ball carrier's torso, using their shoulder/arm, with their head beside, behind, or above the ball carrier. Making initial contact with the ball carrier's head and shoulder/arm, and the tackler placing their head in-front of the ball carrier statistically increased concussion propensity. Likewise, concussion propensity was lowest to the tackled player when they were initially struck on the lower limb and torso, and only statistically increased when they were initially struck on the head. This reinforces that correct tackling technique is necessary to protect both tackling and tackled players.

Interventions by Scottish Rugby or World Rugby aiming to reduce concussion incidence may therefore focus around encouraging correct tackling technique. However, evidence of successful tackling technique interventions is limited. Kerr et al (2018) investigated the efficacy of a World Rugby instructional video on improving tackler technique but found varying results across different player abilities. It appears no educational intervention of correct and safe tackling technique has been implemented within professional rugby. Hendricks et al (2018) have presented a tackling skill training framework for rugby, yet its implementation and efficacy are yet to be studied. The efficacy of this approach in improving tackle technique and reducing tackler concussion propensity requires further exploration, especially in professional rugby.

Interventions may focus on rule changes or harsher sanctions to punish incorrect and poor technique, thereby providing an incentive to use correct technique whilst tackling. Based on recent studies (Cross et al, 2019; Tucker et al, 2017b) harsher sanctions have been applied by World Rugby to disincentivise a tackler from contacting the ball carrier's head (World Rugby, 2019a). Dangerous contact by the tackler to the ball carrier's head now carries a maximum red-card sanction. The current study also found that concussion propensity was statistically increased for the tackler if they struck the ball carrier on the shoulder/arm. This was the second most frequently occurring variable within this risk factor (n = 7,864), and therefore attempting to reduce the frequency of this happening may provide a large opportunity to reduce the number of concussions. By implementing a further rule change to disincentivise the tackler from contacting the ball carrier's shoulder/arm, a reduction in the number of concussions may be seen. However, whilst rule changes have been demonstrated to be effective at reducing injury risk in other sports (Klügl et al, 2010), a trial in 2019/20 to lower the legal tackling height in English Championship rugby to the armpit line aiming to reduce the probability of concussion was not successful. Whilst the number of tackles where contact was made above the ball carrier's armpit line and to the ball carrier's head was reduced, tackler concussion propensity and incidence statistically increased as a result of the law change (Stokes et al, 2021). This illustrates the likely multifactorial aetiology of concussion, and the difficulty in reducing the number of concussions in a sport such as rugby. Regardless, efforts must continue to be made to attempt to reduce the number of concussions, whilst referees should also continue to pay attention to and penalise foul play by the tackler, with data in the current study illustrating an increased probability of concussion to the tackled player when the tackler was judged to perform an illegal tackle by the referee.

Concussion propensity for the tackler statistically increased for what was judged to be moderate and high impact tackles compared with low impact. Concussion propensity for the tackled player also statistically increased in moderate impact tackles compared with low impact, but only a non-statistical increase was found for high impact compared with low impact tackles. The reason for a lack of statistical significance here is unclear, as the majority of previous studies have suggested tackles with greater energy transfer increase concussive propensity for both the tackler and tackled player (Cross et al, 2019; Suzuki et al, 2019; Tucker et al, 2017b). The current study may lack sufficient concussion outcomes to detect a statistical increase in concussion propensity from low to high impact tackles. Impact force was also judged by the primary researcher on a subjective basis. Although kappa statistics suggested good - excellent reliability for subjective impact force judgement, a more valid approach may be to use GPS and accelerometery devices worn by players to accurately quantify tackle impact force. This was not available for the current study, as the validity and reliability of such technology was deemed insufficient (Brennan et al, 2017; Vickery et al, 2014), but is suggested for future work if validity and reliability can be improved.

An associated increase in concussion propensity for tackling and tackled players with an increase in tackle impact force provides a quandary for those interested in minimising concussive propensity in professional rugby union. A successful tackle situation from the attacking or defending team's perspective is often determined by who dominates the collision (Hendricks et al, 2014b; van Rooyen et al, 2014). Players are therefore encouraged and coached to be aggressive in contact situations. The optimal scenario for performance therefore contrasts with the optimal scenario for reduction in concussion propensity. This provides a challenge to rugby stakeholders, to ensure player welfare is not compromised whilst chasing greater performance. Higher impact tackles tend to occur when the tackler is set, and both players accelerate into a front-on tackle (Hendricks et al, 2014a; Seminati et al, 2017). A recent proposal from World Rugby to implement a rugby league style 50:22 kick rule to encourage teams to reduce numbers of players in their defensive line (World Rugby, 2019e) may lead to more passive or side-on tackles, which may reduce impact force and therefore lower concussion propensity (Cross et al, 2019; Hendricks et al, 2014a; Tucker et al, 2017b).

Chapter 3B of this thesis illustrated that collisions were a common mechanism of concussion. The current data illustrated that collision "tackles" non-statistically increased the propensity of concussion compared with shoulder tackles for the tackled player. Collisions in kick contests also possessed the highest propensity of concussion from any contact type. Tucker et al (2017a) similarly demonstrated that kick contests were a high-propensity event for concussion. However, due to their relative infrequent occurrence in matches, little research or intervention to reduce their risk has been undertaken. Current laws are relatively vague around players colliding whilst competing to receive a kick (World Rugby, 2019c). In order to attempt to reduce concussions from this contact type, World Rugby may need to provide more definitive guidelines to protect players in this instance.

The current study found no statistical difference in concussion incidence on scrum cap use for tacklers or those being tackled. This reflects previous research in professional rugby union (Kemp et al, 2008). McIntosh and McCrory (2000) demonstrated that scrum caps are maximally compressed at impact forces below those expected to cause concussion, potentially explaining their null effect on concussion propensity.

Certain extrinsic concussion risk factors such as tackler speed, accelerating into the tackle, tackle direction, body position and tackler legality were not shown to statistically alter concussion propensity for the tackling player in the current study. Similarly, tackler speed, tackled player speed, accelerating into the tackle, tackle direction and body position did not statistically alter concussion propensity for the tackled player. This is somewhat surprising when compared with previous findings. A statistically increased likelihood of concussion has previously been reported for either player when accelerating into the tackle (Cross et al, 2019; Suzuki et al, 2019; Tucker et al, 2017b), or when the tackler approaches the tackle at high speed (Cross et al, 2019; Tucker et al, 2017b). Tucker et al (2017b) also found an increased chance of concussion for the tackler and tackled player when approaching the tackle in upright body positions, and an increased concussion propensity for the tackler when making front-on tackles. Illegal tackle types were shown to increase HIA propensity for either player (Cross et al, 2019), and the tackler (Tucker et al, 2017b), yet were only shown to increase concussion propensity in the current study for the tackled player. The differences between the current study and previous work may have been due to subjective nature of video analysis. Definitions of actions and interpretation of definitions by analysts may differ between studies, limiting validity of inter-study comparisons (den Hollander, Jones, Lambert, & Hendricks, 2018). Recent advancements in this field have resulted in the publication of a rugby union consensus document for video analysis (Hendricks et al, 2020), providing clear descriptions and definitions of key actions to be followed by analysts to improve validity of inter-study comparisons. Unfortunately, this was published after data collection for the current study, and therefore could not be followed. Differences in findings between the current study and previous work may also be due to the relatively small sample sizes in the current study. Although all available concussions and contact events from one men's international team and two men's professional clubs across two full seasons were analysed, this resulted in only 21 concussions to the tackler and 15 to the tackled player available for video analysis from 135 matches and a pool of 78 players. By comparison, Tucker et al (2017a) and Tucker et al (2017b) analysed 335 tackler HIA events and 129 tackled player HIA events from 1,516 matches, whilst Cross et al (2019) analysed 182 concussions from a pool of 2,029 players across three seasons. Larger sample sizes often improve power of epidemiological studies, and improve the likelihood of statistically significant differences being found between groups due to reduced width of confidence intervals (Brooks & Fuller, 2006). It is possible the small sample sizes in the current study resulted in comparatively reduced statistical power and an inability to detect differences in likelihood of concussion outcomes between exposure variables in these instances.

Interaction of Intrinsic and Extrinsic Factors

Intrinsic and extrinsic risk factors which were shown to statistically alter probability of concussion through univariate analysis were entered into regression models for tackling and being tackled to allow for interaction between variables. This was as recommended by the dynamic, recursive model of injury aetiology (Meeuwisse et al, 2007). To the author's best knowledge, this is the first study of its kind in professional rugby to use a regression model to allow for interaction between intrinsic (concussion history) and extrinsic (contact event specific) risk factors for concussion, and report the risk factors which remain statistical influencers on a concussion outcome.

Allowing for interaction between all entered risk factors, the explanatory regression model for the tackling player identified that the largest influence on concussion propensity was their own head making initial contact with the ball carrier, followed by high impact tackles and striking the ball carrier on the head. For the tackled player, once interaction between all risk factors was considered through regression analysis, an illegal tackle by the tackling player had the greatest influence on a concussion outcome, followed by most-recent concussion severity of 8-14 days and being struck on the head by the tackler.

Risk factors which were shown to remain statistical predictors of concussion through regression analysis such as body region used to strike the ball carrier and region struck on the ball carrier for the tackler, and an illegal tackler and being struck on the head by the tackler for the tackled player reaffirms earlier points around interventions to reinforce correct, legal tackling technique. The tackler should aim to use their shoulder/arm region to strike the ball carrier on the torso. Regression analysis in the current study suggests this would present the lowest probability of concussion to both players involved in the tackle. Whether any intervention is based around greater coaching of safe tackle technique, or harsher sanctions for dangerous tackles is open for debate. Recent law changes from World Rugby have increased the sanction for dangerous tackles where the tackling player makes contact with the head of the ball carrier (World Rugby 2019a). Based on results from the current study, including the shoulder region in this bracket may see a further reduction in concussion propensity for the tackling player. Impact forces above what were considered as low also remained variables which statistically increased concussion propensity for the tackler and tackled player through regression analysis. Aforementioned prospective law variations to reduce the number of players in a defensive line may decrease the number of front-on, high impact tackles (World Rugby, 2019e). The data presented suggests this law variation should be trialled, with tackle impact force monitored to assess its validity in reducing concussive propensity in professional rugby.

World Rugby's 2019 law changes around harsher sanctions for contact to the ball carrier's head (World Rugby 2019a) and prospective law variations to reduce the number of players in a defensive line (World Rugby, 2019e) were made based upon the research recommendations of recent concussion aetiology literature. This stated that concussion propensity for both tackler and tackled player were statistically enhanced in tackles where the head of either player was impacted, whilst upright body positions, front-on, high impact tackles also statistically increased concussion probability for either tackler or tackled player, or both (Cross et al, 2019; Tucker et al, 2017a; Tucker et al, 2017b). These studies also developed the rationale for the trial of Stokes et al (2021), who attempted to reduce concussion incidence through a policy change, lowering the legal tackle height from the shoulder to beneath the line of the armpit. However, the unsuccessful outcome from Stokes et al (2021) regarding concussion incidence illustrates the difficulty in reducing the number of concussions in rugby, likely due to the multifactorial aetiology of the injury.

Whilst the current study supports results of previous aetiology studies (Cross et al, 2019; Tucker et al, 2017a; Tucker et al, 2017b) stating that concussion propensity for both tackler and tackled player were statistically enhanced in tackles where the head of either player was impacted, and where impact forces were above that considered as "low", previous studies have neglected the potential modifying effect that individual players' concussion history may have on their susceptibility for concussion. The current study utilised explanatory regression models with data entered by interaction parameters to allow for effect modification between all risk factors entered, aiming to identify risk factors which were statistical influencers on concussion once all entered risk factors were considered simultaneously. Permitting interaction between risk factors allowed for the effect of contact event specific extrinsic risk factors to be analysed with respect to each individual's intrinsic concussion history risk factors, which likely provides a greater validity and context to studying concussion aetiology (Bolling et al, 2018; Fuller & Drawer, 2004; Meeuwisse et al, 2007). In the current study, a most-recent concussion severity of 8-14 days was shown to statistically increase concussion propensity for both the tackler and tackled player through regression analysis. This suggests that the concussion history of each individual may modify their chance of a concussion outcome whilst enduring tackling and being tackled contact situations. This knowledge has ramifications for potential concussion mitigation strategies for both international governing bodies (World Rugby) and national governing bodies such as Scottish Rugby.

It was hypothesised that a most-recent concussion severity of 8-14 days and the associated prolonged/re-emergent symptoms may increase susceptibility of future concussion due to a greater magnitude of tissue damage from the initial injury. Knowledge that this may modify chances of future concussion presents governing bodies with opportunities to mitigate concussion by implementing individualised concussion rehabilitation protocols. For those players who experience prolonged symptoms during initial recovery from concussion, they may benefit from changing to a more gradual rehabilitation process (such as 48-72 hours per stage, and incorporation of an element of co-ordination re-training), rather than continuing to follow the current return to play protocol and attempt to move from stage to stage in the minimum possible time (currently 24 hours) (McCrory et al, 2017, World Rugby, 2017b). Incomplete recovery from previous concussion (resulting in heightened neuronal vulnerability and reduced co-ordination through neurobiological deficits and increased corticomotor inhibition and altered motor unit recruitment) has been hypothesised as an explanation for why prior concussions may impact chances of sustaining a future concussion (Barrett et al, 2014; Bussey et al, 2019; Di Virgilio et al, 2019; Hides et al, 2016; Hollis et al, 2009; Howell et al, 2018). A more gradual rehabilitation process with co-ordination re-training may increase the probability of a more complete recovery, and assist in reducing probability of sustaining a future concussion. Future research may assess how long the influence of the severity of most-recent concussion is present for (and whether re-emergence of any particular symptoms during recovery alter future concussion propensity further). Interaction of this risk factor with time since most-recent concussion, or a regression model based around survival analysis may be required (Kirkwood & Sterne, 2006). Whilst World Rugby and governing bodies should continue to attempt to make the game safer by altering rules and regulations to reduce the occurrence of extrinsic risk factors associated with concussion outcomes, knowledge that individual concussion histories may also influence concussion susceptibility provides greater context to the understanding of concussion aetiology. This also provides an opportunity for national governing bodies such as Scottish Rugby, or international governing bodies such as

World Rugby to potentially trial therapeutic intervention strategies based around individualised rehabilitation protocols which may mitigate concussion risk for repeat concussions.

Univariate analysis suggested a statistically increased risk of future concussion if a player had sustained greater than five previous concussions. However, regression analysis of concussions/1000 tackles suggests that this variable is not a statistical risk factor for players tackling or being tackled. This may be due to the fact that other factors included in both regression models modify the effect of the number of previous concussions, or that the change of exposure variable from hours to tackles alters the effect of the number of previous concussions. Univariate analysis also indicated that HIA 2 symptom score of 6-10 and 11-15 both statistically increased the incidence of concussion, yet this was not the case through regression analysis for tackling or being tackled. Thirteen concussions were recorded for HIA 2 symptom scores of 6-10 and 11-15. However, only five of these concussions were caused by either tackling or being tackled, possibly explaining their lack of impact on regression analysis for these contact types. Six of these concussions were diagnosed with symptoms occurring post game, rather than a single identifiable mechanism during match play. This raises the question of whether a most-recent concussion with a large HIA 2 symptom score may increase the chance of a concussion occurring through multiple sub-concussive impacts. This may be of concern, if no large biomechanical impact is required to induce concussive injury in these instances. Further research to understand susceptibility of future concussion (including mechanism) due to a large number of symptoms recorded during previous HIA 2 may be required.

Limitations

The current study found concussion history factors and extrinsic risks which increased concussion probability through univariate analysis, before using regression analysis to understand concussion aetiology in the context of each individual's concussion history. This was performed by including the intrinsic risk factors around concussion history which were shown to be statistically significant univariate predictors of concussion with the extrinsic risk factors which univariate analysis also suggested were statistical predictors of concussion risk in a regression model for the two contact types responsible for the majority of concussions (tackling and being tackled) (Kirkwood & Sterne, 2006). Not only did this conform with multifactorial injury aetiology models recommended by Meeuwisse (1994) and injury risk factor investigation by Fuller and Drawer (2004) and Bolling et al (2018), but updating concussion history factors on a match-by-match basis allowed for a dynamic, recursive approach to understanding the effect concussion history has on future concussion susceptibility (Meeuwisse et al, 2007). However, the study was not without limitations. Due to the relatively small number of concussions per contact type, there was some evidence of wide effect estimates and confidence intervals. To study for interactions through regression analysis typically requires larger sample sizes than were available in the current study (Kamanger, 2012; Kirkwood & Sterne, 2006). Regression models using categorical variables should have approximately 10 outcomes per variable in the model (Austin & Steyerberg, 2017). In order to fulfil this for the current study, 1,530 matches would be needed to be included, rather than the 135 that were available. This was the maximum number of matches available contested by men's professional rugby in Scotland over the data collection period for this PhD. A larger study with a wider data collection period should increase the statistical power of the current work (Austin & Steyerberg, 2017; Brooks & Fuller, 2006; Kamanger, 2012; Kirkwood & Sterne, 2006), yet such a study was beyond the time constraints imposed by a single PhD research student. However, it is believed that the current study has increased the knowledge around aetiology of concussion in rugby. A larger scale study is likely to be required to confirm the findings of the effect intrinsic risk factors around concussion history can have on the susceptibility of a future concussion outcome. It is recommended to Scottish Rugby that the current investigation is continued over multiple seasons to increase the number of outcomes and improve the statistical power of the study (Austin & Steyerberg, 2017; Brooks & Fuller, 2006; Kamanger, 2012; Kirkwood & Sterne, 2006).

Intrinsic risks included in the current study were based around concussion history. Concussion history was collected from August 2014 onwards. It is therefore not an analysis of lifetime concussions. From limiting data collection from August 2014 onwards, medical records of concussion could be used rather than player recall. Compared with accurate medical records, player recall of concussive injury may lack accuracy and validity (Kerr, Marshall, & Guskiewicz, 2012), suggesting the approach used in the current study was the most appropriate.

Numerous other intrinsic risk factors have also been shown to alter concussion probability, such as neck strength, behaviour and risk inclination, migraines and genetics (Collins et al, 2014; Schneider et al, 2013; Shore & Janssen, 2020; Terrell et al, 2008). The current study aimed to develop explanatory models to illustrate how concussion history interacted with extrinsic risks to alter concussion propensity. Future studies may wish to investigate how other intrinsic risks such as those listed above interact with risks considered in the current study to provide a more global explanation on concussion aetiology in men's professional rugby.

Methodology in the current study relied upon video analysis and subjective interpretation to categorise variables for extrinsic risk analysis. Some previous studies have suggested video analysis may not be a reliable or valid method to study injury aetiology (Andersen, Floerenes, Arnason, & Bahr, 2014; Krosshaug et al, 2007), despite the reliability of the primary researcher found to be good-excellent. In theory a more accurate approach would be to monitor player speed and impact force through GPS and accelerometery, and cranial acceleration through mouthguard or skin patch accelerometery. However, at the start of data collection, these devices were not deemed valid (Brennan et al, 2017; Vickery et al, 2014). As technology advances, it is hoped future research can utilise these tools, and implement this data alongside other intrinsic and extrinsic factors. This may allow a more accurate understanding of risks which influence concussion propensity.

Conclusions

Through univariate analysis, the current study found factors around individual concussion history, and body regions struck in contact, tackle impact force and tackle legality for tackling and tackled players as risk factors for concussion. Explanatory regression models were developed to model concussion aetiology for players tackling and being tackled. Severity of most-recent concussion, body regions struck in contact, tackle impact force and tackle legality remained statistical predictors for concussion. The necessity for correct, safe tackling technique is reinforced, whilst suggestions for changes to current concussion rehabilitation protocols were proposed and discussed, to limit the influence concussion history has on future susceptibility.

The current study highlights key implications for Scottish Rugby and World Rugby. Data presented reinforces the necessity for correct, safe tackling technique. Recent changes implemented by World Rugby have increased sanctions for tacklers making any contact with the head of the ball carrier. The current study suggests this should also include the shoulder to further reduce concussive risk, and to encourage tacklers to aim to contact the ball carrier's torso. Data found in the current study suggested that probability of future concussion may be influenced by details surrounding a player's most recent concussion, in particular the number and severity of symptoms, and the length of the recovery period. Recommendations were made with regards to the current concussion rehabilitation protocol implemented by World Rugby. Although a larger data set may be required to confirm these findings, it is hoped that the possibility of a more conservative rehabilitation protocol, implemented globally by World Rugby, or nationally by Scottish Rugby is explored.

The current study concerned professional male rugby players, and therefore the results cannot necessarily be assumed for all rugby playing populations. Chapter 3A and 3B illustrated that concussion was a common injury for all professional playing groups. It is recommended to Scottish Rugby that further research investigates concussive aetiology in other professional cohorts.

The current thesis chapter was concerned with identifying different intrinsic (concussion history) and extrinsic (contact event specific) risk factors for concussion through univariate analysis, before performing regression analysis of extrinsic and intrinsic risks which were shown by univariate analysis to be statistical predictors of concussion (Kirkwood & Sterne, 2006). This allowed demonstration of whether any interaction effect on concussion outcome existed when intrinsic concussion history and extrinsic contact event specific risk factors were studied simultaneously, providing a greater understanding of total concussive aetiology (Bolling et al, 2018; Fuller & Drawer, 2004; Meeuwisse et al, 2007). This was in-line with the second step of van Mechelen's research model "The sequence of prevention of sports injuries", aiming to further the understanding of concussion mechanisms and aetiology (van Mechelen et al, 1992).

Based on the presented findings, recommendations were made throughout the chapter discussion for methods to limit concussion occurrence. The third step in van Mechelen's research model implies that an intervention, based upon knowledge garnered during steps one and two, be implemented to attempt to reduce the incidence/severity of injury (van Mechelen et al, 1992). However, the majority of suggestions made to reduce concussion outcomes in this chapter target rule or policy changes. Implementing these are beyond the scope of this PhD thesis, although it is hoped that they are considered by rugby stakeholders in the future.

Recent studies have begun to assess the association between greater neck strength and reduced chance of concussion. Collins et al (2014) found that greater neck strength statistically reduced the chance of concussion in a sample of 6,662 high school athletes. Stronger neck muscles may stabilise the head and incorporate the torso as the effective mass, and therefore reduce head acceleration and concussion risk during cranial impact (Broglio et al, 2012; Viano et al, 2007). Due to the fact that being struck on the head was a statistically significant risk factor for concussion in the current study, an intervention to increase neck strength may reduce cranial acceleration during impact, thereby reducing probability of concussion. The following chapter in this thesis will therefore aim to assess the efficacy of a neck training programme targeting improved neck function and reduced concussion incidence. This will be in line with the third and fourth steps of van Mechelen's research model "The sequence of prevention of sports injuries".

END OF CHAPTER 4

CHAPTER 5: NECK MUSCLE FUNCTION AND CONCUSSION INCIDENCE

5.1: Introduction:

The final two steps of van Mechelen's research model "The sequence of prevention of sports injuries" recommend that an intervention be applied to reduce the incidence or severity of injury, and that the effectiveness of said intervention be monitored. Through several acts of United Kingdom Health and Safety legislation, Scottish Rugby have a legal duty to minimise the risks to player welfare to as low a level as practicably possible (Fuller, 1995; HSE, 2001; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992). Scottish Rugby also have a financial interest in improving team performance through greater player availability for selection and reduced injury burden (Drew et al, 2017; Morgan, 2002; Zhang et al, 2003; Williams et al, 2016). Chapter 4 of this thesis illustrated factors around concussion history and extrinsic risks within the game of rugby which statistically altered probability of a concussion outcome. Based on the data presented, suggestions were made for interventions which may reduce probability of concussion in professional rugby. Yet the majority of suggestions targeted rule or policy changes which are beyond the scope of the current PhD thesis. Whilst strict protocol is imposed around concussion diagnosis and management within Scottish Rugby, and professional players are required to participate in compulsory education programmes around concussion recognition, Scottish Rugby currently have no systematic approach to concussion risk mitigation. The need remains for an intervention measure that can be implemented throughout Scottish Rugby which may result in reduced concussion incidence.

Recent studies have begun to investigate the association between enhanced neck strength and reduced chance of concussion. Concussions will occur as a result of direct or indirect force applied to the head, resulting in the sudden acceleration/deceleration of the head and brain (McCrory et al, 2017; Rowson & Duma, 2013). Muscles of the cervical spine are responsible for controlling the acceleration of the head during impulsive loading (Hrysomallis, 2016; Panjabi et al, 1998). The head-neck segment dynamic restraint system may therefore be able to provide protective properties to the head and brain (Mansell et al, 2005). Viano et al (2007) reported that increased neck stiffness reduced peak head acceleration and change in velocity of the head in reconstructed head impacts using a Hybrid III dummy. *In-vivo* neck muscle force production capability may therefore influence probability of sustaining a concussion injury (Hrysomallis, 2016).

Research on measures of neck function in a sporting context have shown positive results. After correcting for gender and sport, neck strength remained a statistical predictor of concussive incidence amongst 6,662 high school athletes (Collins et al, 2014). Athletes who were concussed were shown to have 11-22% less overall neck strength than those who were non-concussed (Collins et al, 2014). Compared with a larger mass, both Newton's second law of motion and the law of energy conservation state a smaller mass will experience greater acceleration for a given force. It is hypothesised that in an anticipated collision, stronger neck muscles may stabilise the head and incorporate the torso as the effective mass (Broglio et al, 2012) This may reduce head acceleration and probability of concussion during impact (Broglio et al, 2012; Eckner et al, 2014; Rowson & Duma, 2013; Viano et al, 2007; Zhang et al, 2004). Enhanced neck muscle force production through resistance training may therefore reduce chance of concussion (Mansell et al, 2005; Viano et al, 2007), with isometric resistance training neck exercises as part of a warm up routine found to reduce incidence of concussion in school-aged (Hislop et al, 2017) and recreational male rugby players (Attwood et al, 2017). However, previous studies using a general strengthening approach to enhance neck muscle strength in elite rugby players have found mixed results.

More specifically, research investigating the impact of five week neck strength programmes have found both statistical improvements (Geary et al, 2014) and no change in maximal voluntary contraction force (Naish et al, 2013). The reasons for inconsistent results are not clear but may be due to methodology of training. An alternative approach to enhancing neck muscle strength is cranio-cervical flexion. Cranio-cervical flexion is a technique which targets increased activation and strengthening of deep cervical flexors (longus colli, longus capitis, rectus capitis anterior, and rectus capitis lateralis) to stabilise the cervical spine (Falla, 2004; Jull, Falla, Vicenzo, & Hodges, 2009; Mayoux-Benhamou et al, 1994) before regular resistance training of more superficial musculature (sternocleidomastoid, anterior scalene and upper trapezius). Cranio-cervical flexion training alongside resistance exercise of superficial muscle was shown to result in improved maximal voluntary contraction force and exercise capacity of the neck when compared with a general strengthening approach in military pilots (Salmon et al, 2013). No study has yet investigated the effectiveness of a neck training programme utilising cranio-cervical flexion to enhance neck muscle function and reduce concussion incidence in elite rugby players.

The aims of the current study were to assess the efficacy of a neck training programme based around cranio-cervical flexion to 1) enhance neck function and 2) reduce match concussion incidence in Scottish Rugby Academy players. This is in-line with the third and fourth steps of van Mechelen's research model "The sequence of prevention of sports injuries". This is intended to provide proof-of-concept of the neck training programme for enhancing neck function and reducing concussion incidence in a controlled setting.

5.2: Methods

5.2.1: Participants

Forty-four Scottish Rugby academy rugby players from East, West, and Borders regions were initially recruited into the study to form the intervention group, and twenty-four rugby players from two Premiership clubs volunteered to act as the control group prior to the start of the 2018/19 season. These groups were not randomly assigned. Although a randomised control design would reduce bias, Scottish Rugby dictated that none of their academy players were to be in a control group. All participants played competitive rugby in the Scottish Premiership and the Scottish Cup. Participants were excluded if they had a recent history of structural or soft-tissue neck injury, determined by discussion with Scottish Rugby physiotherapists (intervention group) and club physiotherapists (control group). Participants provided signed consent to take part in the study (appendix 6). Edinburgh Napier University Ethics Committee provided ethical approval.

All participants were provided with a questionnaire asking them to record the number of concussions they had sustained in the previous three years, time since their most-recent concussion, and severity of the most-recent concussion prior to the study commencement (for example, see appendix 7). The questionnaire contained a definition of concussion, alongside possible symptoms to aid recall of concussive instances, as recommended by Robbins et al (2014).

A sample size calculation was performed to identify the number of participants required (Hazra & Gogtay, 2016). Values from previous research were used to model smallest worthwhile effect (Collins et al, 2014). Using a statistical significance level of

0.05 and power of 80%, it was found that 24 participants per group were needed to observe a worthwhile change in neck function. Fourteen of the original intervention group dropped out of the study, either due to injury during the season (n = 4) or leaving the Scottish Rugby academy programme (n = 10). Four of the original control group left the study, due to either injury and being unable to be tested at the end of the season (n = 2) or moving away from Scotland during the study (n = 2). Table 5.1 presents the participants in each group who completed the study. The control group were statistically older than the intervention group ($p < 0.001$). No other differences were found.

TABLE 5.1: Anthropometric data of participants who completed the study

	n (% Forwards; % Backs)	Age (years)	Height (m)	Mass (kg)	Prior Concussions (n)	Most-Recent Concussion	
						Duration since (months)	Severity (days)
Intervention Group	30 (60%; 40%)	19.0 ± 1.0	1.85 ± 0.08	97.7 ± 12.4	1.1 ± 1.0	19.7 ± 14.1	7.4 ± 7.2
Control Group	20 (65%; 35%)	24.2 ± 2.6*	1.83 ± 0.05	99.7 ± 12.4	1.2 ± 1.4	13.9 ± 10.4	6.0 ± 4.5

Data is mean ± SD. *($p < 0.001$) Control to Intervention Group Age.

5.2.2: Outline

Intervention

Figure 5.1 presents the outline of the study. The intervention group underwent the neck training programme for the duration of one full season. The control group completed no systematic neck training programme. If a participant in the control group began their own neck training, they were to contact the primary researcher - this did not occur. The intervention and control groups were not blinded to treatments.

Outcomes

Neck function for all participants was assessed during pre-season and season-end for the 2018/19 Scottish Premiership season. All testing was completed by the primary researcher. Throughout the season, each participant's match exposure was recorded for Scottish Premiership and Scottish Cup matches. All diagnosed concussions from these matches were reported to the primary researcher, allowing match concussion incidence to be compared between groups.

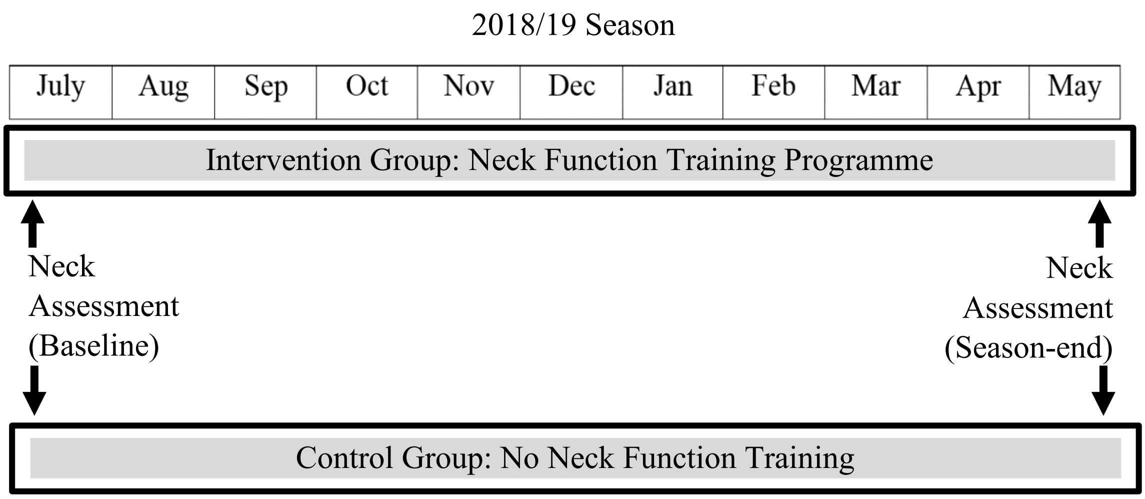

FIGURE 5.1: Study outline throughout the 2018/19 rugby union season

5.2.3: Intervention: Neck Training Programme

The programme was to be implemented twice per week. It was implemented by Scottish Rugby physiotherapy and strength and conditioning staff at each academy location in East, West and Borders regions. Two exercises representing each participant's current level within the programme were chosen per session, with each session totalling ten minutes in duration. Staff judged when a participant had demonstrated adequate ability on their current level and could progress, allowing an individualised approach to training. Participant adherence was monitored at each academy location by staff. Each session, the level the participant was attempting to complete was recorded in adherence sheets. Data from adherence sheets were collected at three month intervals.

The neck training programme was devised in conjunction with Scottish Rugby physiotherapists and strength and conditioning coaches who were assigned to the East region academy. Although this was a controlled trial, and not implemented in a real word setting, recommendations from previous literature were followed to improve chances of the necessary behaviour change required for programme adoption, implementation and maintenance by players and staff (Finch, 2006; DiClemente et al, 2002; Glasgow et al, 1999; McGlashan & Finch, 2010; O'Brien & Finch, 2014; Steffen et al, 2010; Verhagen et al, 2010). The rationale of the programme was clearly explained and presented to staff and players before implementation, with the potential benefits around possible reduced concussion incidence (and subsequent reduced short- and long-term negative sequelae of concussion), and greater player availability for selection and therefore enhanced opportunities for team and personal success identified (Eime, Owen, & Finch, 2004; Finch, 2006, van Tiggelen et al, 2008). The programme was presented in-line with Scottish Rugby's culture of protecting player welfare and maximising player development, with the neck training programme implemented into resistance training and/or injury prevention programmes (Finch, 2006; van Tiggelen et al, 2008). Every effort was made to ensure the programme was professionally promoted, with A4 sheets with photographic examples of each exercise and simple explanation/cues to be placed in gym/physiotherapy departments provided for participant and staff referral (see appendix 8), personal progress and compliance folders provided to each player, and all necessary equipment delivered to each academy location before the intervention began (Eime et al, 2004; Finch, 2006; Hanson et al, 2005). All players at each academy location were to participate in the trial to further improve odds of programme maintenance (Finch, 2006).

To ensure a functionally specific training intervention, the programme was based on recommendations of previous literature around cranio-cervical flexion (Falla, 2004; Jull et al, 2009; Jull, O'Leary, & Falla, 2008; Murray, Lange, Nornberg, Sogaard, & Sjogaard, 2015; Peterson et al, 2015; Revel, Minguet, Gergoy, Vaillant, & Manuel, 1994; Salmon et al, 2013). All physiotherapy and strength and conditioning staff at East, West and Borders academy locations attended a workshop prior to the study commencing and were introduced to the programme and how to instruct the exercises. Staff from each academy were also provided with a magazine booklet, re-emphasising the aims of the programme, exercises, and instructional cues to improve chances of programme uptake and implementation (Eime et al, 2004; Finch, 2006; Glasgow et al, 1999; Hanson et al, 2005). After the initial workshop, meetings were held every three months throughout the 2018/19 season with all academy physiotherapy and strength and conditioning staff to discuss any issues with implementing the programme to aid in maximising programme maintenance (Glasgow et al, 1999).

All participants in the intervention group were first required to learn correct cranio-cervical flexion technique. Beyond this, four physiological strands were targeted: endurance, strength, perturbation and proprioception. The programme was entirely progressive with increasing levels of difficulty within each strand. Progression through the programme and different strands is presented in figure 5.2. The control group had no access to the training programme.

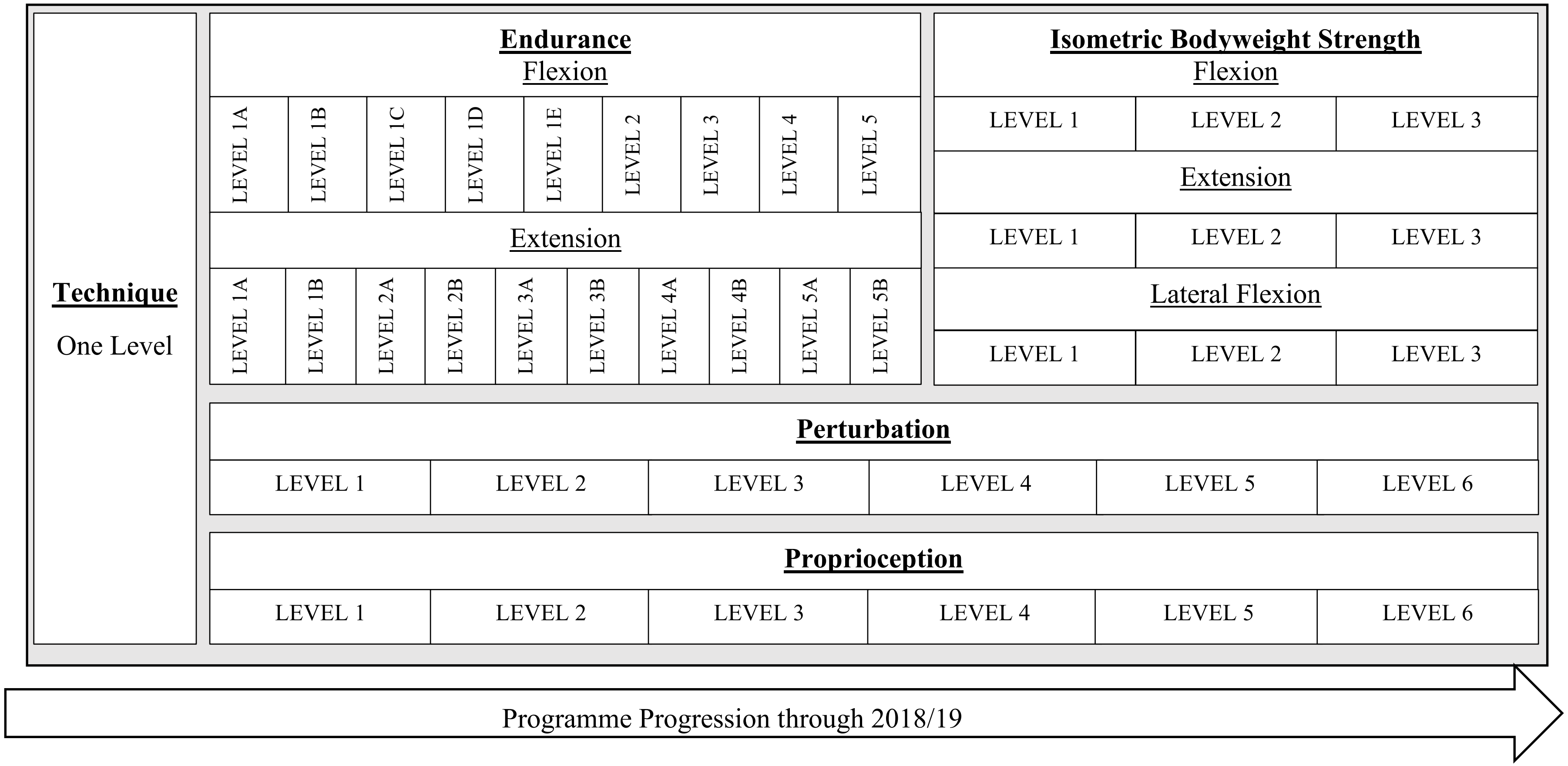

FIGURE 5.2: Neck training programme progression through the 2018/19 season

Cranio-cervical flexion technique was taught as described by Jull et al (2009). With the participant lying supine, they were instructed to gently nod as if saying “Yes” and concentrate on the back of the head sliding on the supporting surface, aiming for sagittal rotation rather than cervical retraction. Once the bottom position of the nod movement could be achieved with minimal superficial musculature activation (judged by the attending physiotherapist), participants could progress to a test to determine what level of flexion endurance they were to begin training at. Remaining supine, a sphygmomanometer cuff was placed behind the neck, abutting the occipital bone and inflated to 20 mmHg (figure 5.3). Participants were to move into a cranio-cervical flexion position and concentrate on the pressure change on the feedback dial of the sphygmomanometer as cervical lordosis flattened to increase the pressure on the cuff. With 5 seconds rest between each repetition, the participant was to perform an isometric hold in cranio-cervical flexion of increasing magnitudes of pressure on the cuff of 22, 24, 26, 28, and 30 mmHg. Once the participant failed to use correct cranio-cervical flexion technique (over-activation of superficial musculature, use of cervical retraction, or lack of movement control) to maintain the prescribed pressure, the test was stopped. Flexion endurance training for each participant began at the level of the last successfully completed pressure during this test (table 5.2).

FIGURE 5.3: Placement of sphygmomanometer cuff behind neck during cranio-cervical flexion task

The same set-up and instructions were provided for the exercises in table 5.2 as described above. On their prescribed level, participants were to control the correct pressure on the sphygmomanometer cuff for ten 10 second isometric holds in cranio-cervical flexion position. Once the attending physiotherapist decreed the level was completed with satisfactory technique, the participant progressed to the next level (table 5.2). For level four and five, the participant was instructed to maintain cranio-cervical flexion whilst inducing a head lift off the supporting surface.

TABLE 5.2: Progression through neck flexion endurance training

Level	Load	Sets/Rest
1A	22 mmHg	10 x 10 s; 10 s rest
1B	24 mmHg	10 x 10 s; 10 s rest
1C	26 mmHg	10 x 10 s; 10 s rest
1D	28 mmHg	10 x 10 s; 10 s rest
1E	30 mmHg	10 x 10 s; 10 s rest
2	30 mmHg	6 x 15 s; 10 s rest
3	30 mmHg	3 x 30 s; 20 s rest
4	Head	6 x 15 s; 10 s rest
5	Head	3 x 30 s; 20 s rest

Neck extension endurance was commenced once correct cranio-cervical flexion technique had been learned. This was a weighted isometric hold lying in a prone position. Participants were to maintain a neutral spine and concentrate on holding a cranio-cervical flexion position throughout the hold. Participants progressed once attending physiotherapy staff were satisfied the level could be completed with correct technique. All participants began at level 1A in table 5.3.

TABLE 5.3: Progression through neck extension endurance training.

Level	Load (kg)	Sets/Rest
1A	5.0	3 x 30 s; 20 s rest
1B	5.0	3 x 45 s; 30 s rest
2A	6.25	3 x 30 s; 20 s rest
2B	6.25	3 x 45 s; 30 s rest
3A	7.5	3 x 30 s; 20 s rest
3B	7.5	3 x 45 s; 30 s rest
4A	8.75	3 x 30 s; 20 s rest
4B	8.75	3 x 45 s; 30 s rest
5A	10.0	3 x 30 s; 20 s rest
5B	10.0	3 x 45 s; 30 s rest

Isometric body weight strength training was progressed to once both flexion and extension endurance training had been completed, and consisted of three progressive levels for neck flexion, extension, and lateral flexion (left and right). Participants were to remain in a cranio-cervical flexion position throughout exercises to maintain activation of deep cervical flexors. Progressions for neck flexion (figure 5.4), neck extension (figure

5.5), and lateral flexion (figure 5.6) are shown below. To complete each level, participants had to be able hold each position correctly for 3 sets of 30 s isometric holds, with 30 s rest.

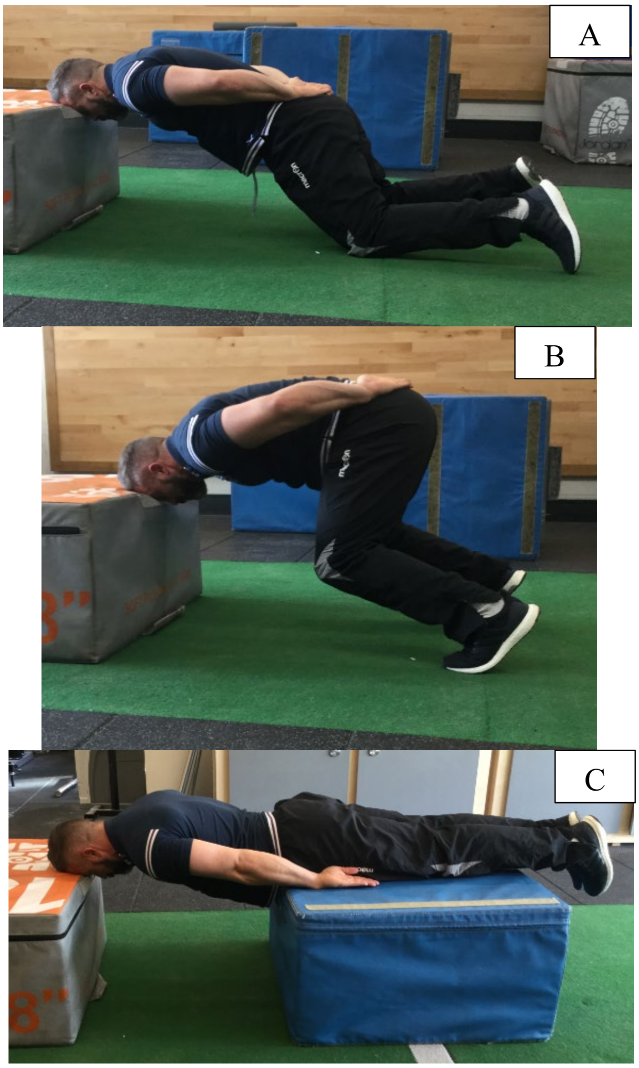

FIGURE 5.4: Progression of neck flexion isometric body weight exercise through position A, B, and C.

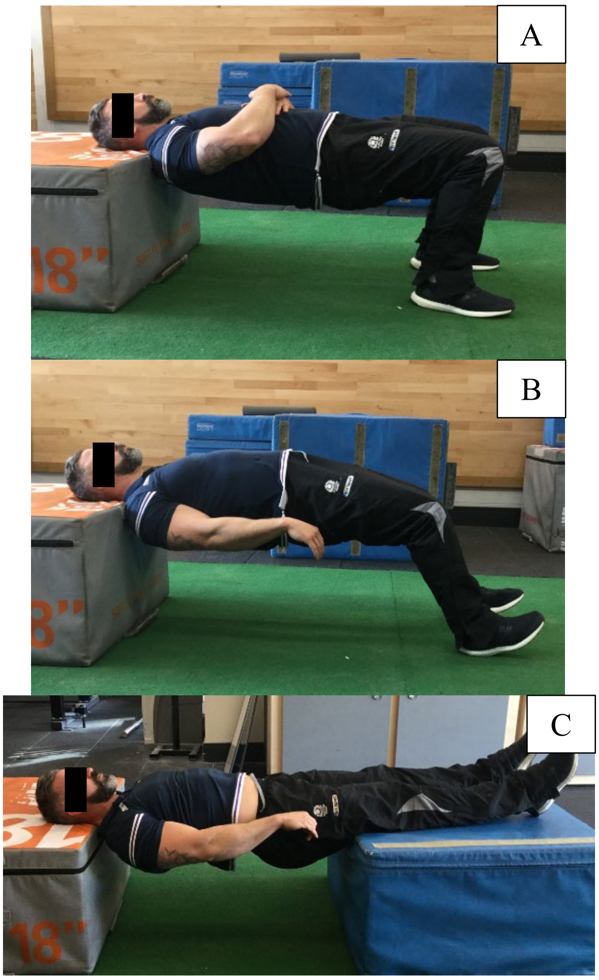

FIGURE 5.5: Progression of neck extension isometric body weight exercise through position A, B, and C.

FIGURE 5.6: Progression of lateral neck flexion isometric body weight exercise through position A and B. Image A shows exercise level one and two - For level one, the foam padding was placed at shoulder/neck height. For level two, the foam was placed at elbow/upper arm height to increase load.

Perturbation exercises were programmed to begin once correct cranio-cervical flexion technique had been achieved. Exercises were developed where participants were to maintain cranio-cervical flexion in a variety of body positions whilst resisting impulse forces to the head. Progression of perturbation exercises used are shown in figure 5.7 below. Four sets of 10 - 20 s work (10 - 20 s rest) were to be completed.

FIGURE 5.7: Progression of neck perturbation exercises from A through to F.

Neck proprioception was introduced once adequate cranio-cervical flexion technique had been achieved. Participants were to wear a scrum cap, on top of which a laser pen device had been affixed. In a variety of positions to progressively increase difficulty, participants were to perform cranio-cervical flexion and trace the projection of the light beam through different targets on printed screens 3 m away. Examples of exercise used are shown in figure 5.8 below.

FIGURE 5.8: Examples of neck proprioception exercises

5.2.4: Outcomes

Neck Assessment

Evaluation of neck proprioception, neck strength, and neck endurance were undertaken during each neck assessment. All equipment was transportable, allowing testing to be completed in different locations.

Neck proprioception was assessed using the cervicocephalic relocation test (Pinsault et al, 2008; Revel et al, 1994). The participant was seated in a custom-made strength chair facing an A1 sheet of paper. A scrum cap, on top of which was affixed a laser pen pointing directly forward, was worn by the participant (figure 5.9). The participant was to sit in a neutral posture, with head in a cranio-cervical flexion position and vision occluded. When this was achieved, the point of the laser beam upon the A1 sheet was marked, indicating the reference position. After 2-3 seconds of concentration on this position, the participant performed a maximal rotation of their head to the right and attempted to relocate back into the reference position.

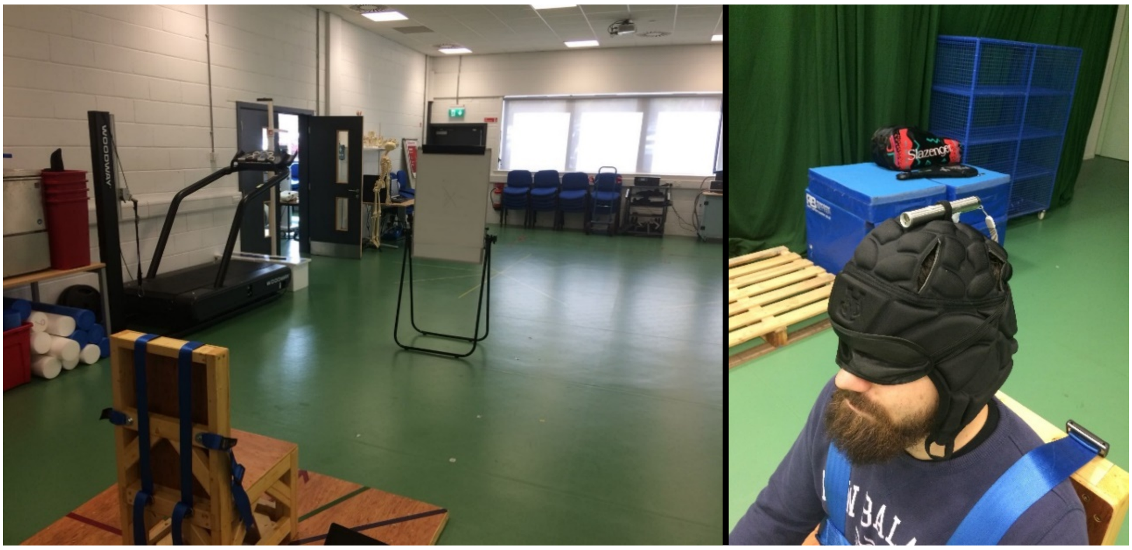

FIGURE 5.9: Set-up for the cervicocephalic relocation test

When the participant believed they had relocated the reference position, the point of the laser beam on the A1 sheet was marked, and the participant's head was returned to the true reference position. Ten trials were performed after head rotation to the right, and ten to the left. No speed instruction was provided to the participant for head rotation.

Each marked location of the beam on the A1 sheet was measured in terms of horizontal and vertical displacement from the reference position (see figure 5.10). The distance between laser pen and the A1 sheet of paper was measured to allow displacement error on the A1 sheet to be converted into angular displacement error of the head in the horizontal and vertical plane. Neck proprioception was assessed in both planes as absolute error (°) and variable error (°) (Schmidt, Allen, & Lee, 2011). The cervicocephalic relocation test possesses intraclass correlation coefficients of 0.52-0.81 and 0.49-0.77 for absolute and variable error respectively (Pinsault et al, 2008).

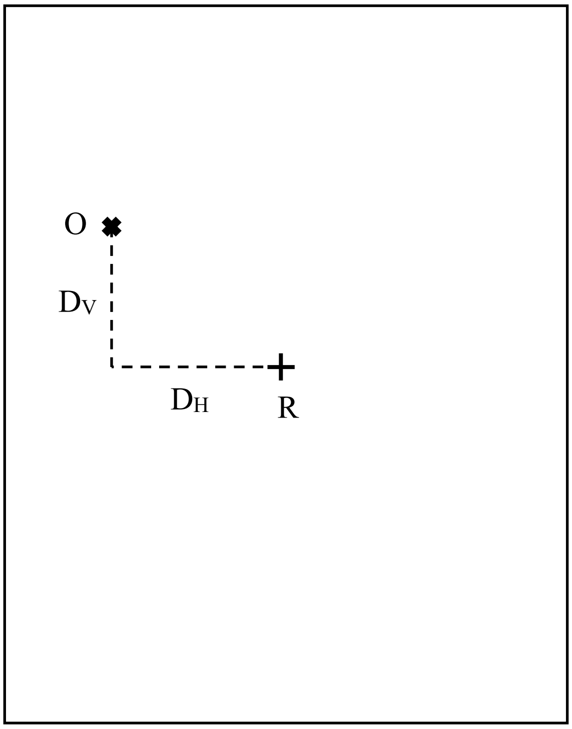

FIGURE 5.10: Measuring results from the cervicocephalic relocation test. "R" is the reference position of the participant in a neutral position. "O" refers to the laser beam falling on the A1 sheet after a single trial. D_V and D_H refers to the vertical and horizontal displacement from the reference position. Trigonometry allowed calculation of angular displacement of the head from this data.

Neck strength was assessed by measuring participant Isometric Maximum Voluntary Contractions (IMVC) using a handheld dynamometer (MicroFet 3; Hoggan Scientific, Salt Lake City, UT). Participants remained seated in the custom-built strength chair in an upright neutral position with arms folded across their chest. Participants were secured to the chair by seat-belt straps to prevent any extraneous torso movement, allowing isolated neck strength assessment (Strimpakos, 2011) (figure 5.11). The strength chair was secured to a 1.5 x 1.5 m platform to prevent slipping movement of the chair during force application by participant.

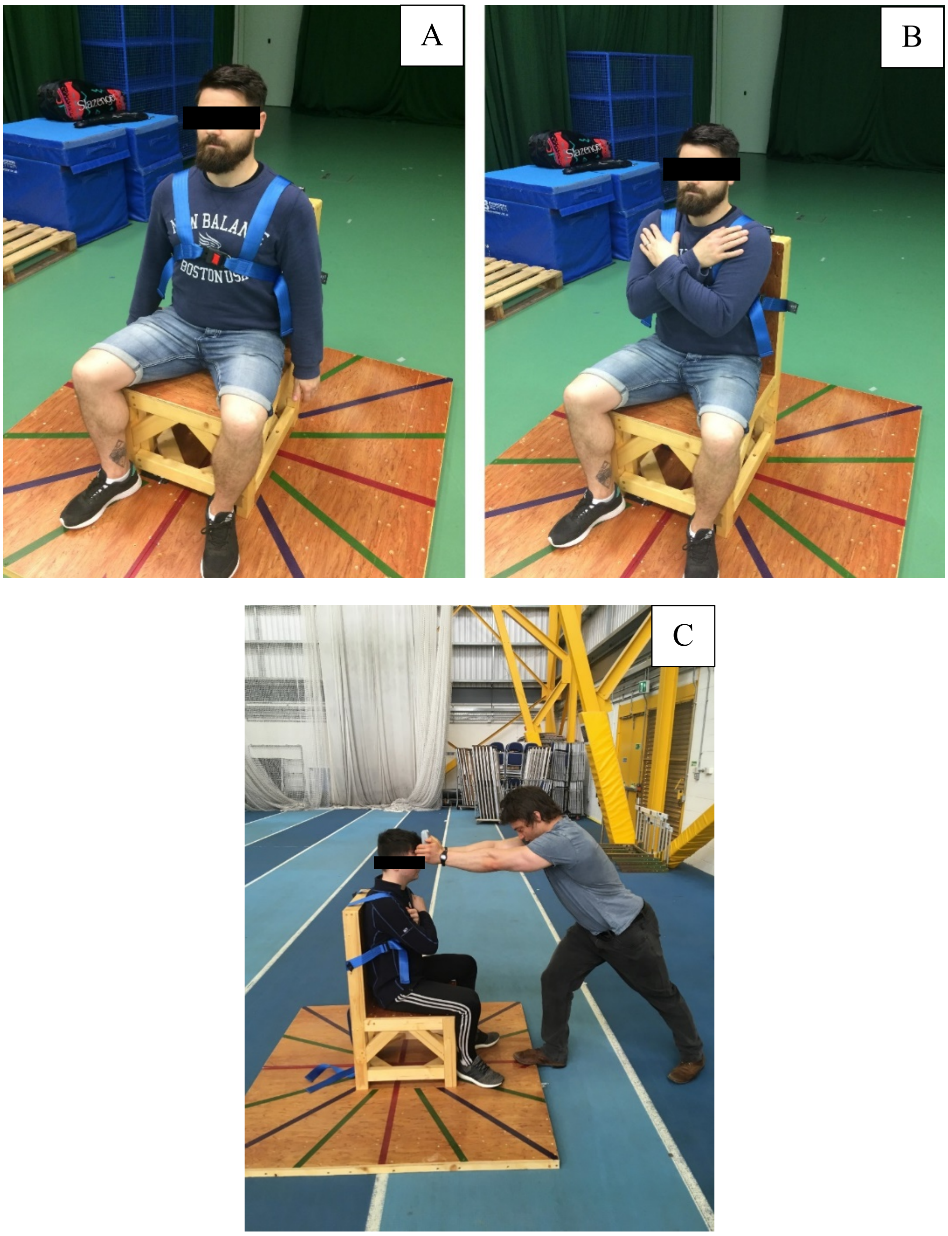

FIGURE 5.11: A: Participant strapped into strength chair. B: Participant in correct testing position. C: Participant undergoing neck function assessment.

A warm-up of cervical spine range of motion and graduated effort IMVCs in flexion, extension and left and right lateral flexion preceded the first trial (Geary et al, 2014). Assessment followed an abbreviation of the Melbourne protocol, in which neck IMVC strength was assessed in four directions in the following order: flexion; left flexion; extension; and right flexion (Hildenbrand & Vasavada, 2013). With the participant's head in cranio-cervical flexion position, they were instructed to gradually increase force production against the handheld dynamometer over a 3 s period to reduce risk of injury or measurement error due to any ballistic movement (Salmon, Sullivan, Handcock, Rehrer, & Niven, 2018) before a 3 s maximal isometric contraction. The handheld dynamometer was placed in the centre of the participant's forehead to assess flexion, 2 cm above the occipital protuberance for extension, and 2 cm above each ear for lateral flexion. A 10 s rest period was provided between flexion, left flexion, extension and right flexion trials, and a 2 minute rest period was observed before repeating the procedure twice more. The dynamometer recorded force application at 100 Hz, and the maximum value (newtons) measured in each direction was taken as the peak isometric force. Intraclass correlation coefficients (3,1) were calculated for intra-rater repeated measures reliability for the primary researcher. Values for each testing direction are presented in table 5.4.

TABLE 5.4: ICC (3,1) values for neck IMVC peak force assessments

Assessment	ICC (3,1)
Flexion MVC	0.91
Left Flexion MVC	0.88
Extension MVC	0.82
Right Flexion MVC	0.87

Neck muscle endurance was assessed by a single isometric exercise capacity trial to task fatigue in both flexion and extension. Participants remained seated and strapped to the custom-built strength chair as described previously. From a cranio-cervical flexion position, participants were to maintain an isometric force of 80 ± 5% of the pre-recorded IMVC force (in the appropriate direction) for as long as possible (Salmon, Handcock, Sullivan, Rehrer & Niven, 2015). For the assessment at season-end, target force was matched to the participant's baseline assessment. Task fatigue was assumed when participants could no longer maintain 80 ± 5% IMVC force for 4 s (Salmon et al, 2015), or had moved out of neutral cranio-cervical flexion position. Force production could only be seen by the tester, and therefore verbal feedback of force production was constantly provided to the participant. A two minute rest period was provided between the flexion and the extension trial. Intraclass correlation coefficients (3,1) were calculated for intra-rater repeated measures reliability: 0.79 (flexion); and 0.92 (extension).

Match Concussion Incidence

Participant match exposure from the Scottish Premiership and Scottish Cup across the 2018/19 season was recorded. Participant match exposure from outside these matches and training exposure were not included in this study. Match exposure was as defined as "Play between two teams" (Fuller et al, 2007d). Match exposure was recorded as the exact time participants spent on the pitch, from kick-off/when they first appeared as a substitute, up until the final whistle/leaving the pitch to be replaced by a substitute. Time spent off the pitch due to half-time, yellow/red cards or blood injury was not counted as exposure. Video analysts at Scottish Rugby recorded participant match exposure for all teams in the Scottish Premiership and Scottish Cup throughout the 2018/19 season.

Certified medical personnel (doctor or physiotherapist) are required to be at each Scottish Premiership or Scottish Cup match by Scottish Rugby. These personnel diagnosed concussion based on medical opinion and the sport concussion assessment tool (SCAT) (version 3 or 5). Weekly contact with club and Scottish Rugby medical staff ensured all match concussions sustained were recorded by the primary researcher. Any concussions sustained in training (intervention group n = 0; control group n = 1) or matches outwith the Scottish Premiership or Scottish Cup (both groups n = 0) were not included in this study.

Although match and training exposure and concussions sustained outwith Scottish Premiership and Scottish Cup matches were not included in the study, training and match exposure between the two groups differed. This was by nature of the intervention group being composed entirely of Scottish Rugby Academy players, who are professionally contracted with Scottish Rugby. These players therefore complete on-pitch training multiple times per week, in addition to the bi-weekly training that Premiership club players (i.e., those in the control group) participate in. By nature of their inclusion in the Scottish Rugby Academy and therefore greater playing ability, a large proportion of participants in the intervention group were also selected for age group international representation matches and training throughout the 2018/19 season, whereas no control group participants were selected for these matches and training. Rugby exposure through training or match play may result in strength adaptations to neck muscle (Salmon et al, 2018), which may then have a confounding effect on reported changes in neck muscle strength across the data collection period. Rugby exposure also has the possibility of a concussion outcome, and therefore a concussion sustained in rugby outwith the exposure recorded in the current study may increase susceptibility of match concussion in the future (Hollis et al, 2009), possibly also causing a confounding effect on reported match concussion incidence in the current study. However, the single concussion sustained outwith the recorded rugby exposure in the current study did not cause a repeat concussion for this participant.

5.2.5: Data Analysis

Changes in neck function between the two groups (intervention vs. control) from baseline to season-end were assessed by two-way repeated measures analysis of variance (ANOVA) using a statistical software package (IBM SPSS statistics for Windows Version 26) (IBM, Armonk, New York, USA). If significant interaction was found between groups over time, dependent sample *t*-tests were used to assess for differences from baseline to season-end for each group. A value of $p \leq 0.05$ was considered statistically significant, yet due to several statistical tests being conducted throughout this chapter (and therefore increased chance of type I error) (Armstrong, 2014), exact *p* values are reported to allow for evaluation certainty to be interpreted (unless $p < 0.001$) (Streiner & Norman, 2001; Rothman, 1990). Unless otherwise stated, all data were normally distributed (Shapiro-Wilk $p > 0.05$), presented with no outliers (data points greater than 1.5 box-lengths from the edge of the box), and presented homogeneity of variances (Levene's test of homogeneity of variances $p > 0.05$) and covariances (Box's M test $p > 0.001$). If data underwent a transformation to meet assumptions required for analysis, data has been back-transformed before reported in text and figures (Bland & Altman, 1996). Data are reported as mean ± standard deviation. In order to obtain standard deviations of back-transformed data, 95% confidence intervals (CI) for the transformed scale were back-transformed to the original scale (Bland & Altman, 1996), before standard deviations were calculated as below:

$$\text{Standard Deviation} = \sqrt{n} * (\text{upper limit} - \text{lower limit})/v$$

Where n = sample size, and v = value obtained from tables of the *t* distribution with degrees of freedom equal to the sample size minus 1 (Higgins & Deeks, 2011). When reporting mean differences for transformed data, differences in back-transformed means are reported, with standard deviations based on mean differences from the original scale.

Incidence of concussion was reported per 1000 player match hours for each group with 95% CI calculated as described in Chapters 3A and 3B (van Belle et al, 2004). The incidence of concussion between groups was compared by incidence rate ratio (IRR) and 95% CI according to the Poisson distribution (Kirkwood & Sterne, 2006). A statistical finding was assumed if 95% CIs did not include 1.00.

5.3: Results

Isometric Maximal Voluntary Contraction

One participant could not complete neck isometric maximal voluntary contraction (IMVC) and exercise capacity assessment at season-end due to neck pain. Data for a further three participants was not collected for neck extension exercise capacity assessment, two due to neck pain and one due to equipment error. These participants' data is excluded where it is not available but included in other analyses.

Figure 5.12 presents neck flexion IMVC force for baseline and season-end for the intervention and control groups. There was a statistical interaction between groups and time on flexion IMVC (intervention group mean difference: 86.8 ± 46.4 N, control group mean difference: 54.6 ± 38.0 N): $F_{(1, 47)} = 6.543$; $p = 0.014$; partial $\eta^2 = 0.122$. The main effect of time reported a statistical difference in mean flexion IMVC at the different time points: $F_{(1, 47)} = 126.808$; $p < 0.001$; partial $\eta^2 = 0.730$. Dependent samples *t*-tests found that the intervention group (222.1 ± 39.5 N) to (308.9 ± 41.7 N) $t_{(28)} = -10.066$, $p < 0.001$ (2-tailed) and the control group (250.2 ± 45.7 N) to (304.8 ± 46.9 N) $t_{(19)} = -6.435$ $p < 0.001$ (2-tailed) both statistically increased flexion IMVC from baseline to season-end.

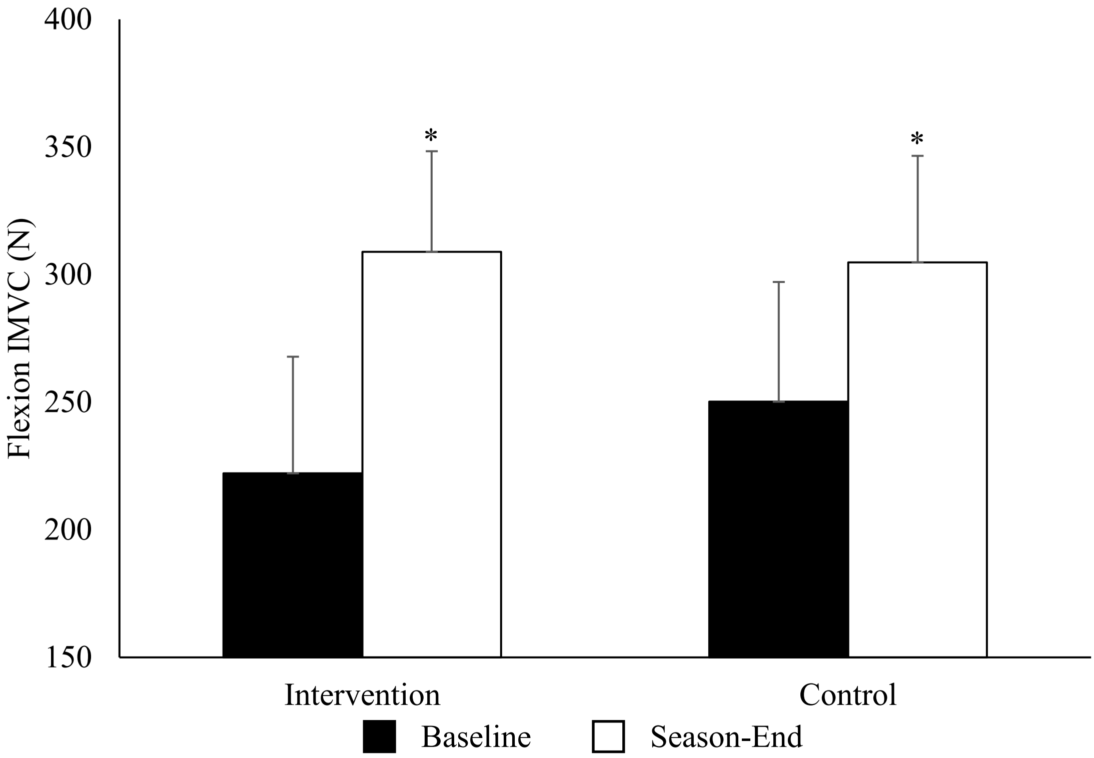

FIGURE 5.12: Flexion IMVC force for baseline and season-end for intervention and control groups. ($p = 0.014$) interaction between groups and time. *($p < 0.001$) season-end to baseline.

Figure 5.13 presents neck left flexion IMVC force for baseline and season-end for the intervention and control groups. There was a statistical interaction between groups and time on left flexion IMVC (intervention group mean difference: 41.6 ± 37.8 N, control group mean difference: -10.5 ± 36.0 N): $F_{(1, 47)} = 23.358$, $p < 0.001$, partial $\eta^2 = 0.332$. The main effect of time reported a statistical difference in mean left flexion IMVC at the different time points: $F_{(1, 47)} = 8.348$, $p = 0.006$; partial $\eta^2 = 0.151$. Dependent sample *t*-tests found that the intervention group statistically improved left flexion IMVC force from baseline (195.7 ± 41.6 N) to season-end (237.3 ± 46.3 N): $t_{(28)} = 5.933$; $p < 0.001$ (2-tailed). No statistical change was found for the control group for baseline (237.5 ± 48.8 N) to season-end (227.0 ± 33.3 N): $t_{(19)} = -1.300$ $p = 0.209$ (2-tailed).

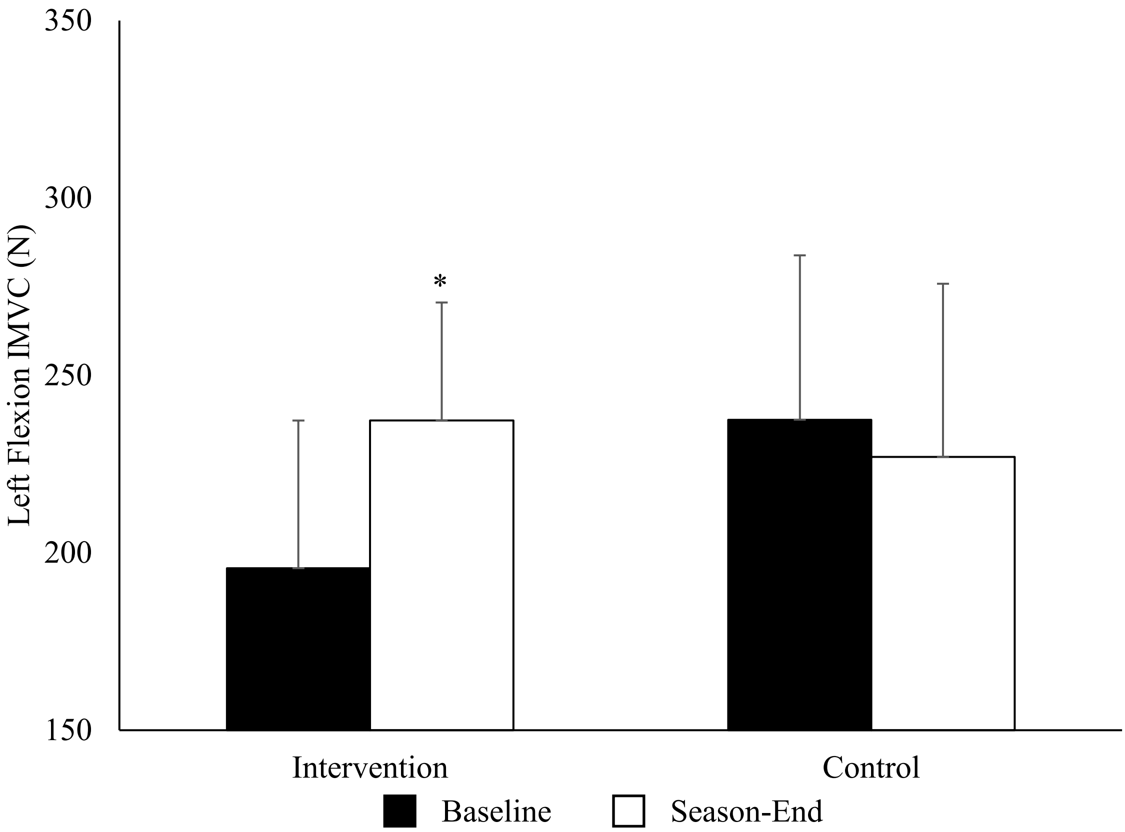

FIGURE 5.13: Left flexion IMVC force for baseline and season-end for intervention and control groups. ($p < 0.001$) interaction between groups and time. *($p < 0.001$) season-end to baseline.

Figure 5.14 presents neck extension IMVC force for baseline and season-end for the intervention and control groups. There was one outlier when assessing raw data and one data set followed a non-normal distribution. A Log10 transformation was applied which removed the outlier and amended all data sets to follow a normal distribution. There was a statistical interaction between groups and time on extension IMVC (intervention group mean difference: 126.1 ± 69.2 N, control group mean difference: 59.8

± 51.5 N): $F_{(1, 47)} = 13.400$; $p < 0.001$; partial $\eta^2 = 0.222$. The main effect of time reported a statistical difference in mean extension IMVC at the different time points: $F_{(1, 47)} = 85.396$; $p < 0.001$; partial $\eta^2 = 0.645$. Dependent samples *t*-tests found that the intervention group (256.9 ± 62.8 N) to (383.0 ± 61.8 N) $t_{(28)} = -9.066$, $p < 0.001$ (2-tailed) and the control group (316.7 ± 70.2 N) to (376.5 ± 59.6 N) $t_{(19)} = -4.513$ $p < 0.001$ (2-tailed) both statistically increased extension IMVC from baseline to season-end.

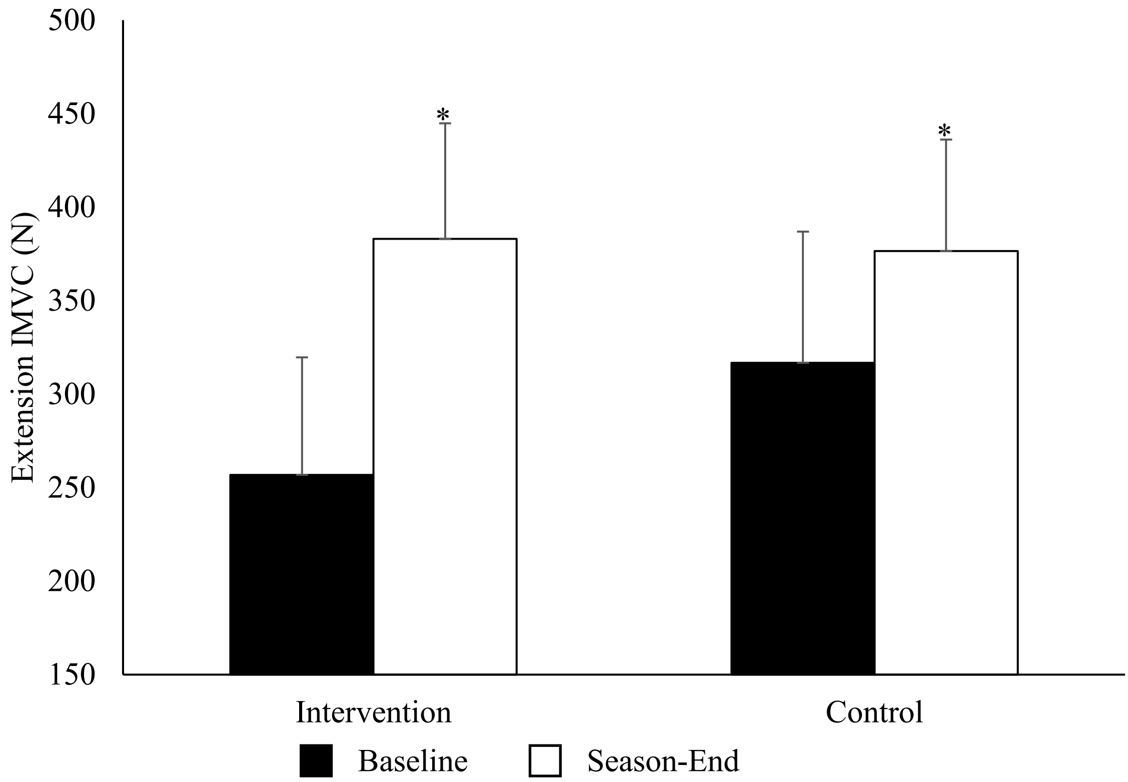

FIGURE 5.14: Extension IMVC force for baseline and season-end for intervention and control groups. ($p < 0.001$) interaction between groups and time. *($p < 0.001$) season-end to baseline.

Figure 5.15 presents neck right flexion IMVC force for baseline and season-end for the intervention and control groups. There were two outliers when assessing the raw data, and one data set followed a non-normal distribution. A square root transformation was applied which removed all outliers and amended all data sets to follow a normal distribution. There was a statistical interaction between groups and time on right flexion IMVC (intervention group mean difference: 48.2 ± 31.1 N, control group mean difference: 9.5 ± 29.6 N): $F_{(1, 47)} = 18.295$; $p < 0.001$; partial $\eta^2 = 0.280$. The main effect of time reported a statistical difference in mean right flexion IMVC at the different time points: $F_{(1, 47)} = 40.113$; $p < 0.001$; partial $\eta^2 = 0.460$. Dependent sample *t*-tests found that the intervention group statistically improved right flexion IMVC force from baseline (188.8 ± 40.0 N) to season-end (237.0 ± 43.7 N): $t_{(28)} = -8.334$; $p < 0.001$ (2-tailed). No statistical change was found for the control group for baseline (215.4 ± 47.1 N) to season-end (224.9 ± 33.2 N): $t_{(19)} = -1.330$ $p = 0.199$ (2-tailed).

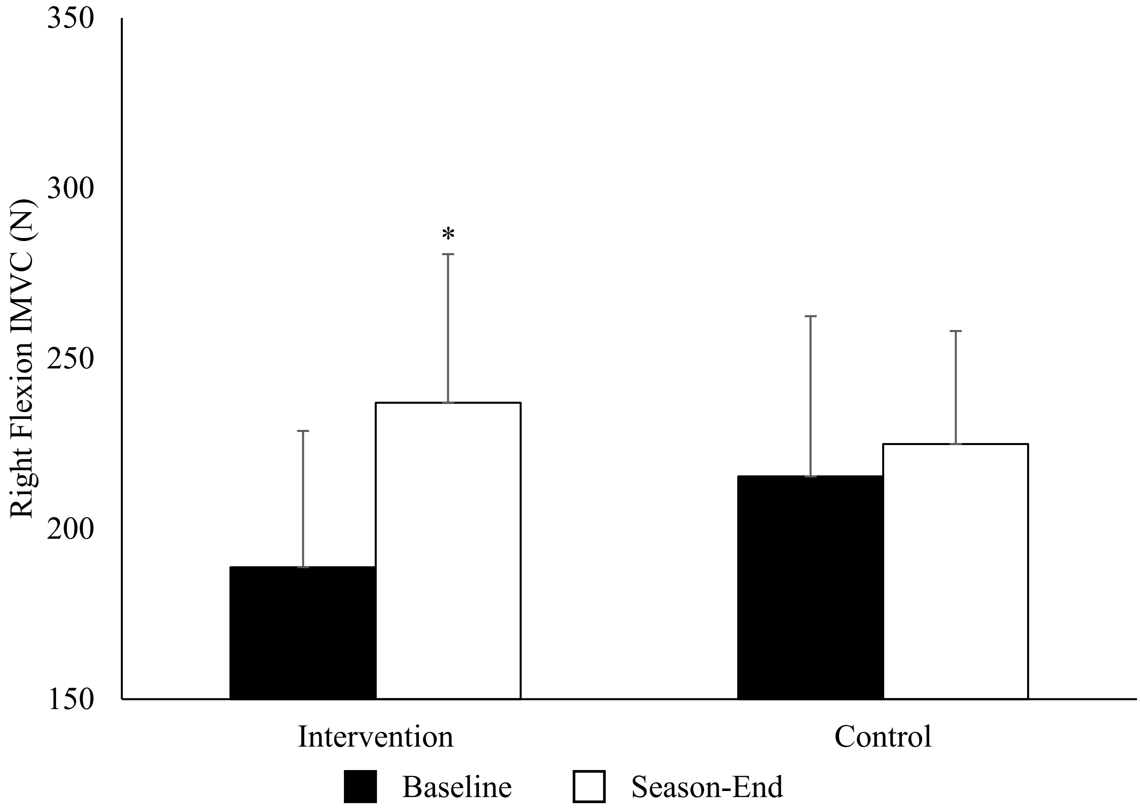

FIGURE 5.15: Right flexion IMVC force for baseline and season-end for intervention and control groups. ($p < 0.001$) interaction between groups and time. *($p < 0.001$) season-end to baseline.

Exercise Capacity

Figure 5.16 presents neck flexion exercise capacity for baseline and season-end for the intervention and control groups. There were five outliers when assessing raw data. No transformations reduced the effect of outliers, therefore raw data was used for analysis. There was a statistical interaction between groups and time on neck flexion exercise capacity (intervention group mean difference: 17.1 ± 14.4 s, control group mean difference: 2.2 ± 9.1 s): $F_{(1, 47)} = 19.555$; $p < 0.001$; partial $\eta^2 = 0.294$. The main effect of time reported a statistical difference in mean flexion exercise capacity at the different time points: $F_{(1, 47)} = 21.637$; $p < 0.001$; partial $\eta^2 = 0.315$. Dependent sample *t*-tests found that the intervention group statistically improved flexion exercise capacity from baseline (15.1 ± 11.9 s) to season-end (32.3 ± 15.5 s): $t_{(28)} = -6.413$; $p < 0.001$ (2-tailed). No statistical change was found for the control group from baseline (21.4 ± 10.7 s) to season-end (23.6 ± 13.1 s): $t_{(19)} = -1.095$ $p = 0.287$ (2-tailed).

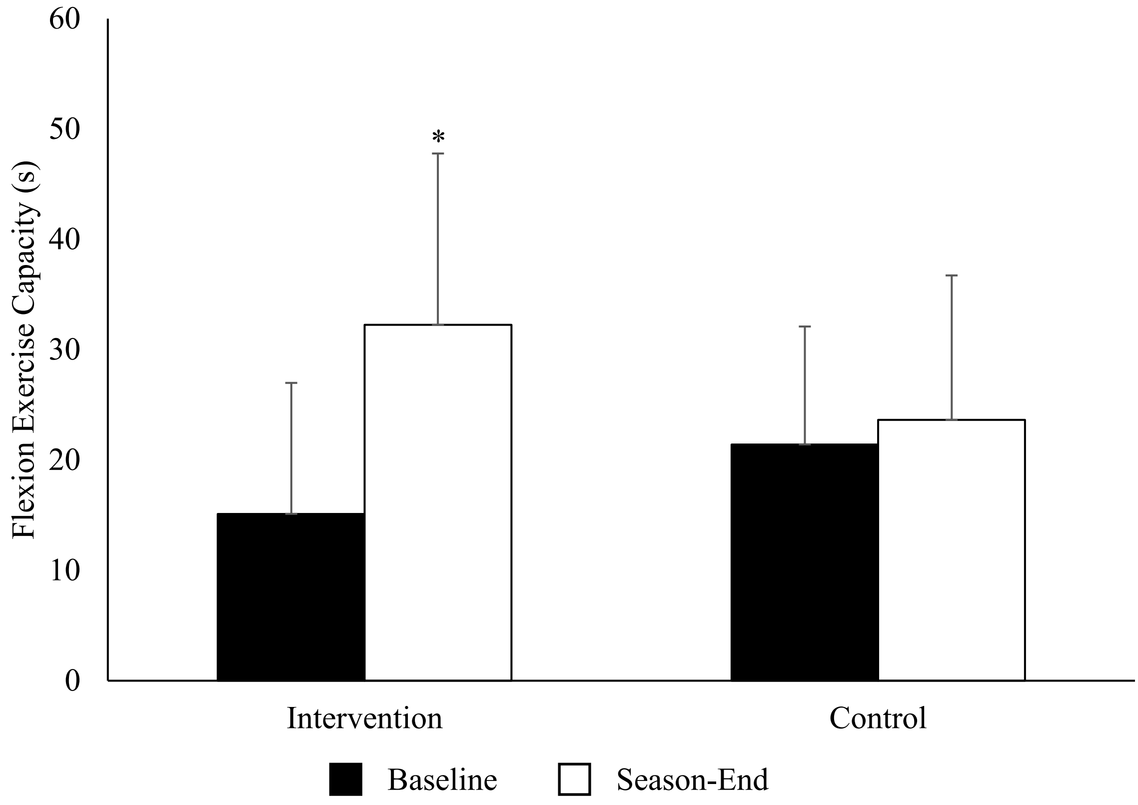

FIGURE 5.16: Neck flexion exercise capacity for baseline and season-end for intervention and control groups. ($p < 0.001$) interaction between groups and time. *($p < 0.001$) season-end to baseline.

Figure 5.17 presents neck extension exercise capacity for baseline and season-end for the intervention and control groups. When assessing raw data, there were several outliers. All data followed a non-normal distribution. A square root transformation reduced outliers to two, and amended all distributions to normal. No other transformation attempted improved data beyond this state. There was no statistical interaction between the two groups and time on extension exercise capacity: $F_{(1, 44)} = 2.856$; $p = 0.098$; partial $\eta^2 = 0.061$. The main effect of time reported a significant difference in extension exercise capacity at the different time points: $F_{(1, 44)} = 17.717$; $p < 0.001$, partial $\eta^2 = 0.287$. Bonferroni post-hoc corrections demonstrated a statistical increase in extension exercise capacity from baseline (22.3 ± 17.3 s) to season-end (37.4 ± 35.2 s; $p < 0.001$) across both groups.

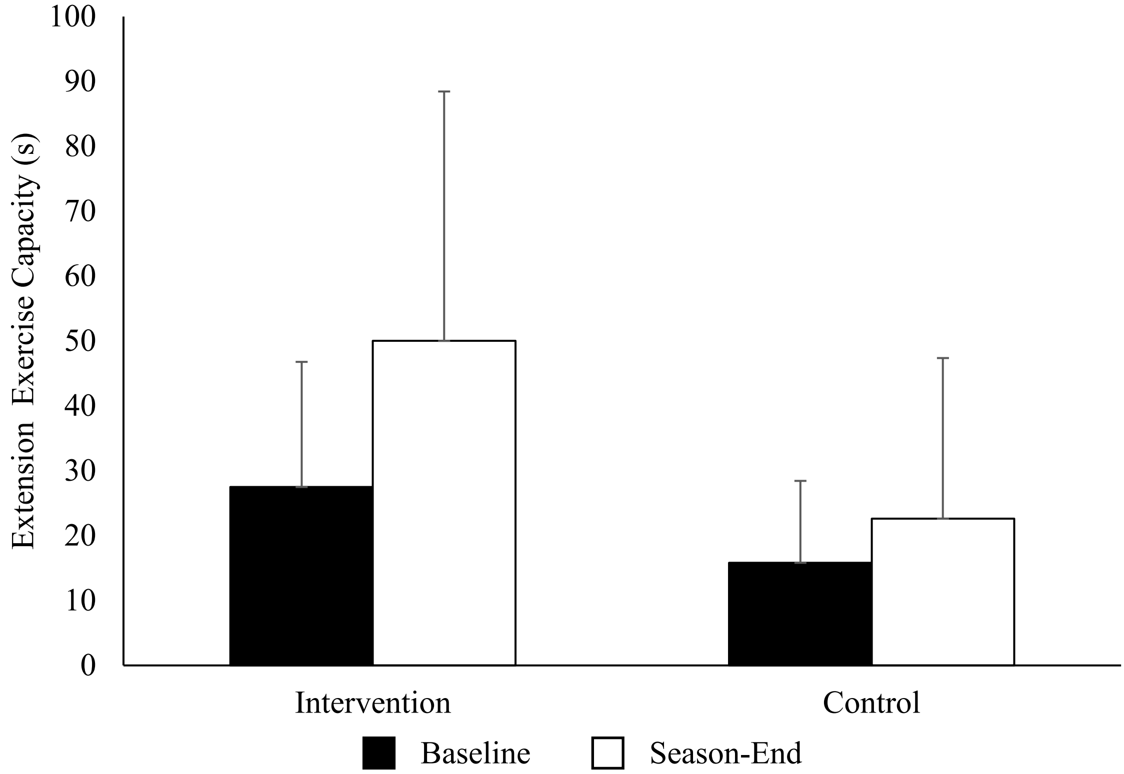

FIGURE 5.17: Neck extension exercise capacity for baseline and season-end for intervention and control groups. (*p* < 0.001) season-end to baseline across both groups.

Neck Proprioception

Figure 5.18 presents neck proprioception vertical error for baseline and season-end for the intervention and control groups. There were several outliers when assessing raw data, and several non-normal data distributions. A Log10 transformation reduced outliers to three, yet with one data set remaining non-normal. Other transformations attempted did not improve outliers or normality beyond this. Due to ANOVA being relatively robust to violations of normality (Schmider, Ziegler, Danay, Beyer, & Bühner, 2010) it was assumed that normality can be slightly violated and still provide valid results. There was no statistical interaction between the two groups and time on vertical error: $F_{(1, 48)} = 0.220$; $p = 0.641$; partial $\eta^2 = 0.005$. The main effect of time reported a statistical difference in mean vertical error at the different time points: $F_{(1, 48)} = 5.164$; $p = 0.028$; partial $\eta^2 = 0.097$. Bonferroni post-hoc corrections demonstrated a statistical decrease in vertical error from baseline (1.6 ± 0.55°) to season-end (1.4 ± 0.46°; $p = 0.028$) across both groups.

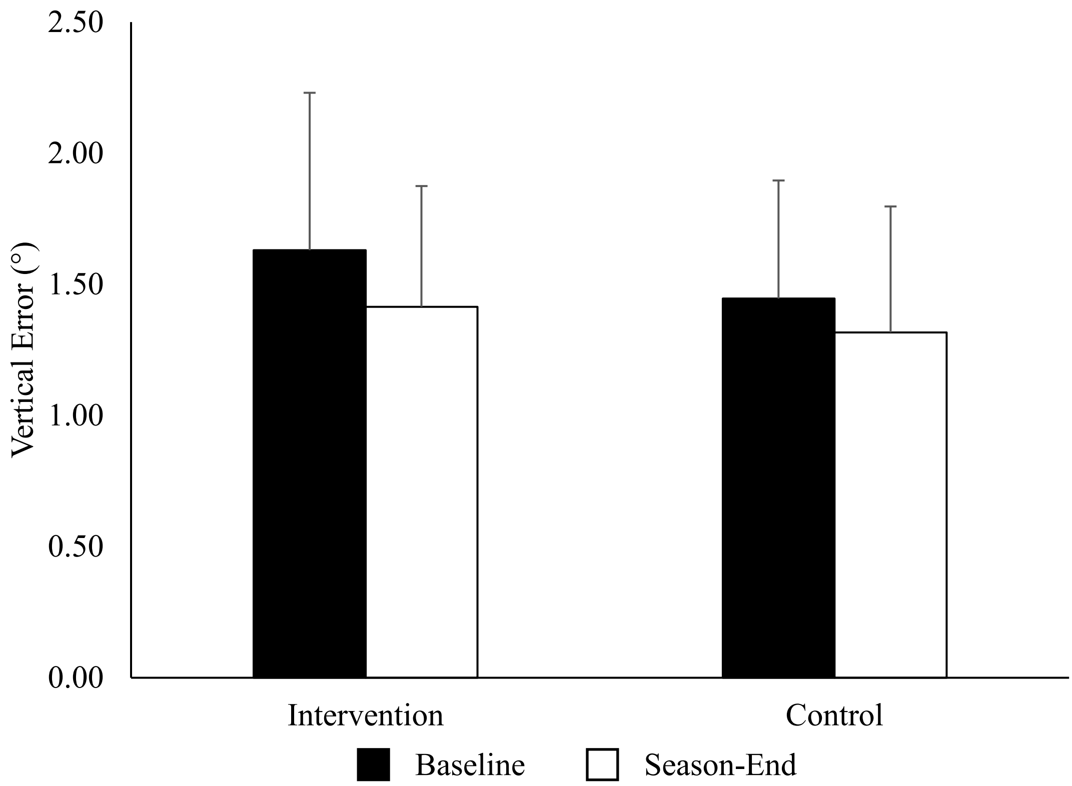

FIGURE 5.18: Neck proprioception vertical error for baseline and season-end for intervention and control groups. (*p* = 0.028) season-end to baseline across both groups.

Figure 5.19 presents neck proprioception vertical variance for baseline and season-end for the intervention and control groups. There were several outliers when assessing raw data, and three data sets were non-normally distributed. An inverse function transformation removed all outliers and amended all data to a normal distribution yet reported with no homogeneity of variances ($p < 0.05$). A Log10 transformation of raw data removed all but one outlier and amended all data to follow a normal distribution. This transformation was used for analysis. There was no statistical interaction between the two groups and time on vertical variance: $F_{(1, 48)} = 0.117$; $p = 0.734$; partial $\eta^2 = 0.002$. The main effect of time reported a statistical difference in mean vertical variance at the different time points: $F_{(1, 48)} = 7.904$; $p = 0.007$; partial $\eta^2 = 0.141$. Bonferroni post-hoc corrections demonstrated a statistical decrease in vertical variance from baseline (1.6 ± 0.46°) to season-end (1.5 ± 0.43°; $p = 0.007$) across both groups.

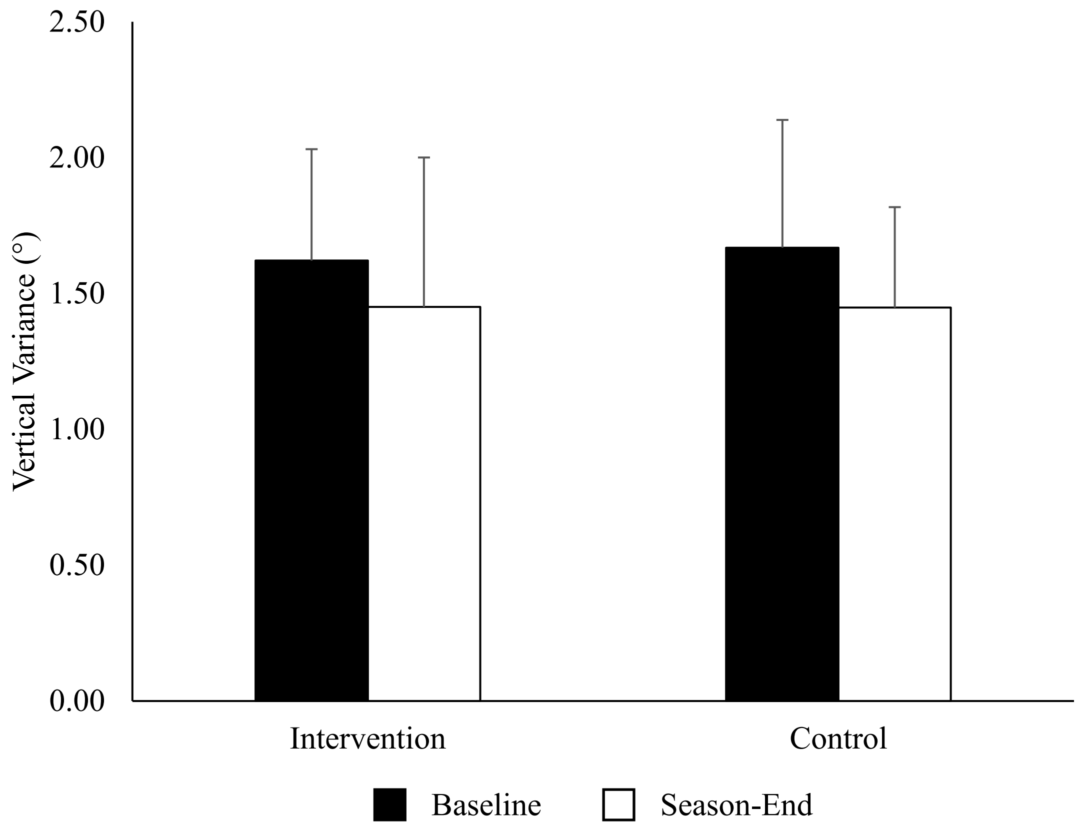

FIGURE 5.19: Neck proprioception vertical variance for baseline and season-end for intervention and control groups. (p = 0.007) season-end to baseline across both groups.

Figure 5.20 presents neck proprioception horizontal error for baseline and season-end for the intervention and control groups. There were three outliers when assessing raw data, with two data sets following a non-normal distribution. A Log10 transformation reduced outliers to one and corrected all data to follow a normal distribution. This was the best outcome from various transformations attempted. There was no statistical interaction between the two groups and time on horizontal error: $F_{(1, 48)} = 0.053$; $p = 0.820$; partial $\eta^2 = 0.001$. The main effect of time reported a statistical difference in mean horizontal error at the different time points: $F_{(1, 48)} = 4.773$; $p = 0.034$; partial $\eta^2 = 0.090$. Bonferroni post-hoc corrections demonstrated a statistical decrease in horizontal error from baseline (2.2 ± 0.57°) to season-end (2.0 ± 0.64°; $p = 0.034$) across both groups.

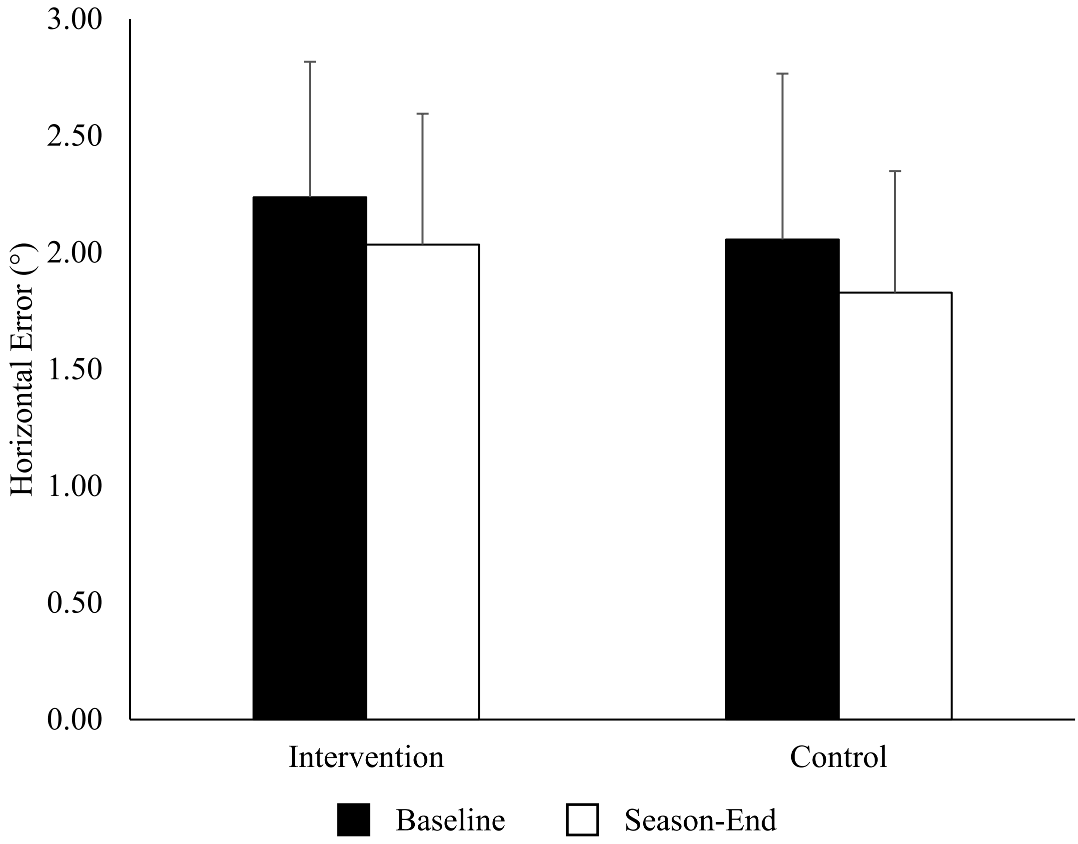

FIGURE 5.20: Neck proprioception horizontal error for baseline and season-end for intervention and control groups. (p = 0.034) season-end to baseline across both groups.

Figure 5.21 presents neck proprioception horizontal variance for baseline and season-end for the intervention and control groups. When assessing raw data, there were four outliers, and one data set which followed a non-normal distribution. Log10 transformation reduced outliers to three and amended all data to a non-normal distribution. This was the best outcome from various transformations attempted. There was no statistical interaction between the two groups and time on horizontal variance: $F_{(1, 48)} = 1.244$; $p = 0.270$; partial $\eta^2 = 0.025$. The main effect of time reported no statistical difference in mean horizontal variance at the different time points: $F_{(1, 48)} = 1.354$; $p = 0.250$; partial $\eta^2 = 0.027$.

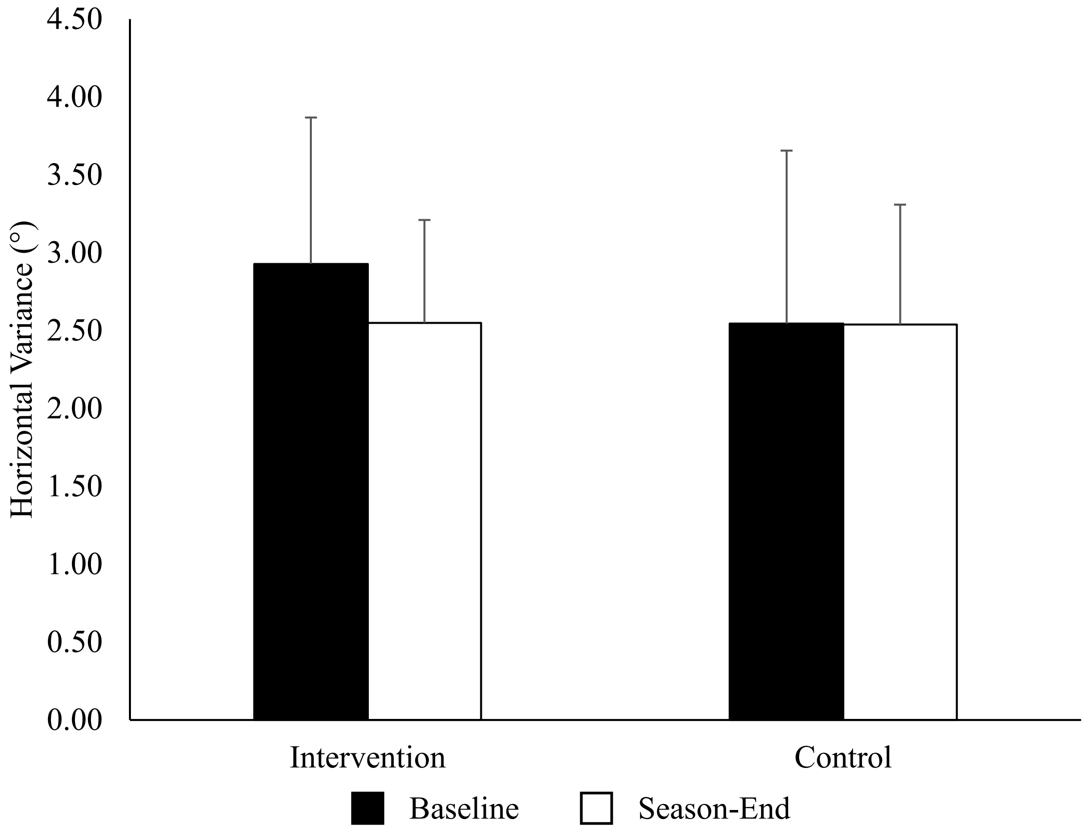

FIGURE 5.21: Neck proprioception horizontal variance for baseline and season-end for intervention and control groups.

Concussion Incidence

Table 5.5 presents participant match exposure, match concussions and match concussion incidence for both groups across the 2018/19 Scottish Premiership and Scottish Cup season. The control group reported the greatest match concussion incidence (18.4/1000 player match hours), followed by the intervention group (7.7/1000 hours). Compared with the control group, the reduction in concussion incidence for the intervention group was not statistically significant (IRR: 0.42; 95% CI: 0.08 - 2.1; p = 0.295).

TABLE 5.5: Concussion incidence for both groups across the 2018/19 Season.

	Match Exposure (h)	**Concussions (n)**	**Incidence (95% CI)**
Intervention Group	260.4	2	7.7 (-3.0 - 18.3)
Control Group	271.3	5	18.4 (2.3 - 34.6)

Programme Adherence

Figure 5.22 presents adherence to the neck training programme throughout the 2018/19 season. Twelve participants completed at least two sessions per week, as instructed. The mean sessions per week for the whole intervention group was 1.8 ± 0.66. Due to small number of match concussions sustained by the intervention group across the 2018/19 season, concussion incidence by programme adherence was not analysed.

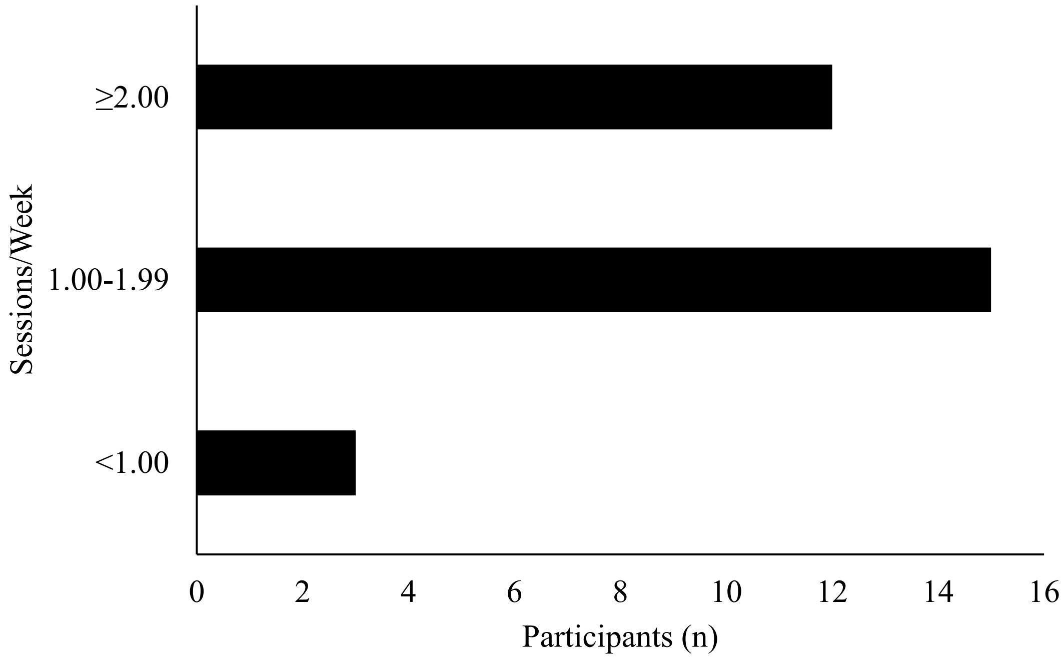

FIGURE 5.22: Neck training sessions per week for the intervention group

5.4: Discussion

The current study aimed to assess the effectiveness of a novel neck training programme based around cranio-cervical flexion to enhance neck function and reduce match concussion incidence in Scottish Rugby academy players. The aims of the study were in-line with the third and fourth steps of van Mechelen's research model "The sequence of prevention of sports injuries". The current study found that the neck training programme statistically enhanced neck strength and neck flexion endurance in comparison to a control group who had no access to the programme. However, match concussion incidence was not statistically different in the intervention group (7.7/1000 player match hours) compared with the control group (18.4/1000 player match hours) across the 2018/19 season.

This thesis has found concussion to be the most frequent injury in professional rugby in Scotland (Chapter 3A and 3B). Concussion is associated with potential short- and long-term negative implications around player welfare and future cognitive decline (Baugh et al, 2012; de Beaumont et al, 2007; Gouttebarge et al, 2017; Guskiewicz et al, 2005; Lewis et al, 2017; McKee et al, 2009; Stern et al, 2011) and reduced availability for selection, either through the initial concussion, or through increased risk of future injury, risking a decline in team performance (Cross et al, 2016; Drew et al, 2017; Hägglund et al, 2013b; Herman et al, 2016; Nordström et al, 2014; Williams et al, 2016). This thesis has also highlighted the effect prior concussion can have on risk of sustaining a future concussion (Chapter 4), potentially causing further player absence. Scottish Rugby have a legal duty to minimise the risks to player welfare to as low a level as practicably possible (Fuller, 1995; HSE, 2001; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992). Scottish Rugby also have a financial interest in improving team performance through greater player availability for selection and reduced injury burden (Drew et al, 2017; Morgan, 2002; Zhang et al, 2003; Williams et al, 2016). Therefore, concussion prevention techniques able to be implemented on a wide scale would be of great interest to Scottish Rugby in particular, as well as the world-wide rugby community in general. Previous research had postulated a link between greater neck strength and a reduced probability of sustaining a concussion (Broglio et al, 2012; Collins et al, 2014; Eckner et al, 2014; Hyrsomallis, 2016). In an anticipated collision, a stronger neck should provide a stable link between the torso and the head, resulting in a larger effective mass to be accelerated (Broglio et al, 2012). According to Newton's second law of motion and the law of energy conservation, a larger mass would witness a smaller magnitude of acceleration, potentially reducing the risk of concussion (Rowson & Duma, 2013; Viano et al, 2007). The ability to stabilise the head also relies on interactions between visual and vestibular stimuli and feedback from neck muscle spindles (Armstrong, McNair, & Taylor, 2008; Keshner & Peterson, 1995). Both neck strength and proprioception may be affected by fatigue (Armstrong et al, 2008; Fuller, Brooks, & Kemp, 2007c), and therefore it was hypothesised that a training programme targeting enhanced neck strength, proprioception and endurance may result in an associated reduction in concussion incidence.

Isometric Maximal Voluntary Contraction Force

Both neck flexion and neck extension isometric maximal voluntary contraction (IMVC) force statistically improved in both groups across the 2018/19 season. The increase in strength in the control group with no access to the neck training programme was expected based on previous work (Salmon et al, 2018). Salmon et al (2018) found statistical increases in neck strength in a cohort of elite rugby players across a season without completing any neck training. Contact situations in rugby such as tackling, being tackled and scrummaging have all been shown to activate muscles responsible for flexion and extension of the neck in an effort to stabilise the head (Bussey et al, 2019; Cazzola, Stone, Holsgrove, Trewartha, & Preatoni, 2016; Dempsey et al, 2015; Hasegawa et al, 2014). Data presented suggests that repetitive engagement in these contact situations over the course of a season places sufficient metabolic and mechanical stress to overload neck muscles and cause strength adaptations to occur. However, a statistical interaction between groups over time was present with a larger increase in flexion and extension IMVC force found in the intervention group. This would suggest that the neck training programme provided an additional stimulus which augmented the increase in flexion and extension strength observed through rugby match play alone as seen in the control group. This confirms initial research suggesting specific exercise modalities targeting cervical musculature results in the greatest improvement in neck strength (Conley, Stone, Nimmons, & Dudley, 1997).

A statistical interaction was also found between groups over time for left and right lateral neck flexion IMVC, with statistical increases in the intervention group for both directions compared with no change in the control group. Rugby contact situations appear a stimulus which may increase neck flexion and extension strength, yet although left and right lateral flexion strength is correlated with resisting head acceleration whilst tackling (Dempsey et al, 2015), lateral flexion strength appears to not be altered through rugby participation alone. The current training programme appears to result in gains of left and right lateral flexion strength. Concussion is likely to be caused by acceleration of the head in more than one plane of motion, and therefore increased strength in multiple directions is likely to be required to reduce the probability of sustaining a concussion injury.

Previous studies aiming to enhance neck strength in elite rugby players have used a general strengthening approach with mixed results (Geary et al, 2014; Naish et al, 2013). As a result of the metabolic and mechanical stress placed on muscles of the neck through rugby participation and the subsequent strength adaptations to flexion and extension musculature (Bussey et al, 2019; Cazzola et al, 2016; Dempsey et al, 2015; Hasegawa et al, 2014; Salmon et al, 2018), elite rugby players may have limited potential to improve neck strength through a general strengthening approach. The current study developed a training programme whereby participants were to enhance activation of deep cervical flexors through cranio-cervical flexion, before progressing onto training of more superficial muscle. Cranio-cervical flexion was a new technique to participants in the intervention group, and those who have not learnt correct technique may struggle to activate the deep cervical flexor muscles longus colli, longus capitis, rectus capitis anterior and rectus capitis lateralis (Falla, 2004; Jull, 2000). By implementing cranio-cervical flexion, it may allow more musculature to be activated and trained than before. This may explain the improved neck IMVCs after a period of training in the current study, and as seen in previous literature in trained military pilots (Salmon et al, 2013). Neck proprioception training has also been shown to augment changes in neck muscle hypertrophy when performed alongside resistance training (Kramer, Hohl, Bockholt, Schneider & Dehner, 2013). Although neck muscle girth was not measured in the current study, the proprioception training may have resulted in greater neck muscle fibre hypertrophy as seen in previous studies, allowing for greater gains in IMVC force (Erskine, Fletcher, & Folland, 2014).

The current study found improvements in neck IMVCs by using relatively light loads (up to 10 kg for extension endurance and head and body weight exercises) with longer holds (10 - 45 s), compared with heavier yet shorter holds such as 12 x 5 s at 70% one-repetition maximum used by Naish et al (2013). Using high loads is generally advised when using resistance exercise to enhance maximal force (Schoenfeld, Grgic, Ogborn, & Krieger, 2017), yet this is often associated with higher chance of injury (Fisher, Steele, Bruce-Low, & Smith, 2011). The current study supports previous work that suggests improvements in isometric neck strength can be achieved through relatively light loads (Hämäläinen, Heinijoki, & Vanharanta, 1998; Salmon et al, 2013). By using lighter loads, odds of injury whilst undertaking the prescribed training programme are likely to be reduced, offering an advantage for practitioners when using the current programme in applied settings.

Exercise Capacity

Data presented shows neck flexion exercise capacity statistically improved for the intervention group, with no change in the control group across the 2018/19 season. (Whilst there were five outliers analysed within the data, four of these were in the control group, and therefore unlikely to affect the results of the intervention group over the study period). Both groups statistically improved neck extension exercise capacity during the study period, with no interaction between groups. Using a similar training intervention in military pilots, Salmon et al (2013) found statistical improvements in neck flexion exercise capacity, but no statistical change in neck extension exercise capacity at 70% IMVC. In under-19s rugby, Barrett et al (2015) found no statistical change in neck extension exercise capacity at 50% IMVC after a training intervention. Whilst increases in neck flexion exercise capacity appear attainable when training using cranio-cervical flexion, improvements in neck extension exercise capacity appear more difficult to achieve as a result of a training intervention.

In neck flexion and neck extension exercise capacity trials at 70% IMVC, changes in normalised electromyographic mean frequency found that neuromuscular fatigue was most evident in the smallest muscles of the neck (Harrison et al, 2009). Although the current study used exercise capacity trials at 80% IMVC, similar mechanisms of fatigue may have occurred during baseline and season-end assessment as found by Harrison et al (2009). The neck training programme in the current study utilised cranio-cervical flexion to improve activation and endurance of deep cervical flexor muscles. Improved endurance of these small muscles through the intervention may have resulted in enhanced neck flexion exercise capacity by season-end in the intervention group. If there were a previous inability to activate these muscles (Falla, 2004; Jull, 2000), it may suggest that cranio-cervical flexion is a vital technique to enhance neck flexion endurance in trained rugby participants.

There was a statistical increase in neck extension exercise capacity for both groups across the 2018/19 season, although no statistical interaction was found between the groups. Muscles to extend the neck are frequently activated in rugby contact situations such as tackling and scrummaging (Bussey et al, 2019; Cazzola et al, 2016; Dempsey et al, 2015). The data appears to suggest that the metabolic and mechanical stimulus placed upon neck extensor musculature through repetitive contact scenarios across a rugby season is capable of statistically increasing neck extension exercise capacity. Harrison et al (2009) illustrated that during neck exercise capacity trials at 70% IMVC, the only statistical reduction in normalised electromyographic mean frequency at fatigue was in the left and right splenius capitis muscle. Prime extensor agonists such as left and right upper trapezius showed no sign of neuromuscular fatigue (Harrison et al, 2009). It appears that the limiting factor in neck extension exercise capacity trials may be endurance of the splenius capitis muscle. Future training interventions specifically isolating and targeting endurance adaptation of this muscle may see improvements in neck extension exercise capacity beyond what is seen by participating in a season of rugby.

Neck Proprioception

Rugby has been shown to reduce neck proprioceptive ability in semi-professional and professional players (Lark & McCarthy, 2007; Pinsault, Anxionnaz, & Vuillerme, 2010), likely through mechanoreceptor dysfunction in cervical musculature. This may occur through repetitive microtrauma of tackling, rucking, mauling, and scrummaging (Pinsault et al, 2010), or through previous whiplash-type injury (Treleaven, Jull, & Sterling, 2003). Therefore, it was hypothesised that proprioceptive training over a season may prevent further deterioration in neck joint position error in the intervention group, whilst a decline in proprioceptive ability would be seen in the control group. However, across the 2018/19 season vertical error, vertical variance, and horizontal error resulted in a statistical improvement for both groups with no interaction, whilst no change for either group was found for horizontal variance.

The fact that no further improvement was seen in the intervention group compared with the control group may be due to the amount of proprioceptive training that was undertaken. For example, Revel et al (1994) found statistical improvement in neck proprioception over an eight week period with two 30 - 40 minute sessions per week. However, neck proprioception was part of a larger neck training programme in the current study, and less time was therefore available for proprioceptive training. Across the whole intervention, an average of 2 minutes of proprioception training was completed per week per participant in the current study (data not shown). If greater time is required to improve neck proprioception, a challenge for future researchers/practitioners would be how to fit approximately an hour of proprioception training per week in amongst a professional/academy rugby training schedule.

The similar response between groups for proprioception measures across the 2018/19 season may suggest an element of learning effect and that a familiarisation period may be required in future studies. The reliability of the cervicocephalic relocation test may also be questionable. Pinsault et al (2008) reported intraclass correlation coefficients for the test of 0.52 (vertical error), 0.49 (vertical variance), 0.80 (horizontal error) and 0.77 (horizontal variance). Vincent (2005) states intraclass correlation coefficients below 0.80 are unsuitable for use in physiological assessment. The poor reliability of assessing vertical error, vertical variance and horizontal variance may have resulted in type II errors, with the cervicocephalic relocation test unable to detect differences between groups over the 2018/19 season. Whilst other methods of assessing neck proprioception are used, they are yet to demonstrate greater reliability than the cervicocephalic relocation test used in the current study (Basteris, Hickey, Burgess-Gallop, Pedler, & Sterling, 2016; Strimpakos, Sakellari, Gioftsos, Kapreli, & Oldham, 2006; Swait, Rushton, Miall, & Newell, 2007). It is recommended future studies develop a test for neck proprioception possessing greater reliability.

Concussion Incidence

The second aim of the current study was to assess whether those participants who undertook the neck training programme throughout the 2018/19 Scottish Premiership and Scottish Cup rugby season witnessed a reduction in concussion incidence. It was hypothesised that a neck training programme targeting strength, endurance and proprioception would result in a reduction in concussion incidence. Compared with the control group, the current study found statistically enhanced isometric neck strength and flexion endurance for the intervention group, yet match concussion incidence between the groups was not statistically different.

The lack of statistical difference in concussion incidence between the intervention group (7.7/1000 player match hours) and the control group (18.4/1000 hours) may have been due to the small sample sizes in the current study. Larger sample sizes of concussions and match exposure would increase power of the study, reduce the size of confidence intervals, and increase the likelihood of finding a statistical difference in concussion incidence between the two groups (Brooks & Fuller, 2006). Across the whole season, seven concussions and 531.7 h of match exposure were recorded for 49 participants across both groups. By comparison, Attwood et al (2017) (45 concussions and 19,560 hours from 673 participants) and Hislop et al (2017) (105 concussions and 15,938 hours from 2,452 participants) both found statistical reductions in match concussion incidence from the use of a pre-activity conditioning programme including isometric neck exercise from far larger sample sizes. All available Scottish Rugby academy players were initially recruited into the study, but participant dropout through injury and leaving the academy programme reduced the size of the intervention group. It was also decided that assessing neck strength and endurance would likely be most accurate from a single tester, due to previous evidence of tester strength having an impact on handheld dynamometry results (Wikholm & Bohannon, 1991). Due to time constraints, the use of a single tester therefore impacted the number of participants that could be recruited into the control group. Whilst this is a small study, it represents a promising step-forward in prevention techniques for concussion in elite rugby. It is recommended the current neck training programme is implemented in a larger study in future research to confirm its effectiveness in reducing match concussion incidence.

Programme Adherence

The neck training programme implemented in the current study was designed for participants to complete two sessions per week. This was based on previous research suggesting two sessions per week was more effective than one at improving neck muscle strength (Pollock et al, 1993). Mean session adherence in the current work of 1.8 sessions per week was similar to that reported by Hislop et al (2017) (1.9), and greater than 1.3-1.4 sessions per week reported by other injury prevention studies (Hägglund et al, 2013a; Soligard et al, 2010). The relatively high mean adherence in the current study suggests the set-up and communication of the programme was effective, as was the implementation and delivery by Scottish Rugby academy staff in the three academy locations. Previous studies have demonstrated that greater adherence is often associated with reduced injury risk (Hägglund et al, 2013a; Hislop et al, 2017; Myklebust et al, 2003; Salmon et al, 2013; Soligard et al, 2010). Due to the small number of concussions reported for the intervention group in the current study, concussion incidence by programme adherence could not be investigated.

Adoption and implementation of an intervention relies upon a behaviour change from participants and staff (Finch & Donaldson, 2010; Glasgow et al, 1999; Glasgow, Klesges, Dzewaltowski, Bull, & Estabrooks, 2004; McGlashan & Finch, 2010; Verhagen et al, 2010), which may depend upon communication of rationale and optimum programme delivery (Steffen et al, 2010). Factors which may have provided barriers to programme uptake in the current study were considered, such as ensuring all players and staff were aware of the potential benefits of the intervention, ensuring the programme was easy to adopt through provision of all necessary equipment and designed so that each training session was only 10 minutes in duration. This allowed the programme to fit into pre-existing resistance training or injury prevention programmes, ensuring the current intervention was aligned with the pre-existing culture of player development and welfare

(Eime et al, 2004; Finch, 2006; Hanson et al, 2005; van Tiggelen et al, 2008). The programme was also professionally presented, with each participant receiving their own adherence/progress folder, A4 exercise cue sheets provided to each academy location (appendix 8), and each member of staff receiving their own booklet containing the rationale and theory behind the programme and the exercises to be used (Finch, 2006). All staff also attended a workshop before the intervention commenced on how to instruct the exercises and how to progress participants through the programme. It is believed these points may have allowed for the successful uptake and adoption of the intervention (Eime et al, 2004; Finch, 2006; Glasgow et al, 1999; Hanson et al, 2005; van Tiggelen et al, 2008).

Whilst the implementation context of the intervention in the current study and potential barriers to programme uptake, adoption and implementation were therefore considered, it is important to recognise that the programme in the current study was instigated as a controlled trial, and not implemented in a pragmatic, real world setting (Bolling et al, 2018; Finch, 2006). Whilst trials such as this still represent an important step in the injury prevention process by increasing the evidence base around intervention efficacy and proof-of-concept (Finch, 2006, Glasgow et al, 1999; Verhagen et al, 2010), it is unlikely that this can be translated directly into injury prevention in real-world settings without further consideration of the implementation context and further barriers to programme uptake and adoption in real-world settings away from the "ideal", controlled settings that this trial was implemented under in the current study (Finch, 2006).

Both Finch (2006) and van Tiggelen et al (2008) have proposed extensions to the "Sequence of Prevention of Sports Injuries" model developed by van Mechelen et al (1992), dictating the importance of considering barriers to intervention uptake in real-world settings once the efficacy of an injury mitigation measure has been established under ideal conditions. In addition, both Bolling et al (2018) and McGlashan and Finch (2010) recommend a multidisciplinary approach to considering the context of injury prevention implementation, with a need to understand the contextual factors which affect the behaviour of the targeted athlete(s) and/or staff. If the programme developed in the current study were to be implemented on a wider scale across Scottish Rugby for use by all elite/professional squads, knowledge of the attitudes and perception towards concussion risk/probability of the targeted players and their respective coaches and associated medical staff, as well as authoritative figures within Scottish Rugby would provide key information on potential barriers for programme reach, adoption, implementation and maintenance (Finch, 2006, Fuller & Drawer, 2004; Glasgow et al, 1999; Lund & Aarø, 2004; van Tiggelen et al, 2008). It is essential to consider athletes and staff as individual entities, with differing attitudes towards concussion incidence likely to be present, possibly influenced by previous experience of the injury themselves, or vicarious experience of others that they may have witnessed (Bolling et al, 2018; Lund & Aarø, 2004; van Tiggelen et al, 2008; Verhagen, 2012). Knowledge of financial cost of implementing the intervention versus potential reward of reduced injury burden (resulting in improved care of player welfare as well as enhanced possibility of team and financial success) as well as available infrastructure around implementation of the intervention (equipment, player-hours, staff-hours, and staff:player ratios required for successful implementation) would also be necessary (Drawer & Fuller, 2002a; Drawer & Fuller, 2002b; Finch, 2006). For an injury preventative measure to be successful, it must be implemented in a specific context which considers these above points (Bolling et al, 2018). If the current programme is to be implemented across Scottish Rugby on a wider scale, initial research to consider these factors is recommended, possibly by following Stage 5 of the Translating Research into Injury Prevention Practice (TRIPP) model proposed by Finch (2006). Due to the need for understanding the correct context for implementation, qualitative research methods to identify potential barriers for programme uptake and tailor interventions to suit targeted athletes/cohorts may be required (Bolling et al, 2018; Jack, 2006; Verhagen & Bolling, 2018). Combining the efficacy results of this proof-of concept controlled trial in the current study with findings from a future qualitative study following TRIPP Stage 5 should improve the odds of a successful neck training concussion prevention measure being implemented across all Scottish Rugby elite teams in the future (Bolling et al, 2018; Finch, 2006; Glasgow et al, 1999).

Methodological Considerations

The current study employed a passive control group to assess the absolute effect of a novel neck training programme which was developed around cranio-cervical flexion to enhance neck function and potentially reduce concussion incidence across a season of rugby union (Karlsson & Bergmark, 2015). At this stage in the "proof-of-concept" process, this was deemed the most appropriate approach to understand the efficacy of the programme which was developed (Karlsson & Bergmark, 2015). Previous research has assessed the relative effects of a training programme utilising a cranio-cervical flexion approach with a general neck training programme in military pilots (Salmon et al, 2013).

The relative effect of the cranio-cervical flexion approach was greater in enhancing neck strength and endurance compared with a general approach. Future studies may utilise active control groups and attempt to assess the relative effects of the cranio-cervical flexion approach utilised in the current study in comparison with other neck training modalities/approaches to determine the optimum programming for enhancing neck function and potentially reducing concussion incidence in rugby players.

Specific familiarisation testing sessions for neck function assessment were not employed in the current study. Familiarisation to the testing protocol and a warm-up routine have previously been suggested as necessary for reliable and valid assessment of cervical spine muscle strength and endurance (Du Toit, Buys, Venter, & Olivier, 2003). However, Strimpakos, Sakellari, Gioftsos and Oldham (2004) stated that a single test was sufficient to improve validity of neck muscle assessment through isometric dynamometry. The current study employed a warm-up routine of neck and shoulder mobilisation before two submaximal isometric contractions (approximately 50% effort and 80% effort) in the correct assessment posture in all planes of movement that were to be tested (flexion, extension, left and right lateral flexion). Three trials were taken in all four directions for isometric maximal voluntary contractions in the current study, with the peak force value recorded. Assuming that only one trial in each direction is required for adequate familiarisation to the test procedure (Strimpakos et al, 2004), this approach appears sufficient to allow participants to become familiarised with the isometric testing procedure and still produce a valid assessment of isometric neck strength. This is also the extent of familiarisation used by other researchers assessing neck muscle function (Geary, Green, & Delahunt, 2013; Salmon et al, 2015; Salmon et al, 2018).

In assessing the reliability of the cervicocephalic relocation test, Pinsault et al (2008) reported no evidence of habituation from individuals performing the test twice within the same day, and therefore it was assumed no familiarisation was required in the current study. Previous research suggests rugby exposure diminishes neck proprioceptive ability, likely through mechanoreceptor dysfunction in cervical musculature from repetitive microtrauma from tackling, rucking, mauling, and scrummaging or whiplash-type injuries (Lark & McCarthy, 2007; Pinsault et al, 2010; Treleaven et al, 2003). Therefore, it was hypothesised that the proprioceptive ability of the control group would decline across the data collection period, whilst the proprioceptive training of the intervention group would prevent/lessen this decline. The fact that both groups similarly improved on the majority of measures of proprioceptive ability however suggests that a habituation effect may have occurred in the current study, potentially masking any beneficial effect of the proprioceptive training undertaken by the intervention group through type II error. Further research may be required to assess the effect of any habituation effect of the cerivocephalic relocation test in rugby players.

Limitations

The current study was not without limitations. Primarily, the study was not a randomised control trial. From an ethical standpoint, Scottish Rugby would not allow any academy players to be used as a control group, and therefore all players in the intervention group were Scottish Rugby academy players. The control group was comprised of volunteers who also played Premiership and Scottish Cup rugby yet were not part of Scottish Rugby's academy system. This may have resulted in selection bias. Conceivably due to the age difference in participants in the two groups, the intervention group were often less advanced at baseline on measures of neck function (independent t-tests found statistically greater neck flexion, extension and left and right flexion IMVC strength in the control group at baseline, data not shown). This may have allowed for greater potential for improvement in neck strength in the intervention group.

Chapter 4 of this thesis found that tackling with correct technique is also likely to reduce concussion propensity. Scottish Rugby academy players in the intervention group who may have greater rugby ability could be less likely to tackle with incorrect technique, and therefore be at a lower chance of sustaining a concussion. The effect modification of tackling ability between groups may have confounded any differences in concussion incidence, yet this was unavoidable due to Scottish Rugby's request that none of their players were placed in the control group. Despite this, other confounding risk factors between groups were considered. No differences were found at baseline in the number of previous concussions, severity of most-recent concussion, or time since most-recent concussion. There was also no difference in the proportion of forwards and backs between the two groups and although the control group were statistically older, data from chapter 4 illustrated that age had no effect on concussive incidence.

Training volumes and rugby exposure outwith Scottish Premiership and Scottish Cup matches were not recorded for either group. Contact situations in rugby may increase neck strength, and different levels of exposure to contact situations in training/other matches between groups may have influenced reported changes in neck strength across the 2018/19 season. There were also a relatively small number of participants involved compared with previous injury prevention studies. A future randomised controlled trial with recorded volume of rugby exposure outwith the matches being studied (both training and further match play) and a larger sample size is likely to fully ascertain the efficacy of the neck training programme in reducing match concussion incidence.

Conclusions

The current study found that a neck training programme for elite rugby players based around cranio-cervical flexion statistically improved isometric neck strength and neck flexion exercise capacity in comparison to a control group across a season of rugby. Across the study period, match concussion incidence in Scottish Premiership and Scottish Cup matches was 7.7/1000 player match hours in the intervention group, compared with 18.4/1000 hours in the control group.

This thesis has found that concussion is the most frequent match injury in all professional cohorts within Scottish Rugby aside from women's international rugby sevens, where concussion was the second most frequent. Due to their legal duty of care to protect player welfare (Fuller, 1995), and their financial interest in maximising player availability for greater team performance (Morgan, 2002; Zhang et al, 2003; Williams et al, 2016), concussion prevention methods should therefore be of high importance to Scottish Rugby. Whilst implemented in a controlled setting to obtain proof-of-concept, the data from the current study recommends to Scottish Rugby that this programme be implemented on a wider scale throughout their professional cohorts and academy institutions on a permanent basis. In order to ensure an effective programme through high levels of reach, adoption, implementation, and maintenance, intermediary research is first recommended to assess potential barriers to programme uptake by following Stage 5 of the TRIPP injury prevention model (Finch, 2006).

Concussion is not only a frequent injury in Scottish Rugby but has been recorded to occur at a high incidence in differing levels of rugby competition across the world. The current study appears the first of its kind in developing a neck training concussion prevention measure for use in elite rugby, resulting in a concussion incidence of 7.7/1000 player match hours for the intervention group, compared with 18.4/1000 hours in the control group. Although small sample sizes were used, and the trial was run in a controlled setting, it is a promising start for future work. In order to fully understand the efficacy of the current programme, the training programme should be implemented on a larger scale in a randomised controlled trial, potentially with an active control group utilising a general neck training programme to assess the relative effect of the cranio-cervical flexion approach used in the current study. It is hoped this is undertaken in future research.

The current chapter of this thesis aimed to follow step three and four of van Mechelen's research model "The sequence of prevention of sports injuries". The intervention of a neck training programme was devised and introduced for Scottish Rugby academy players for the 2018/19 season. Although the training programme was administered in a controlled setting to the intervention group, potential barriers to programme uptake were considered to improve the context of implementation and therefore improve the chance of a successful intervention (Eime et al, 2004; Finch, 2006; van Tiggelen et al, 2008). The efficacy of the programme in reducing match concussion incidence was monitored in comparison with a control group playing at the same level of competition. This completes the research model of van Mechelen et al (1992) and completes the investigation of the current thesis into concussion injury patterns in elite Scottish rugby union.

END OF CHAPTER 5

CHAPTER 6: THESIS CONCLUSIONS

6.1: Introduction

Scotland is regarded as a tier one rugby nation. As of November 2019, the men's and women's international teams were ranked 9th and 11th in the world (World Rugby, 2019d), and the men's and women's international rugby sevens teams were ranked 10th and 12th (World Rugby, 2019f). Additionally, there are two men's professional clubs who compete at the highest level of the men's professional club game. As the national governing body for rugby in Scotland, Scottish Rugby have a legal duty of care towards their professional players and should understand the possible hazards to health and welfare that are present in rugby, be able to communicate the magnitude of risk to player welfare to all relevant stakeholders, and attempt to reduce said hazards to a level as low as reasonably practicable (Fuller 1995; Fuller 2018a; Fuller & Drawer, 2004; HSE, 2001 Junge et al, 2008; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992). Scottish Rugby also have a financial interest in improving team performance through greater player availability for selection by reducing injury burden (Drew et al, 2017; Morgan, 2002; Zhang et al, 2003; Williams et al, 2016). However, the most recent injury epidemiology study in rugby in Scotland was completed early after the onset of professionalism for men's professional club rugby (Garraway et al, 2000). This does not therefore consider potential changes to the risks to player welfare over the past 20 years, during which time reported match concussion incidence has increased in multiple rugby formats (Best et al, 2005; Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2014; Fuller & Taylor, 2017; Moore et al, 2015; Rafferty et al, 2019; RFU, 2019; RFU, 2020; Rugby Safe, 2019; Rugby Safe, 2020; Schick et al, 2008; Taylor et al, 2011; West et al, 2020). General injury and concussion specific epidemiology had previously not been studied amongst other elite rugby cohorts in Scotland. Without contemporary injury and concussion epidemiology studies, Scottish Rugby could not fulfil its legally bound duty of care towards players, had only a limited understanding of the risks to player welfare and team performance that rugby posed in Scotland, and had no understanding of methods to mitigate concussion injury risk (Fuller, 1995; Fuller & Drawer, 2004; van Mechelen et al, 1992).

The primary aim of this thesis was to increase understanding of concussion in elite rugby in Scotland. In order to achieve this, a series of research aims were proposed in chapter one, in line with van Mechelen's research model "The sequence of prevention of sports injuries" (van Mechelen et al, 1992). However, in order to consider the context and complexity of injury aetiology, and the context in which injury interventions are implemented, certain factors from other injury investigation frameworks and models were also adhered to, improving the validity of the injury investigation (Bahr & Krosshaug, 2005; Bekker & Clark, 2016; Bittencourt et al, 2016; Bolling et al 2018; Finch, 2006; Fuller, 2020; Fuller & Drawer, 2004; Fuller & Vassie, 2004; Meeuwisse et al, 2007). Chapter two presented a review of the existing literature surrounding general injury and concussion specific epidemiology, concussion risk factors and preventative measures, and illustrated the research gaps that existed. This demonstrated why the research aims laid out in chapter one were pertinent to increasing the knowledge of concussion injury in elite rugby in Scotland and beyond.

This chapter will summarise the key findings from the studies developed to meet each research aim, and how results from this thesis make an original and significant contribution to scientific knowledge in this area. The main strengths and limitations of methodologies used in each study will be reflected upon, and the impact of the findings to rugby policy in Scotland and across the world will be discussed. Future research directions that are recommended for further exploration based on results of this thesis will also be described.

6.2: Summary of Key Findings

The research aims made in chapter one are laid out below, alongside key findings from each study.

Research Aims One and Two (Sequence of Prevention Stage One – Injury Epidemiology):

- **v)** Undertake a detailed epidemiological study of match and training injuries sustained by professional Scottish Rugby cohorts across the 2017/18 and 2018/19 seasons.
- **vi)** Establish the incidence, severity, and burden of concussion and undertake a detailed analysis of concussion injuries sustained during the 2017/18 and 2018/19 seasons.

Key Findings (Chapter 3A and 3B)

A match and training injury epidemiology study was run during the 2017/18 and 2018/19 seasons, with definitions as recommended from the most recent rugby research consensus (Fuller et al, 2007d). This was in-line with the first step of van Mechelen's research model. Match injury incidences of 120.0 (men's international), 166.7 (women's international), 136.2 (men's professional club), 229.0 (men's international sevens) and

153.6/1000 player match hours (women's international sevens) were found. Match injury severity ranged from 20.7 - 45.6 days (mean) and 7.0 - 12.0 days (median), whilst match injury burden ranged from 2,887.0 – 7,011.2 days absence/1000 player match hours. Concussion was the most frequent specific match pathology for men's international (22.5), women's international (26.7), men's professional club rugby (28.5), and men's international rugby sevens (37.3), and the second most frequent for women's international rugby sevens (27.9/1000 player match hours). Match concussion injury severity ranged from 7.7-17.6 days (mean) and 7.0-13.0 days (median) and was primarily caused by contact situations, particularly due to tackling and collision mechanisms. Concussion was the injury with the greatest match injury burden for men's professional club rugby (501.6 days absence/1000 player match hours), and the third greatest burden for men's (287.5) and women's (293.3 days absence/1000 player match hours) international rugby sevens.

Training injury incidences of 3.0 (men's international) and 4.1/1000 player training hours (men's professional club) were found, with mean injury severities of 19.9 (men's international) and 24.7 days (men's professional club), and median injury severities of 6.0 (men's international) and 7.5 days (men's professional club). Training injury burden was 58.8 (men's international) and 102.3 days absence/1000 player training hours (men's professional club). Concussion was the equal most common injury for men's international (0.42) and the second most frequent for men's professional club rugby (0.30/1000 player training hours), and was primarily caused by contact situations, particularly due to tackling and collision mechanisms. Training concussion severity for men's professional club rugby was 28.4 days (mean) and 7.0 days (median). Training concussion burden was 1.9 (men's international) and 8.5 days absence/1000 player training hours (men's professional club rugby) and was the training injury with the third greatest burden for men's professional club rugby.

Research Aim Three (Sequence of Prevention Stage Two – Concussion Risk Factors and Aetiology)

vii) Identify intrinsic (concussion history elements) and extrinsic (contact event specific) risk factors for concussion within professional Scottish rugby, and to demonstrate whether any interaction effect exists when intrinsic concussion history and extrinsic contact event specific risk factors are studied simultaneously.

Key Findings (Chapter 4)

Collation of concussion history data for men's international and men's professional club rugby players, and their exposure to extrinsic risks through video analysis was completed. This was in-line with the second step of van Mechelen's research model. Univariate analysis found the following intrinsic factors around concussion history statistically altered future concussion incidence when compared to those with no previous concussion:

- Greater than five previous concussions (Incident Rate Ratio: 4.8; 95% CI: 1.9 - 12.0; $p < 0.001$)
- Severity of most-recent concussion of 8-14 days (IRR: 2.6; 95% CI: 1.1 - 6.1; $p = 0.031$)
- HIA 2 symptom score of most recent concussion of 6-10 (IRR: 2.7; 95% CI: 1.0 - 7.3; $p = 0.048$)
- HIA 2 symptom score of most recent concussion of 11-15 (IRR: 3.7; 95% CI: 1.1-12.6; $p = 0.037$)
- HIA 2 symptom severity of most-recent concussion of 31-40 (IRR: 7.3; 95% CI: 1.5 - 35.2; $p = 0.013$)

Univariate analysis found the following extrinsic factors statistically increased tackling player concussion propensity:

- Striking the ball carrier on the head compared with torso (IRR: 10.8; 95% CI: 1.8 - 64.6; $p = 0.009$)
- Striking the ball carrier on the shoulder/arm compared with torso (IRR: 4.0; 95% CI: 1.1 - 14.4; $p = 0.036$)
- Tackler striking ball carrier with their own head compared with shoulder/arm (IRR: 53.4; 95% CI: 21.3 - 133.9; $p < 0.001$)
- Tackler placing their head in-front of the ball carrier compared with beside (IRR: 6.3; 95% CI: 2.4 - 16.2; $p < 0.001$)
- High impact tackles compared with low impact (IRR: 15.1; 95% CI: 3.9 - 58.5; $p < 0.001$)
- Moderate impact tackles compared with low impact (IRR: 5.7; 95% CI: 1.6 - 20.5; $p = 0.007$)

Univariate analysis found the following extrinsic factors statistically increased tackled player concussion propensity:

- Being initially struck by the tackler on the head compared with torso: (IRR: 17.4; 95% CI: 3.9 - 77.6; $p < 0.001$)
- Moderate impact tackles compared with low impact (IRR: 6.7 95% CI: 1.8 - 24.3; $p = 0.004$)
- An illegal tackler compared with a legal tackler (IRR: 67.4; 95% CI: 15.2 - 298.8; $p < 0.001$)

Concussion aetiology is likely extremely complex and context specific, dependent upon numerous interactions between intrinsic and extrinsic factors. To improve the validity of the investigation of concussion risk factors, two explanatory regression models (one for tackling, one for being tackled) were developed, consisting of intrinsic and extrinsic risk factors which were shown to be statistical risk factors for concussion through univariate analysis. These regression models followed the dynamic, recursive model of injury aetiology developed by Meeuwisse et al (2007), allowing contact event specific extrinsic risk factors to be analysed with respect to each individual's concussion history. By allowing interaction between all exposures entered into the model, any effect modification between risk factors on concussion outcome could occur, improving the understanding of concussion aetiology. Through regression analysis, the following risk factors remained statistical predictors of a concussion outcome for the tackling player:

- Severity of most-recent concussion of 8-14 days compared with no previous concussion (IRR: 8.4; 95% CI: 2.2 - 31.4; $p = 0.002$)
- Striking the ball carrier on the head compared with torso (IRR: 9.3; 95% CI: 1.1 - 76.6; $p = 0.038$)
- Striking the ball carrier on the shoulder/arm compared with torso (IRR: 4.3; 95% CI: 1.1 - 17.1; $p = 0.037$)
- Tackler striking ball carrier with their own head compared with shoulder/arm (IRR: 48.7; 95% CI: 15.0 - 157.6; $p < 0.001$)
- High impact tackles compared with low impact (IRR: 13.2; 95% CI: 3.0 - 57.1; $p = 0.001$)
- Moderate impact tackles compared with low impact (IRR: 4.0; 95% CI: 1.0 - 15.5; $p = 0.047$)

Through regression analysis, the following risk factors remained statistical predictors of a concussion outcome for the tackled player:

- Severity of most-recent concussion of 8-14 days compared with no previous concussion (IRR: 18.6; 95% CI: 2.3 - 151.6; $p = 0.006$)
- Being initially struck by the tackler on the head compared with torso: (IRR: 8.3; 95% CI: 1.4 - 47.8; $p = 0.018$)
- Moderate impact tackles compared with low impact (IRR: 6.4; 95% CI: 1.5 - 26.5; $p = 0.010$)
- An illegal tackler compared with a legal tackler (IRR: 54.4; 95% CI: 7.1 - 415.1; $p < 0.001$)

Research Aim Four (Sequence of Prevention Stage Three and Four – Concussion Prevention)

viii) Assess the efficacy of a neck training programme aiming to enhance neck function and reduce match concussion incidence.

Key Findings (Chapter 5)

Due to time constraints of the PhD data collection period, the intervention strategy was not informed from modifiable risk factors discovered in Chapter 4, but was developed following a review of potential modifiable concussion risk factors from pre-existing scientific literature. A neck training programme based around cranio-cervical flexion was implemented in an intervention group of Scottish Rugby academy players for the 2018/19 Scottish Premiership and Scottish Cup season. Neck function and match concussion incidence was monitored throughout the season and compared to a control group. This was in-line with the third and fourth steps of van Mechelen's research model. Although this was a controlled trial aiming to provide proof-of-concept of whether the programme could enhance neck function and reduce concussion incidence, implementation context and barriers to programme uptake were also considered. Programme rationale and potential benefits were clearly identified and presented to staff and participants, and the programme was professionally presented with each participant receiving their own progress folder, and each member of staff receiving a printed booklet detailing the aims and content of the programme. The training programme was presented in-line with the culture of player development and welfare, and was designed to enable easy adoption, with sessions only 10 minutes in duration, and all necessary equipment provided.

The neck training programme statistically enhanced isometric neck strength and neck flexion exercise capacity in the intervention group compared with the control group across the 2018/19 season. Match concussion incidence was 7.7 (intervention group) and 18.4/1000 player match hours (control group).

6.3: Original and Significant Contributions to Research

The current thesis has made several original contributions to the understanding of concussion in professional rugby in Scotland. Prior to the current thesis injury, and concussion specific epidemiological knowledge in match and training in professional rugby in Scotland was limited. For all professional cohorts, match injury incidences were greater than previous multiple cohort studies have indicated, but displayed greater similarity with previous single cohort studies. Training injury incidence for men's international rugby was similar to previous multiple cohort studies, whilst men's professional club rugby had a greater training injury incidence than previous studies have reported. Greater injury incidences than previous multiple cohort studies for the majority of cohorts may support prior suggestions that single cohort studies potentially provide a greater validity to injury recording and reporting. However, the single cohort approach also likely reflects playing/training tactics and styles specific to Scottish Rugby, as well as potentially indicating intrinsic injury risk factors which may be more prevalent in this population. These factors may also contribute to the greater injury incidences reported. Whilst match injury burden for men's international sevens was comparable with previous studies, match burden figures were high for rugby 15s cohorts. These were within the upper ranges previously recorded for men's international and men's professional club rugby, yet injury burden for women's international rugby was greater than has been recorded in previous studies. Training injury burden for men's international rugby was similar to what has been found previously, whilst training burden for men's professional club rugby was substantially greater than men's international rugby, yet similar to recent studies in comparable cohorts.

Scottish Rugby has a legal duty of care to understand the risk to player welfare from professional rugby in Scotland, and attempt to mitigate risks to an acceptable level (Fuller, 1995, Fuller & Drawer, 2004; HSE, 2001). Most frequent specific injuries, and specific injuries responsible for the greatest injury burden were identified for each cohort. Injury proportion, median severity, and proportion of injury burden of all injuries by recurrence status, position, location, type, cause, mechanism, time of year, time in match and training activity were identified for each cohort where possible. This provides Scottish Rugby with a quantification of injury occurrence, severity and risk by a multitude of different factors, allowing identification of potential areas to target through future risk mitigation strategies to reduce injury incidence, severity and/or burden. This allows Scottish Rugby to fulfil their legal obligation towards player welfare (Fuller, 1995, Fuller & Drawer, 2004; HSE, 2001).

Concussion incidence, mean and median severity and burden for each professional cohort were reported through Chapter 3A and 3B, which were previously unknown in scientific literature. Aside from men's international rugby, all cohorts reported match concussion incidences above what have been found previously. Since the introduction of the head injury assessment (HIA) protocol into elite rugby and input from World Rugby on best practices for concussion recognition & awareness (McCrory et al, 2009; McCrory et al, 2013; Fuller et al, 2015b; Raftery & Falvey, 2021; Raftery et al, 2016) reported concussion incidence and burden has increased (Best et al, 2005; Brooks et al, 2005a; Cosgrave & Williams, 2019; Fuller et al, 2008; Fuller et al, 2013; Fuller et al, 2017b; Fuller & Taylor, 2017; Fuller et al, 2020a; Rafferty et al, 2019; RFU, 2019; RFU, 2020; West et al, 2020). Evolutions to the HIA protocol since its inception may also have lowered the diagnostic threshold for concussion across this time frame (Fuller et al, 2020b; Raftery et al, 2016; Raftery & Tucker, 2016; West et al, 2020). Therefore, rather than a true increase in concussion incidence, it has been suggested that the work to improve the diagnosis and recognition of the injury has contributed to an increased rate of reported concussions and the subsequent burden associated with this (Cosgrave & Williams, 2019; Cross et al, 2017; Emery et al, 2017; Lincoln et al, 2011; West et al, 2020). Scottish Rugby have also been at the forefront of driving increased awareness of concussion, including participating in the "If in Doubt, Sit Them Out" campaign which was launched in 2015 (Sport Scotland, 2018). The increased awareness of concussion in Scotland specifically, alongside a general increase in concussion recognition and diagnostic ability of concussion in general, may explain the greater concussion incidence and burden values reported in the current research. As the most contemporary study of concussion epidemiology, greater incidence rates reported here may be a continuation of improved concussion recognition and diagnostic ability.

Whilst probability of concussion injury is unlikely to ever be reduced to zero, understanding factors which influence concussion aetiology may provide opportunity to reduce concussion incidence. Alongside extrinsic factors which support previous research, Chapter 4 found intrinsic factors around individual player concussive histories which were reported to alter chances of sustaining a future concussion. This was the first study of its kind in professional rugby which allowed for the interaction of intrinsic and extrinsic concussion risk factors. Regression analysis found that the most-recent concussion severity statistically influenced tackling and tackled player concussion propensity. Data suggests recurrence of symptoms or prolonged recovery into a second week of a player's most-recent concussion statistically increased chances of future concussion. Univariate analysis also found that greater than five previous concussions, and high HIA 2 symptom score and symptom severity also statistically increased future concussion incidence. This is the first study to quantify how factors surrounding previous concussions statistically alter chances of future concussion in professional rugby and provides rationale for investigation of concussion return to play protocols and rehabilitation management (see discussion around this in section 6.5).

Whilst Chapter 4 found intrinsic and extrinsic factors which statistically increased concussion probability, most of the solutions suggested were targeted at rule or policy changes. The need remained for a preventative measure for concussion which could be implemented within Scottish Rugby, or within any rugby setting. The results from the neck training programme implemented in Scottish Rugby academy players suggested an effective method of enhancing neck strength and neck flexion exercise capacity. Previous studies in rugby have found mixed results when implementing neck training programmes (Geary et al, 2014; Naish et al, 2013), and therefore the cranio-cervical flexion technique which was targeted in the Chapter 5 training programme appears an effective method to enhance neck function in rugby players. Prior studies have suggested that enhanced neck function may reduce concussion probability (Attwood et al, 2017; Collins et al, 2014; Hislop et al, 2017), and the study undertaken in Chapter 5 appeared the first in elite rugby to assess the efficacy of a neck training programme in enhancing neck function and reducing concussion incidence. Whilst the intervention group experienced a concussion incidence of 7.7/1000 player match hours compared with 18.4/1000 player match hours in the control group across the 2018/19 season, this was not a statistical reduction in concussion incidence, potentially due to the relatively small sample sizes which were available for the study (Brooks & Fuller, 2006). Whilst this was a small study implemented in a controlled setting, it appears a promising step forward for concussion prevention strategies and paves the way for further investigation in elite rugby of neck training programmes and reductions in concussion incidence, a reduction which would be of interest both to Scottish Rugby and many global rugby stakeholders.

Overall, this thesis demonstrates the application of van Mechelen's research model "The sequence of prevention of sports injuries" (van Mechelen et al, 1992) for concussion in elite rugby in Scotland, yet with several modifications to take into account the context and complexity of concussion aetiology, and the implementation context of a concussion prevention programme. General injury epidemiology data as well concussion specific epidemiology data for professional Scottish Rugby cohorts was reported, risk factors which statistically altered future concussion probability were outlined, and the efficacy of a preventative measure to reduce concussion incidence was assessed. As a result, this thesis presents novel findings in the topic area of concussion in professional rugby. Scottish Rugby have both a legal obligation and a financial interest to understand the risks to player welfare, and to attempt to reduce said risks to as low a level as practicably possible, and therefore findings from this thesis should be of great interest (Fuller, 1995, Fuller & Drawer, 2004; HSE, 2001; Morgan, 2002; Zhang et al, 2003; Williams et al, 2016). Due to the negative short- and long-term implications of concussion injury around increased susceptibility of further concussion or musculoskeletal injury, and increased likelihood of common mental disorders and neurocognitive degeneration (Cross et al, 2016; Decq et al, 2016; Gouttebarge et al, 2017; Hollis et al, 2009; Hume et al, 2016; McKee et al, 2009; Nordström et al, 2014), findings should also be of interest to World Rugby and the wider concussion epidemiology research community.

6.4: Methodological Strengths and Limitations

Injury Investigation Framework

The current PhD followed the "Sequence of Prevention of Sports Injuries" framework developed by van Mechelen et al (1992). The sequence of prevention model has provided a reliable framework for many investigations into sports injury and sports injury prevention (Emery et al, 2015; Myklebust, et al, 1998; Myklebust et al, 2003; O'Brien et al, 2019; Verhagen & van Mechelen, 2010; Verhagen et al, 2010; Wedderkop et al, 1997; Wedderkop,et al, 1999). However, despite its wide-spread use in controlled scientific studies, injury risk and/or incidence in real-world scenarios has not been reduced (Bahr, Thorborg and Ekstrand, 2015; Verhagen, Voogt, Bruinsma, & Finch, 2014). As a result, researchers have recently questioned the validity of the sequence of prevention model in ultimately reducing sports injury risk in "real-world" situations (Bittencourt et al, 2016; Bekker & Clark, 2016; Bolling et al, 2018; Finch, 2006). Many of these criticisms have focused on the context and complexity of injury occurrence and aetiology, the context in which resulting interventions are implemented in pragmatic real-world settings, and how the effectiveness of these interventions are assessed (Bahr & Krosshaug, 2005; Bittencourt et al, 2016; Bekker & Clark, 2016; Bolling et al 2018; Finch, 2006; Glasgow et al, 1999; Glasgow et al, 2019).

Due to it's widespread use in previous research, it was decided that van Mechelen's sequence of prevention model would be followed for this PhD research project. However, to address the concerns of this model surrounding the context and complexity of injury aetiology, and the context in which any intervention is implemented (Bolling et al, 2018; Fuller, 2019; Fuller, 2020; Meeuwisse et al, 2007), modifications to the model were applied to improve the validity of the injury investigation. These involved following the dynamic, recursive model of injury aetiology proposed by Meeuwisse et al (2007) during step two of the sequence of prevention model, allowing the effect of extrinsic contact event specific risk factors on concussion outcome to be analysed with respect to each player's individual concussion history (Fuller & Drawer, 2004). Although a controlled trial under "ideal" conditions, the implementation context of the concussion prevention programme in Chapter 5 was also considered, taking into account the potential barriers to uptake and necessary behaviour change required by Scottish Rugby staff and players for programme adoption, implementation, and maintenance. These were based upon recommendations from previous literature and other injury intervention frameworks (Bolling, Barboza, van Mechelen, & Pasman, 2020; DiClemente et al, 2002; Eime et al, 2004; Finch, 2006; Hanson et al, 2005; Steffen et al, 2010; van Tiggelen et al, 2008).

The TRIPP model proposed by Finch (2006) is an extension of van Mechelen's sequence of prevention model. This model proposes an extra two stages once the efficacy of an injury intervention has been established under ideal conditions. This proposes research to consider potential barriers to programme uptake in pragmatic, real-world settings (stage five), before utilising this information to implement the intervention in a real-world setting and assess intervention effectiveness (stage six) (Finch, 2006). Whilst the study in Chapter 5 assessed the efficacy of a neck training programme under controlled, "ideal" conditions, and potential barriers to uptake under these conditions were considered and acted upon, it is well understood that the programme as it is will not necessarily lead to concussion prevention if it is implemented immediately across all elite teams in Scottish Rugby or other rugby settings (Bolling et al, 2018, Finch, 2006). It could therefore be considered that not following the TRIPP model in it's entirety to fully comprehend the effectiveness of the neck training programme in pragmatic, real-world settings was an inherent weakness of the methodology for the current PhD.

However, the primary aim of Chapter 5 was to provide proof-of-concept by assessing programme efficacy in enhancing neck function and reducing concussion incidence in a controlled setting. Data suggest the programme results in enhanced neck function, and could possibly see statistical reductions in match concussion incidence with larger sample sizes (Brooks & Fuller, 2006). This process matches stage four of the TRIPP model, and therefore remains an important step on the pathway to injury prevention in real-world settings (Finch, 2006; van Mechelen et al, 1992). Due to time and funding constraints on the PhD data collection period, it was not possible to follow recommendations of stage five and six of the TRIPP model. However, it is recognised these steps are likely necessary to increase probability of concussion prevention in real-world settings. Although two feedback seminars (summer 2019) where results of the programme were presented, and practicality, feasibility and barriers to adoption, implementation and maintenance were discussed with the aim of providing greater detail to Scottish Rugby on how the neck training programme could be implemented union-wide in the future, it is recognised that this was not formal research. It is recommended and hoped future research builds on the data from the current PhD thesis to achieve this. Proposed methods for this research are discussed further in section 6.5.

Aside from the sequence of prevention and TRIPP, another injury investigation framework frequently utilised in sport is the Risk Management framework (Fuller & Drawer, 2004; Fuller et al, 2012). The Risk Management framework provides a structure for governing bodies to quantify and investigate risks to player welfare through the process of risk assessment, before communicating said risks to key stakeholders (Fuller & Drawer, 2004; Fuller, 2020). The processes of risk evaluation and risk perception, govern the need for risk mitigation strategies. If needed, these may take the form of preventive or therapeutic intervention (Fuller & Drawer, 2004). The principles of the Risk Management framework therefore align with the legal duty of care bestowed upon Scottish Rugby to understand potential hazards and risks to player welfare, to communicate these risks to players and key stakeholders, and attempt to reduce the risk to as low a level as practicably possible (Fuller, 1995; HSE, 2001; HSE, 2013; UK Public General Acts, 1974; UK Statutory Instruments, 1992).

Many of the required steps within the Risk Management framework are broadly similar with the sequence of prevention model, with injury epidemiology, risk factor analysis for injury aetiology, and an intervention featuring throughout both approaches (Fuller & Drawer, 2004; van Mechelen et al, 1992). However, the Risk Management framework places these steps in greater context, likely improving the validity of any injury epidemiology, aetiology, and risk mitigation intervention studies undertaken (Fuller, 2019). It is argued that the sequence of prevention model does not consider injury burden, does not consider the context in which injuries are sustained when assessing injury aetiology, does not provide standards against which mitigation strategies are assessed, nor does it provide valid criteria against which a mitigation strategy can be deemed successful (Fuller, 2019). Although following the sequence of prevention model, the current thesis attempted to correct these issues where required. Injury and concussion epidemiology undertaken in Chapter 3A and 3B of this thesis considered incidence, severity and burden of injuries, and the study of concussion risk factors and aetiology in Chapter 4 followed the dynamic, recursive model of injury aetiology proposed by Meeuwisse et al (2007), as recommended by Fuller and Drawer (2004) and Fuller (2007). Lastly, the context of implementation and potential barriers to uptake of the concussion prevention strategy in Chapter 5 was also considered prior to intervention initiation, whereas adherence to the programme was also assessed alongside its ability to enhance neck function and reduce concussion incidence.

Whilst the Risk Management framework suggests the concept of risk/burden should be the focus of any injury assessment and mitigation processes, the current thesis was concerned primarily with the injury of concussion. This was a pre-determined path and was not informed from any risk estimation or injury epidemiology results. Due to the negative short- and long-term implications of sustaining a concussion injury (Abrahams et al, 2014; Bertrand et al, 2016; Cross et al, 2016; de Beaumont, et al, 2007; Decq et al, 2016; Gouttebarge et al, 2017; Hay et al, 2016; Hollis et al, 2019; Hume et al, 2016; Lewis et al, 2017; McGuine, et al, 2014; Nordström et al, 2014), prevention of the injury and therefore reduced incidence appeared the most appropriate approach. Therefore, throughout investigations in Chapter 4 and Chapter 5 of this thesis, the sole interest was on probability of sustaining concussions and attempting to reduce concussion incidence.

Whilst this would likely affect concussion burden, concussion burden was not the primary outcome of interest.

The Risk Management framework focuses primarily on injury burden/risk, does not necessarily stipulate risk mitigation unless it is deemed necessary, allows flexibility around the processes of risk perception and risk evaluation, and is underpinned by corporate governance principles and health and safety legislation, allowing governing bodies to communicate the identification and quantification of risks within their sport (Fuller, 1995; Fuller, 2020; Fuller & Drawer, 2004; Fuller et al, 2012). As a result, the Risk Management framework is ideal for governing bodies such as Scottish Rugby to implement across their entire injury research strategy, as has been done in other sports (Fuller et al, 2012). For Scottish Rugby to fulfil their legal obligation in identifying and communicating risks to player welfare, and where deemed necessary, attempt risk reduction through risk mitigation measures, it is recommended a Risk Management approach is implemented as soon as possible across the union.

Individual Chapters

Chapter 3A and 3B utilised a single cohort methodology. As previously suggested, this may result in a more valid representation of injury incidence in professional rugby settings. However, it also accurately represents injury incidence/severity/burden pertinent solely to the cohort under observation, and therefore provides Scottish Rugby with an accurate and valid understanding of the risks present within elite rugby in Scotland. Data collection was conducted over more than a single season, to reduce the impact of single season variation. Studies in Chapters 3A and 3B utilised the definitions recommended by the rugby research consensus document (Fuller et al, 2007d), allowing comparisons to other research.

The time-loss injury definition of "an injury that results in a player being unable to take a full part in future rugby training or match play" (Fuller et al, 2007d) was utilised in Chapters 3A and 3B. If a player could not participate fully in training or would not be considered for match selection due to injury, they were deemed injured. Whilst this may accurately monitor time-loss during initial stages from acute injuries such as ligament rupture and fractures, it does not necessarily accurately record time-loss from chronic or overuse injury. In these instances, players may continue to train or play at less than full capacity with considerable pain (Bahr, 2009; Bahr et al, 2020). It may also not accurately represent the closing stages of an acute injury, where there is likely to be a graded return to full participation (Bahr et al, 2020; Palmer-Green, Fuller, Jaques, & Hunter, 2013). An injury definition which encapsulates the magnitude of training/performance restriction may be more valid (Bahr, 2009; Palmer-Green et al, 2013), and provide greater detail to the risk of rugby participation on player welfare and player availability. It is recommended a system such as this is integrated within Scottish Rugby and should be considered for the next edition of recommendations by the rugby research consensus group.

Although this was a prospective study across two seasons, a small sample of match injuries and match exposure was recorded for some cohorts. Due to time constraints of the PhD research project, the study period could not be extended. It is recommended to Scottish Rugby that injury epidemiology data collection is continued indefinitely, enhancing sample size and increasing the statistical power of the study (Brooks & Fuller, 2006), whilst also providing the opportunity to monitor injury patterns over time. Training injury epidemiology was not studied for women’s international rugby and men’s and women’s international rugby sevens, primarily due to missing training exposure data for these cohorts. Training injury epidemiology remains unknown in these populations. Implementing consistent methods of training exposure recording in these cohorts is required by Scottish Rugby to further their understanding of risks to player welfare and player availability for selection.

Off-pitch training exposure for men’s international and men’s professional club rugby cohorts was mainly recorded by players on their personal mobile phone devices using a Scottish Rugby application. In several instances throughout the study period, this data was incomplete, leading to the development of equations to estimate exposure to off-pitch training modalities. This resulted in 12.4% (men’s international rugby) and 6.7% (men’s professional club rugby) of total training exposure being estimated. This may have reduced the accuracy of training exposure and injury incidences. It is recommended to Scottish Rugby that improved methods of monitoring off-pitch training are utilised in the future. The obligation of monitoring and recording off-pitch training exposure should fall to sport science and/or strength and conditioning staff with each team.

As with previous examples in this area of research in English and Irish rugby (Brooke et al, 2005b; Cosgrave & Williams, 2019; RFU, 2020; West et al, 2019; West et al, 2020), recording of injury data and monitoring of training exposure was not the responsibility of the primary researcher, yet relied upon Scottish Rugby medical staff, performance staff and players. As a result, there will always be issues around the compliance of third parties to collect data as requested. However, meetings with Scottish Rugby ahead of the 2017/18 season dictated points on how injury data and training exposure was to be recorded, and these were reinforced with meetings in summer 2018 and throughout the 2018/19 season. These meetings also provided opportunity to check and validate recent training exposure with Scottish Rugby's own records. Injury data was collected from Scottish Rugby at 3-monthly intervals throughout the study, with any unclear data queried with the medical staff responsible for the data entry. At the end of each season, large data checks were performed comparing training exposure with another researcher associated with Scottish Rugby, and Scottish Rugby's own records. Equations were developed to estimate off pitch training exposure where data was lacking. It was believed this ensured training exposure data was as accurate as possible. Thorough, objective analysis of injury data to protect against duplicate data entry, incorrect cohort/scenario (match or training) injury attribution, and incorrect reporting of severity was undertaken prior to analysis. Any situation where injury data was not clear was discussed with the relevant medical staff. Future studies should attempt to implement clear, precise definitions and instructions around monitoring all forms of training exposure, whilst employing regular validation of injury data. Recording training exposure data should be the responsibility of staff rather than players. Systems and relationships should be in place to allow the primary researcher to perform regular checks with performance and medical staff over any queries on data recording/reporting.

Chapter 4 used univariate analysis to determine statistically significant intrinsic and extrinsic risk factors for concussion, before using explanatory regression models to allow for interaction of risk factors to determine the exposures which remained statistical predictors of concussion (Kirkwood & Sterne, 2006). Concussion is likely multifactorial in aetiology, and therefore consideration of the interaction of risk factors provides a greater validity to how these factors affect the probability of concussion (Fuller & Drawer, 2004; Meeuwisse, 1994). In-line with the "dynamic, recursive model of injury aetiology", contact event specific extrinsic risk factors were analysed with respect to each individual's concussion history intrinsic risk factors, providing specific context to the aetiology investigation (Fuller & Drawer, 2004; Meeuwisse et al, 2007). Concussion history risk factors were also updated for each match played, allowing for any changes to occur on a match-by-match basis for how concussion history may affect chance of future concussion (Meeuwisse et al, 2007).

Progressing from models focused on identifying risk factors associated with injury outcome, Bittencourt et al (2016) proposed a new "web of determinants" model for injury aetiology, reliant upon multi-directional relationships between multiple risk factors. This theory proposes an injury will occur when a specific pattern of interaction occurs between multiple intrinsic and extrinsic risk factors and an inciting event (Bittencourt et al, 2016). Therefore to understand injury occurrence, comprehension of the relationship and interaction between risk factors would provide greater detail, rather than solely identifying/quantifying exposure to specific risk factors as was done in the current thesis (Bittencourt et al, 2016). However, assuming the "web of determinants" model holds true, identification of risk factors which should be present within this complex system is still required (Bittencourt et al, 2016), and therefore the approach taken in the current thesis is still a valid approach to further the understanding of concussion aetiology. Future studies should look to include risk factors identified in this thesis and previous concussion aetiology studies to include in a complex systems approach such as that recommended by Bittencourt et al (2016) and Phillipe and Mansi (1998).

Concussion history data was collated from past medical records. Previous studies investigating the effect of concussion history on chances of sustaining a future concussion have relied upon participant recall to collate information on past concussions (Hollis et al, 2009; Schneider et al, 2013). However, participant recall has been suggested to lack validity (Kerr et al, 2012), suggesting the methodology used here was more appropriate.

Video analysis was used to collect data around extrinsic risks for concussion. Some previous studies have suggested video analysis may not be a reliable or valid method to study injury aetiology (Andersen et al, 2014; Krosshaug et al, 2007). Video analysis reliability of the this researcher was found to be good-excellent, and currently other methods of interpreting extrinsic risks (speed and impact force through GPS and accelerometery) are not deemed valid (Brennan et al, 2017; Vickery et al, 2014). As technology advances, it is hoped future research can utilise these tools.

Prospective concussion diagnosis through the HIA process was also used for concussion cases in chapter 4, as opposed to some previous research which has used removal for HIA 1 as a "concussion" case, regardless of whether the player was eventually diagnosed as concussed (Tierney et al, 2019; Tucker et al, 2017a; Tucker et al, 2017b). This is likely to improve validity of findings for the current thesis. Although analysing all concussions for men's international and men's professional club rugby cohorts across two seasons (assuming players gave consent for concussion history to be used), this still resulted in a relatively small number of concussions and match exposure. In some instances, this resulted in wide confidence intervals and may have resulted in larger errors (Agresti, 2018). Using regression analysis to study for interactions typically requires larger sample sizes than were available in the current study (Kamanger, 2012; Kirkwood & Sterne, 2006). To agree with the basic recommendation of 10 outcomes per variable for regression models (Austin & Steyerberg, 2017), approximately 1,530 matches would be needed to be included, rather than the 135 that were available. Due to time constraints of the PhD research project, the data collection period could not be elongated to increase sample size and improve the statistical power of the study (Austin & Steyerberg, 2017; Brooks & Fuller, 2006; Kamanger, 2012; Kirkwood & Sterne, 2006). There is also no certainty that statistical associations found between factors and concussion risk are causal. Chance association is a possibility, especially with smaller sample sizes (Meeuwisse, 1994). Whilst valid explanations can explain the associations found in this chapter suggesting a causal link, greater certainty would be provided with larger sample sizes and greater statistical power, and it is recommended to Scottish Rugby that the video analysis project continues over subsequent seasons to fulfil this aim. The study also only included professional male players, and therefore results may not be applicable to other professional populations within Scottish Rugby (international women's rugby or international rugby sevens), or to amateur rugby/rugby sevens of both genders.

Chapter 5 implemented a neck training programme, following recommendations to ensure necessary behaviour change and "buy-in" by Scottish Rugby staff and participants (Eime et al, 2004; Finch, 2006; Hanson et al, 2005; Steffen et al, 2010; van Tiggelen et al, 2008). This was evidenced by the good adherence of 1.8 sessions per week. The study also considered confounding factors which may also have influenced concussion incidence for the intervention and control groups as evidenced in Chapter 4, such as number of previous concussions and severity of most-recent concussion. As concussion recall may lack validity (Kerr et al, 2012), participants were provided a definition of concussion in the same questionnaire where they were to report their concussion history. This has been shown to improve validity of participant concussion recall (Robbins et al, 2014).

However, the greatest limitation with this study was the lack of randomised groups. Once the idea of a neck training intervention was proposed to Scottish Rugby for this study, they dictated from an ethical standpoint that they would not allow any of their academy players to be placed into a control group. Therefore, a control group was recruited from volunteers who also played their competitive rugby at the same level, but outside of Scottish Rugby's academy system. This selection bias may have resulted in differences at baseline for neck function, with independent t-tests finding statistically greater neck flexion, extension and left and right flexion strength in the control group at baseline. This may have resulted in greater opportunity for improvement in the intervention group compared with the control group. The players in Scottish Rugby's academies are players with a greater ability than others in the Scottish Premiership. Tackling with correct technique was found to reduce concussion risk in Chapter 4 of this thesis, and therefore the greater ability of Scottish Rugby academy players in the intervention group may also have reduced their chance of sustaining a concussion. A randomised trial would have controlled for these elements of bias. The study was also relatively underpowered to find a statistical difference in concussion incidence between the two groups (Brooks & Fuller, 2006). However, promising results were found, and it is hoped a future study monitors the efficacy of this neck training programme and concussion incidence on a larger randomised sample.

The study was implemented in a controlled setting, with the primary aim of providing proof-of-concept that the devised neck training programme could enhance neck function and reduce concussion incidence. The results of the programme were therefore based upon changes in neck function, efficacy in reducing concussion incidence, and adherence to the programme. Further dimensions to assess the impact of the intervention, such as the RE-AIM principles were not considered (Glasgow et al, 1999). However, it is recognised these principles allow a more comprehensive evaluation of an intervention, providing explanations for the magnitude of success and aid in a continued decision making process to improve the intervention for the future (Gaglio et al, 2013; Glasgow et al, 2019). On the assumption this avenue of research is continued, aiming for implementation of the neck training programme across all Scottish Rugby elite teams in the future, monitoring success of the intervention by use of the RE-AIM principles is heavily recommended. This is discussed further in section 6.5 below.

6.5: Potential Applied Implications and Future Research Directions

The overall aim of this thesis was to increase the understanding of concussion in elite rugby in Scotland. As a result of following van Mechelen's research model "The sequence of prevention of sports injuries", results that may improve player welfare and team performance were found. However, translating findings from sports medicine research into practice has previously been ineffective, due to lack of interest from those capable of implementing changes, and/or capability of translating controlled trials and research into an environment with multiple social and time-constrained factors (Green, 2001; Hanson, Allegrante, Sleet, & Finch, 2014). The following section will bring together relevant findings and discuss potential implications from the current PhD thesis for Scottish Rugby and other applied rugby associations/settings, as well as identify possible future research directions.

General Injury & Concussion Epidemiology

The primary reason for undertaking injury epidemiology research is to highlight specific injuries or a particular nature of injury (recurrence status, cause, mechanism, location, type etc.) which reports a high incidence, severity, or burden (Fuller & Drawer, 2004; van Mechelen et al, 1992). In-line with the legal responsibilities as an employer (Fuller, 1995), this allows professional sporting governing bodies to comprehend the risks present, communicate them to all stakeholders, and to attempt implementation of injury mitigation measures with the potential to improve player welfare and team performance if deemed necessary (Fuller & Drawer, 2004). The epidemiological data produced in Chapters 3A and 3B therefore provide Scottish Rugby with contemporary assessment of the hazards and risks to player welfare present in elite Rugby in Scotland. This data was shared with medical and performance staff from all men's and women's professional cohorts in Scottish Rugby in two feedback sessions in November 2019. The key findings that were presented are detailed below.

The current thesis was primarily concerned with concussion, and incidence, severity, burden, and nature of concussion injuries sustained in matches and training was shared with Scottish Rugby staff. Due to negative short-term implications of concussion injury on player welfare and player availability (and therefore team success) such as increased possibility of subsequent concussive or musculoskeletal injury (Cross et al, 2016; Drew et al, 2017; Morgan, 2002; Zhang et al, 2003; Williams et al, 2016), and potential long-term welfare implications such as neurocognitive decline, common mental disorders and chronic traumatic encephalopathy in later life (Bertrand et al, 2016; de Beaumont et al, 2007; Decq et al, 2016; Gouttebarge et al, 2017; McKee et al, 2009; Stern et al, 2011), the concussive incidences and burden found in the current study should be of a concern to Scottish Rugby. Concussion severity data also illustrated that there were several cases of players being returned to play within the minimum recommendation of 6 days. It is unclear whether this was due to incorrect recording of severity by Scottish Rugby medical practitioners, or a true reflection of players being returned too soon. Due to the greater chance of potential neuropsychological deficits and further injury if returned to play before adequate recovery (Barkhoudrian et al, 2011; McCrory et al, 2013; McCrory et al, 2017), this fact warrants investigation by Scottish Rugby, either to improve accuracy of injury severity recording, or to implement further safeguards/systems to prevent players returning to play too soon.

Although concussion was the most common injury for all cohorts aside from women's international rugby sevens (where it was the second most frequent), the greatest proportion of injury and greatest proportion of injury burden occurred to the lower limb across matches and training for all cohorts studied. Knee and ankle sprain/ligament injuries were particularly common in matches across all cohorts, and also represented a substantial proportion of match injury burden. Lower limb muscle injuries were particularly common in training, whilst knee injuries were again responsible for a substantial proportion of training injury burden for men's international and men's professional club rugby. Recurrent match injuries were substantially more common in women's international rugby compared with all other cohorts, and these injuries also represented a substantial proportion of the match injury burden for this group. Finally, rucking/mauling training activities also had the greatest injury incidence, median severity, and burden of all training activities for men's professional club rugby.

The data presented to Scottish Rugby provides an accurate statement of the hazards to player welfare. Whilst the current PhD thesis subsequently contributed a study of concussion aetiology and assessed the efficacy of a concussion preventative measure, further areas where risk could be mitigated to improve player care and reduce potential time loss were discussed with Scottish Rugby staff. It is hoped the data from this thesis allows Scottish Rugby to make informed decisions around potential risk mitigation strategies and interventions to improve their care of players and reduce total injury burden, potentially resulting in improved chances of team and financial success.

During feedback sessions with Scottish Rugby, the need for a constant injury epidemiology to monitor injury risk and patterns over time was implored to staff and practitioners who were present. The current PhD investigation followed the Sequence of Prevention model developed by van Mechelen et al (1992) on what was a pre-determined path to investigate concussion. However, researchers have recently questioned its validity in reducing sports injury risk in "real-world" situations (Bittencourt et al, 2016; Bekker & Clark, 2016; Bolling et al, 2018; Finch, 2006; Fuller, 2019; Fuller 2020), and therefore future investigations within Scottish Rugby should perhaps follow a different approach. For a union-wide injury investigation/monitoring policy in the future, it is recommended that Scottish Rugby utilise the Risk Management framework as the strategy for injury research across all elite teams, as has been utilised by other sporting governing bodies (Fuller et al, 2012). The Risk Management framework focuses primarily on injury burden within injury epidemiology, and is underpinned by corporate governance principles and health and safety legislation (Fuller, 1995; Fuller & Drawer, 2004; Fuller et al, 2012). Through flexibility of the processes of risk perception and risk evaluation, risk mitigation measures are implemented when deemed necessary, rather than as a matter of course (Fuller, 2020). Implementation of this approach union-wide across all elite teams, alongside valid and reliable methods of monitoring match and training exposure and workload, would allow Scottish Rugby to fulfil their legal obligation in identifying and communicating risks to player welfare and attempt risk reduction through risk mitigation measures where deemed necessary to improve player care and possibility of team and financial success (Fuller, 1995; Morgan, 2002; Zhang et al, 2003; Williams et al, 2016). A continued/constant approach such as this would allow Scottish Rugby to monitor injury trends over time, as well monitor the effectiveness of any injury mitigation measures which are implemented. Chapter 3A also illustrated examples where player load monitoring may help to reduce soft-tissue injury incidence in training. As training is more modifiable than match play, understanding interactions in player load, training activities, and injury cause/mechanism may provide opportunity to reduce injury burden through altering training activity content, removing high-risk activities, or manipulating player load. An integrated injury epidemiology and workload monitoring system as part of the Risk Management framework would allow this to happen.

Whilst a constant injury epidemiology system may benefit player welfare and team performance in the short- to medium-term, an accurate record of all injuries sustained per player may allow research to quantify the effect a rugby playing career has on quality of life in retirement. Previous studies have demonstrated a link between retired elite sportspeople, injury, and long-term musculoskeletal health issues (Cooper, Scammell, Batt, & Palmer, 2018; Davies et al, 2017; Russell, Tracey, Wiese-Bjornstal & Canzi, 2018). However, these studies tend to rely on participant recall for injuries sustained during sporting careers which may be inaccurate. Ongoing reliable injury epidemiology data collection may allow Scottish Rugby to commence research on player musculoskeletal health in retirement, described by injuries recorded prospectively during their career, rather than based on participant recall.

Similarly, research has begun to associate concussions in a sporting career with poor mental health and neurodegeneration in later life, a key issue for Scottish Rugby player welfare (Decq et al, 2016; Gouttebarge et al, 2017; Guskiewicz et al, 2005; Lewis et al, 2017). Again, these studies rely on participant recall for concussion history, which has been shown to possibly lack validity (Kerr et al, 2012). With all concussion injury information stored due to injury epidemiology, Scottish Rugby would have the potential to produce research where player concussion history is based upon medical record rather than participant recall. This could be paired with Scottish Rugby's use of "CogSport" as a computerised cognitive assessment. As a reliable monitor of cognitive function (Collie et al, 2003), baseline measures could be taken from the start of a professional career and be used to monitor changes into retirement. If these data were to be compared with a non-rugby playing control group, this would be the first research of its kind in rugby to monitor the effects of concussion on cognitive function throughout a career and into later-life. Results may aid in determining the number or severity of concussions in a playing career which statistically increase chances of poorer health outcomes in following years, allowing Scottish Rugby to make evidence-informed decisions around concussion injury management.

The notion of an injury definition which encapsulates the magnitude of training/performance restriction was discussed previously. Utilising an injury definition which considers training/performance restriction (Bahr, 2009; Palmer-Green et al, 2013) may provide further comprehension on the occurrence and effect of chronic injuries, which is currently difficult to ascertain (Bahr, 2009; van Wilgen & Verhagen, 2012). Whilst this may place extra effort and time on injury reporting, it is recommended that future studies in rugby investigate how the current time-loss injury definition and one which considers training/performance restriction result in differences in the described injury burden. This may pave the way for an updated rugby research consensus recommendation on injury definitions, possibly increasing validity of rugby injury epidemiology in applied settings.

One further point for future research to consider would be to further the understanding of differences between single and multiple cohort studies. Taking men's international rugby match injuries as an example, previous multiple cohort studies have found injury incidence at recent Rugby World Cups as 89.1 (2011), 90.1 (2015), and 79.4 per 1000 player match hours (2019) (Fuller et al, 2013; Fuller et al, 2017b; Fuller et al, 2020a). Yet whilst following the same injury definition, the current study found an injury incidence of 120.0/1000 hours. Whilst single cohort studies are likely to reflect the risk factors pertinent to that particular cohort, such as playing style, tactics, and contact technique (Alexander et al 1980; Bolling et al, 2018; Fuller & Drawer, 2004; Fuller et al, 2010; Gissane et al, 1998; Quarrie & Hopkins, 2008), single cohort studies may also provide a more accurate description of injury incidence in rugby, as recognising, diagnosing, and reporting of injury is likely to be more reliable and consistent amongst single medical teams (Moore et al, 2015). Future research aiming to clarify the differences between reported injury incidences dependent upon single or multiple cohort methodologies may improve understanding of the differences between these approaches and reported injury data.

Concussion Risk Factors

Chapter 4 found intrinsic and extrinsic risk factors which statistically increased chances of concussion. The data supported previous studies (Burger et al, 2016; Sobue et al, 2017; Tucker et al, 2017b) suggesting that the lowest probability of concussion to the tackling and tackled player was for the tackler to use their shoulder/arm to strike the ball carrier's torso, which is currently encouraged as "correct" tackling technique (Rugby AU, 2017; Rugby Smart, 2018). The data illustrated that probability of concussion increased to both the tackling and tackled players if their head was the first point of contact in the tackle, or if the impact force was above what was considered as "low", as has also been found previously (Cross et al, 2019; Sobue et al, 2017; Suzuki et al, 2019; Tucker et al, 2017a; Tucker et al, 2017b). For the tackling player, striking the ball carrier on the shoulder/arm compared with the torso also statistically increased probability of a concussion outcome.

From this researcher's perspective, these findings of extrinsic concussion risk factors point to two potential strategies to mitigate concussion probability in the tackle. Firstly, contact technique where the tackler uses their shoulder/arm to make contact with the ball carrier's torso needs to be encouraged. This could be achieved through a contact skill training framework, such as the tackling training model outlined by Hendricks et al (2018). Although a previous attempt implemented amongst non-elite players to improve tackler technique using a World Rugby instructional video was unsuccessful (Kerr et al, 2018), the effectiveness of the five-week pre-season tackle training framework proposed by Hendricks et al (2018) amongst professional rugby players is yet to be studied. Understanding the effectiveness of this approach, as well as development of a ball carrier proficiency programme may provide a path to improve contact skill proficiency and therefore reduce probability of concussion outcomes in the tackle. If deemed effective, a "minimum standard" of contact skill proficiency could be introduced into professional rugby, only allowing players to be selected for competition who have demonstrated adequate ability in this area. Safer tackler and ball carrier performance may also be encouraged by harsher sanctions for incorrect/dangerous technique. World Rugby recently introduced harsher sanctions for the tackler if they made dangerous contact with the ball carrier's head (World Rugby, 2019a). Data from the current study supports this law change, and also recommends that the shoulder/arm region is included in this sanction bracket, which may result in reduced concussion propensity for the tackler.

Secondly, the current work suggests that reducing impact force in the tackle would potentially reduce probability of concussion for both the tackler and tackled player. This provides a quandary for reducing tackle concussion propensity in professional rugby union, as a successful tackle situation from the attacking or defending team's perspective is often determined by who dominates the collision (Hendricks et al, 2014b; van Rooyen et al, 2014). From an attacking team's perspective, a dominant collision providing forward momentum allows for a gain in territory, forcing the defensive team to retreat and re-organise and/or contribute more defenders to the tackle situation, potentially resulting in fewer defenders in the correct place for the subsequent defensive phase. Conversely, for the defensive team, a dominant collision also likely allows a gain in territory, as well as increasing the difficulty for the attacking team to retain the ball, increasing the chance of a turnover in possession. These elements are integral to the game of rugby, yet the question for researchers or governing bodies should be how to remove the focus of dominant, high impact collisions to achieve these aims, and encourage other playing styles and behaviours which provide the same key performance outcomes. One potential method would be a rule change to reduce the number of defenders in the first defensive line, which has been the aim of a proposed rule change from World Rugby to implement a 50:22 kick rule encouraging defending teams to place more players behind the defensive line to limit kicking opportunities by the attacking team (World Rugby, 2019e). An alternative approach recommended by this researcher would be to introduce a law governing the number of players in a defensive line at any one time. This may be as low as eight or nine players, yet as phases progress, defensive teams would be allowed to introduce more defenders – a potential system being an extra player allowed in the first line of defence for every five attacking phases. With more space to attack, especially in early phases, the team in possession may attempt to gain territory and forward momentum by attacking the space available, rather than attempting to dominate any potential collision. With fewer defenders, the defensive team would likely prioritise try prevention as opposed to winning turnovers and gaining territory through dominant collisions. Due to the extra space to defend, it is likely there would be a greater frequency of passive front-on tackles or side-on tackles, which have been shown to have a reduced impact force and reduced probability of concussion outcome compared to active, front-on tackles where players are looking to dominate the potential collision (Cross et al, 2019; Hendricks et al, 2014a; Seminati et al, 2017; Tucker et al, 2017b).

However, whilst law changes in other sports have been shown to be successful in reducing probability of targeted injuries (Black et al, 2016; Cantu & Mueller, 2000; Heck et al, 2004; Janda et al, 2001; Marshall et al, 2003), a trial implemented in the English Championship during the 2019/2020 rugby season introducing harsher sanctions to the tackler for tackles made above the line of the armpit of the ball carrier was unsuccessful in reducing concussion incidence to the tackler (Stokes et al, 2021). Whilst frequency of occurrence of extrinsic concussion risk factors such as the proportion of upright tacklers and ball carriers, tackles where the tackler made first contact with the ball carrier's head/neck, and tackles where the initial contact was above the armpit line were all statistically reduced pre- to post-policy change, tackler concussion incidence statistically increased across the same time frame (Stokes et al, 2021). This trial reinforces the difficulty of reducing concussion frequency in rugby, as well as the likely multi-factorial aetiology of concussion.

By considering concussion as a multifactorial injury, further potential methods to reduce concussion probability may be to consider the concussion history of each player. This chapter illustrated that a player's concussion history can alter their chance of sustaining a future concussion. Univariate analysis suggested the number of previous concussions and symptom score and severity from the most recent concussion influenced future concussion incidence, whilst regression analysis also found that a most-recent concussion severity of 8-14 days statistically increased concussion propensity for both the tackling and tackled player. Prior concussion may increase chances of sustaining a future concussion through inadequate recovery and remaining neuromuscular control deficits (Bussey et al, 2019; Di Virgilio et al, 2019; Hides et al, 2016; Howell et al, 2018).

As current medical technology lacks necessary sensitivity and specificity to detect concussion recovery (Arfanakis et al, 2002; Broglio et al, 2017; Hammeke et al, 2013; Makdissi et al, 2017; Shahim et al, 2016; Zetterberg et al, 2016), more conservative rehabilitation protocols may be required to increase chances of complete recovery. To utilise this information to develop concussion prevention strategies, introduction of a database with detail of the concussion history of each player on either a national (Scottish Rugby) or international scale (World Rugby) would be required with date, symptomology, and recovery rate/exacerbation of symptoms of each concussion sustained by each player recorded. Individualised recovery strategies could then be implemented for each player, with more conservative protocols utilised where concussion history data and rate of symptom resolution deem it necessary. To accommodate this, all players must initially follow the current return to sport protocol outlined by World Rugby (McCrory et al, 2017, World Rugby, 2017b). For players who progress through this recovery protocol with no exacerbation of symptoms or prolonged symptoms, data from the current study indicates these players would have no statistical alteration in future tackle/being tackled concussion propensity, and could therefore return to play once the return to play protocol is complete. However, for those players who experience exacerbation/prolonged symptoms during recovery at any stage, for those who have greater than five previous concussions, or experience a large number or intensity of symptoms at most-recent concussion diagnosis, data from Chapter 4 suggests these players should follow a more conservative rehabilitation protocol of at least 14 days. This may allow greater opportunity for any potential residual tissue damage from the most-recent/previous concussions to repair, potentially reducing chance of future concussion.

Assuming this approach is followed, a challenge for practitioners and researchers is to ensure player honesty when reporting symptoms. Players may lie in order to be available for selection sooner if they believe that honestly describing prolonged or exacerbated symptoms during the recovery period may lead to a longer rehabilitation (Bruce & Echemendia 2004; Kerr, Register-Mihalik, Kroshus, & Baugh, 2016). Previous research has found that professional rugby players ignore concussion symptoms due to not understanding how serious concussion injuries can be (Fraas, Coughlan, Hart, & McCarthy, 2014), demonstrating that player education in this area is paramount. Rugby has made great strides in improving the culture and education of players and their attitudes towards concussion in recent years. It is imperative that this continues, and players understand the risks to future participation and performance (as well as potential negative short- and long-term health implications) associated with concussion injury.

In order to confirm the findings from Chapter 4 of this thesis, a study with a larger number of concussion outcomes is likely required to improve the statistical power of the study (Austin & Steyerberg, 2017; Kamanger, 2012; Kirkwood & Sterne, 2006). Assuming that prolonged severity of the most recent concussion remains a statistical influencer on future concussion probability, investigation of whether re-emergence/excacerbation of any particular symptom (double vision, headaches, dizziness etc.), it's duration and severity would appear the next step in improving the understanding of prior concussion and future concussion aetiology. Inclusion of other intrinsic risk factors for concussion, such as biological sex, neck strength, genetic pre-dispositions and behaviour may also increase the understanding of concussion aetiology. Use of micro-technologies such as player global positioning systems, and accelerometers monitoring head and body acceleration were deemed too inaccurate at the start of data collection to be used for this study (Brennan et al, 2017; Vickery et al, 2014). However, as accuracy of these technologies advance, it is hoped these tools can be utilised to obtain a more accurate understanding of extrinsic risks of player speed, impact forces, and resultant body and head accelerations and their influence on concussion outcome in the tackle. Finally, the research carried out in Chapter 4 focused on a cohort of professional male rugby players, and therefore findings can not necessarily be applied to other rugby or rugby sevens playing cohorts. It is hoped future research addresses these points through further studies.

Neck Function and Reduced Concussion Incidence

The aim of Chapter 5 of this thesis was to assess the efficacy and establish proof-of-concept of a neck training programme based around cranio-cervical flexion to enhance neck function and reduce concussion incidence in a controlled setting. Whilst the neck training programme statistically enhanced isometric neck strength and neck flexion exercise capacity compared with a control group, recorded concussion incidence in the intervention group (7.7/1000 player match hours) was not statistically different to the control (18.4/1000 player match hours). However, the lack of statistical difference in concussion incidence between the groups may have been due to the relatively small sample sizes and subsequent wide confidence intervals (Brooks & Fuller, 2006). Nevertheless, the neck training programme provides promise as an efficacious way to enhance neck strength in elite rugby players and may have the potential to reduce concussion incidence. Due to the legal duty of care bestowed upon Scottish Rugby (and/or other rugby governing bodies) to protect player welfare and attempt to reduce risks to health to as low a level as practicably possible (Fuller, 1995; HSE, 2001), a training programme which may reduce concussion incidence should be of great interest to rugby governing bodies.

In order to confirm the findings of this proof-of-concept study, a larger, randomised control trial with recorded volume of rugby exposure outwith the matches being studied (both training and further match play) is first required. Further studies utilising active control groups to establish optimal training protocols is also recommended. Chapter 5 targeted a global approach to improving neck function, targeting strength, endurance, proprioception and perturbation through cranio-cervical flexion. Perturbation training of the neck may improve activation and protective mechanisms of dynamic stabilisers in cervical spine musculature through feed-forward and feedback motor control (Mansell et al, 2005), mirroring plyometric style training which has been shown to increase neuromuscular ability to stabilise other joints such as the knee (Swanik, Lephart, Giannantonio, & Fu, 1997) and shoulder (Swanik et al, 2002). Whilst the current study utilised perturbation training, changes in neck stiffness as a result were not assessed. Future studies may wish to examine the effect of perturbation training alone on neck stiffness and isometric neck strength and whether there is any correlation with reduced concussion incidence.

Assuming efficacy of the neck training approach to enhance neck function and reduce concussion incidence is proven, it is advised to Scottish Rugby that this programme is implemented across all elite teams. This may be of particular importance amongst women players, with previous research suggesting that women may experience greater head acceleration upon head impact due to weaker neck musculature compared with men (Tierney et al, 2005; Gutierrez et al, 2014). A programme enhancing neck strength may therefore see great benefit in reducing concussion incidence for female players. To aid in ensuring programme effectiveness, following stages five and six of the TRIPP framework (Finch, 2006) is advised.

Stage five of the TRIPP framework aims to comprehend how the results of efficacy research in ideal conditions can be introduced effectively into real-world situations, and therefore aims to develop understanding around the implementation context (Finch, 2006). If the neck training programme were to be implemented on a wider scale across Scottish Rugby, the targeted player squads and respective staff first need to be identified. Subsequent understanding of current concussion mitigation behaviours, as well as knowledge of the attitudes and perception towards concussion of the targeted players and their respective coaches and associated medical staff, as well as authoritative figures within Scottish Rugby would provide key information on potential barriers for programme uptake (Finch, 2006, Fuller & Drawer, 2004; Lund & Aarø, 2004; van Tiggelen et al, 2008). These attitudes towards concussion and concussion prevention are likely influenced by risk perception and evaluation of all parties, possibly affected by previous personal or vicarious experiences of the injury (Finch, 2006; Fuller & Drawer, 2004). It is therefore important to consider targeted athletes and staff as individual entities when considering the implementation context (Bolling et al, 2018; Lund & Aarø, 2004; van Tiggelen et al, 2008; Verhagen, 2012). Knowledge of financial and time costs (player- and staff-hours and staff:player ratios) of implementing the intervention versus potential reward of reduced injury burden (resulting in improved care of player welfare as well as enhanced possibility of team and financial success) as well as access to necessary equipment would also be necessary to understand the likelihood of programme adoption (Drawer & Fuller, 2002a; Drawer & Fuller, 2002b; Finch, 2006). In order to identify and comprehend the above points, a qualitative research study is likely required in order to understand how best to tailor interventions to suit elite playing squads across Scottish Rugby (Bolling et al, 2018; Jack, 2006; Verhagen & Bolling, 2018). With this approach in mind, results of the efficacy study implemented in Chapter 5 were disseminated to medical and performance staff from various professional and academy Scottish Rugby cohorts through a series of feedback presentations in summer 2019. Alongside methodology and results, discussions were raised around barriers to programme uptake and maintenance, and which aspects of the programme could be improved to ensure greater adherence and a more effective training programme. Whilst these feedback sessions resulted in elements of the neck training programme being implemented *ad hoc* into resistance training/injury prevention programmes amongst various Scottish Rugby cohorts for the 2019/20 season and beyond, it is recognised this was not formal research. If Scottish Rugby's interest remains in a union-wide concussion prevention programme, a qualitative or mixed methods investigation aiming to improve understanding of the implementation context is recommended prior to programme implementation through stage six of the TRIPP framework (Finch, 2006).

Stage six recommends implementation of the intervention with consideration to the contextual cues identified through research in stage five, and monitoring its effectiveness (Finch, 2006). Beyond solely monitoring the programme's effectiveness at reducing concussion incidence however, observing all dimensions presented in the RE-AIM framework may demonstrate how multiple factors may impact upon concussion incidence reduction (Gaglio et al, 2013; Glasgow et al, 1999; Glasgow et al, 2019; O'Brien & Finch, 2014). This may allow for a more comprehensive intervention evaluation, and can aid in a continuous decision-making feedback-process, identifying which components of the intervention are successful, and which require alteration to improve the overall intervention impact (Gaglio et al, 2013; Glasgow et al, 1999; O'Brien & Finch, 2014). By building on the efficacy study of the neck training programme in Chapter 5 of this thesis by following stages five and six of the TRIPP model (Finch, 2006), it is hoped a successful concussion prevention intervention can be implemented across all elite teams in Scottish Rugby. It is hoped this process is followed by Scottish Rugby in subsequent years.

6.6: Conclusion

Rugby is a contact sport where concussion occurs frequently. Despite Scotland being a tier one rugby nation, knowledge of concussion epidemiology was previously limited, despite Scottish Rugby's legal duty of care to understand risks to player welfare. The primary aim of this thesis was therefore to increase understanding of concussion in elite rugby in Scotland. In order to complete this primary aim, four research aims were constructed which followed van Mechelen's research model "The sequence of prevention of sport's injuries" (van Mechelen et al, 1992), yet with adaptations which considered the context and complexity of concussion injury, and the implementation context of any intervention strategy. These aims were: to establish concussion injury incidence, severity and burden in professional Scottish rugby, to be compared with all other injuries; ascertain concussion cause, mechanism, and further nature of concussion injuries; identify statistical concussion history and extrinsic risk factors for concussion, and demonstrate whether any interaction effect exists between these risk factors; and establish the efficacy/proof-of-concept of a neck training programme in enhancing neck function and reducing concussion incidence.

Concussion was the most frequent match injury for all professional cohorts, aside from women's international rugby sevens where it was the second most frequent. Regression analysis illustrated extrinsic factors such as head and shoulder/arm being struck in the tackle and greater tackle impact forces, and intrinsic factors around the most-recent concussion sustained were all reported to influence chance of future concussion injury. This illustrates the necessity for rule adaptations to the tackle, as well as implementation of individualised or more conservative concussion rehabilitation protocols to potentially reduce future concussion probability. Finally, in an attempt to reduce concussion incidence, the efficacy of a concussion prevention measure was assessed. The implementation of a neck training programme resulted in enhanced neck function, yet no statistical reduction in concussion incidence between the intervention (7.7/1000 player match hours) and the control group (18.4/1000 player match hours) was found.

Several original and significant contributions were made to the rugby concussion epidemiology research literature throughout this thesis. It is hoped the information provided allows Scottish Rugby to make evidence-informed decisions around concussion injury which positively impacts player welfare and team performance. However, the need remains for ongoing concussion injury related research, both in Scottish Rugby and across the world. It is hoped future investigations lead to improved understanding and management of concussion injury in rugby, resulting in concussion incidence being minimised to a low a level as practicably possible.

END OF CHAPTER 6

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APPENDICES

Appendix 1: Head Injury Assessment Forms

INTERNATIONAL RUGBY BOARD

Head Injury Assessment Tool HIA 1

The assessing Doctor's clinical judgment that a player has sustained a concussive injury should overrule a "negative" HIA Tool result and sideline neurological assessment.

Player's name: **Competition:** **Date:** DD/MM/YYYY

Kick-off time: **Team:** **Time of suspected event:** ☐ 0-20 mins ☐ 21-40 mins ☐ 41-60 mins ☐ 61-80 mins

HIA completed by: ☐ Team medic ☐ MDD ☐ Other **Match Day Doctor present:** ☐ Yes ☐ No

Temporary substitution requested by: ☐ Team doctor ☐ MDD ☐ Referee

Reason for HIA or permanent removal (see options page 2 – identify number):

HIA TOOL - Part of the sideline neurological assessment (answer ALL questions)			
Any answer in column 1 = positive HIA - Player must NOT return to play	**1**	**2**	**3**
Maddocks Questions - Orientation	Incorrect	Correct	N/A
What venue are we at today?			
Which half is it now?			
Who scored last in this match?			
What team did you play last week/game?			
Did your team win the last game?			
Immediate memory (ABNORMAL = score < 12 or less than baseline) Use one of the options and test three times. Max. score = 15	Abnormal	Normal	N/A
Option 1 - elbow / apple / carpet / saddle / bubble			
Option 2 - candle / paper / sugar / sandwich / wagon			
Option 3 - baby / monkey / perfume / sunset / iron			
Digits backwards (ABNORMAL = score < 2 or less than baseline) Each correct string in an option is one point	Abnormal	Normal	N/A
Trial 1 numbers: 4-3-9 / 3-8-1-4 / 6-2-9-7-1 / 7-1-8-4-6-2			
Trial 2 numbers (if needed): 6-2-9 / 3-2-7-9 / 1-5-2-8-6 / 5-3-9-1-4-8			
Balance evaluation (ABNORMAL = score > 14 seconds. Max. of 4 trials) One trial < 14 seconds is normal balance and no further trials required	Abnormal	Normal	N/A
Tandem gait			
Symptom checklist	Yes	No	N/A
Do you have a headache?			
Do you have any dizziness?			
Do you have any 'pressure in your head'?			
Do you feel nauseated or do you feel like vomiting?			
Do you have any blurred vision?			
Does the light or noise worry you?			
Do you feel as though you are slowing down?			
Do you feel like you are 'in a fog'?			
Do you feel unwell?			
Delayed recall (ABNORMAL = score < 2 or less than baseline)	Abnormal	Normal	N/A
Test recall of immediate memory words			
Clinical signs	Yes	No	N/A
Emotional - sad, anxious, nervous, irritable			
Drowsy/has difficulty concentrating			

Player removed from game? ☐ Player removed from game because of HIA result

☐ Player removed from game because team medic performing HIA suspects concussion despite normal HIA

☐ Player removed due to another injury; detail:

Video review? ☐ Yes ☐ No **Video influenced decision?** ☐ Yes ☐ No

Please send this form to the HIA Competition Co-ordinator

INTERNATIONAL RUGBY BOARD	*Head Injury Assessment Tool*	**HIA 2**

This form should be completed on all players removed permanently from the field following a head injury and on all players who have had a HIA independent of the result.
It should also be completed on any player who develops concussive symptoms after the game.

Player's name: ______ **Competition:** ______ **Date:** DD/MM/YYYY

Team: ______ **Form completed by:** ☐ Team doctor ☐ MDD ☐ Other **Time:** ______

Was a HIA 1 form completed for this event? ☐ Yes ☐ No, the player presented with symptoms after the match

Ask the player: *"How do you feel?"*
You should score each symptom, based on how the player feels at the time of questioning:

	NONE	MILD		MODERATE		SEVERE	
Headaches	0	1	2	3	4	5	6
'Pressure in head'	0	1	2	3	4	5	6
Neck pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like 'in a fog'	0	1	2	3	4	5	6
'Don't feel right'	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Excessive tiredness	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or anxious	0	1	2	3	4	5	6
Number of symptoms*:	**/22**						
Severity of symptoms:**	**/132**						

* This score is determined by counting the number of individual symptoms reported. The result should be compared to each individual's baseline score. **For athletes without a baseline score**, any symptom declared in the symptom list which is not usually experienced by the player following a Rugby match or training is strongly in favour of concussion.
** This score is determined by adding up each number related to a reported symptom and is generally used to monitor recovery of a concussion.

Head Injury Assessment Tool HIA 2

INTERNATIONAL RUGBY BOARD

STANDARDISED ASSESSMENT of CONCUSSION (SAC) AND BALANCE TESTS

ORIENTATION (1 point for each correct answer)		
What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score: out of 5		

IMMEDIATE MEMORY						
List	**Trial 1**		**Trial 2**		**Trial 3**	
1. Elbow	0	1	0	1	0	1
2. Apple	0	1	0	1	0	1
3. Carpet	0	1	0	1	0	1
4. Saddle	0	1	0	1	0	1
5. Bubble	0	1	0	1	0	1
TOTAL						
Immediate memory score: out of 15						

Alternative word lists (use five words)				
1. Candle	2. Paper	3. Sugar	4. Sandwich	5. Wagon
1. Baby	2. Monkey	3. Perfume	4. Sunset	5. Iron
1. Finger	2. Penny	3. Blanket	4. Lemon	5. Insect

CONCENTRATION: DIGITS BACKWARD					
List	Trial 1		Alternative digit lists		
4 – 9 – 3	0	1	6 – 2 – 9	5 – 2 – 6	4 – 1 – 5
3 – 8 – 1 – 4	0	1	3 – 2 – 7 – 9	1 – 7 – 9 – 5	4 – 9 – 6 – 8
6 – 2 – 9 – 7 – 1	0	1	1 – 5 – 2 – 8 – 6	3 – 8 – 5 – 2 – 7	6 – 1 – 8 – 4 – 3
7 – 1 – 8 – 4 – 6 – 2	0	1	5 – 3 – 9 – 1 – 4 – 8	8 – 3 – 1 – 9 – 6 – 4	7 – 2 – 4 – 8 – 5 – 6

CONCENTRATION: MONTHS IN REVERSE ORDER (1 point for entire sequence correct)		
Dec-Nov-Oct-Sep-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0	1
Concentration score: out of 5		

INTERNATIONAL RUGBY BOARD	Head Injury Assessment Tool	HIA 2

STANDARDISED ASSESSMENT of CONCUSSION (SAC) AND BALANCE TESTS

UPPER LIMB CO-ORDINATION		
	Left	Right
Which arm was tested?		
Co-ordination score:		out of 1

BALANCE EXAMINATION	
	No. of errors
Double leg stance	
Single leg stance	
Tandem stance	
TOTAL BALANCE SCORE Assessment of a population of Rugby players suffering from a concussive injury will usually elicit the following results: • Tandem test - 3 or more errors • Single leg stance - 4 or more errors	

DELAYED RECALL		
Word		
Elbow	0	1
Apple	0	1
Carpet	0	1
Saddle	0	1
Bubble	0	1
TOTAL		

Alternative word lists (use five words)				
1. Candle	2. Paper	3. Sugar	4. Sandwich	5. Wagon
1. Baby	2. Monkey	3. Perfume	4. Sunset	5. Iron
1. Finger	2. Penny	3. Blanket	4. Lemon	5. Insect

SAC SCORE	
Orientation	/5
Immediate memory	/15
Concentration	/5
Delayed recall	/5
TOTAL Assessment of a population of Rugby players suffering from a concussive injury will usualy elicit the following results: • Total SAC score 24 or below • Concentration score 2 or below (digits backward) • Delayed recall 3 or less words	/30

At the end of HIA 2, the diagnosis of concussion is:

☐ Now confirmed ☐ Probable, but I prefer to consider the player concussed ☐ Excluded

Head Injury Assessment Tool — HIA 3

INTERNATIONAL RUGBY BOARD

Player's name: ____ **Competition:** ____ **Date of match:** DD / MM / YYYY **Kick-off time:** ____ **Team:** ____

Age: ____ **Height:** ____ **Weight:** ____ **Was a HIA 1 form completed for this event?** ☐ Yes ☐ No

Was a HIA 2 form completed for this event? ☐ Yes ☐ No, the player presented with symptoms 24-48 hours after the match

Has this player been previously diagnosed with a concussion? ☐ Yes ☐ No ☐ Don't know If yes, how many? ____

Year player began playing Rugby: ____ **Year player began playing professional Rugby:** ____

Player position: ☐ Front row (1, 2, 3) ☐ Second row (4, 5) ☐ Back row (6, 7, 8) ☐ Half-backs (9, 10) ☐ Centre (12, 13) ☐ Wing (11, 14) ☐ Full-back (15)

Injury mechanism: A selection **MUST** be made for **each of the four areas**, that is 'Game event', 'Collision', 'Contact' and 'Player technique':

Game event: ☐ Tackling ☐ Being tackled ☐ Ruck or maul ☐ Scrum ☐ Unknown

Collision: ☐ Opponent ☐ Co-player ☐ Ground ☐ Unknown

Contact: ☐ Head/head ☐ Head/shoulder ☐ Head/upper limb ☐ Head/knee or hip ☐ Head/foot ☐ Head/ground ☐ Unknown

Player technique: ☐ Correct technique ☐ Head incorrect position ☐ Other incorrect technique

Additional tool: Identify (below) the supportive tool used at this 36-48 hour follow up:

☐ None ☐ SCAT3 ☐ CogSport ☐ Headminder ☐ Impact ☐ Other

Was the result abnormal? ☐ Yes ☐ No

Diagnostic summary:
☐ Concussion confirmed on game day with no residual signs or symptoms at time of completion of HIA 3
☐ Concussion confirmed with signs and/or symptom(s) still present(s) at time of completion of HIA 3
☐ Concussion excluded (no sign or symptom of concussion since the injury)

Definition - final diagnosis

1. If the player had a post-game, same day diagnosis of confirmed concussion, **the final diagnosis is confirmed concussion**
2. If the player has developed a concussion post-game, **the final diagnosis is confirmed concussion**
3. A 'concussion excluded' diagnosis applies to a player with:
   - a negative post-game, same day diagnosis (HIA 2), AND
   - a negative concussion assessment at 36-48 hours after the game (HIA 3)

Head Injury Assessment Tool — HIA 3

INTERNATIONAL RUGBY BOARD

This form should be completed for **every case** of suspected and confirmed concussion and for any player developing symptoms or signs after the game that may suggest the development of a delayed concussion. The form is to be completed after two nights' sleep – including the night of the game.

Today's date: DD / MM / YYYY **Time form completed:** ____ **Physician's name:** ____ **Player's name:** ____

To the player: From the kick-off time until now:

HOW MANY?			HOW MUCH?						WHEN?				HOW LONG?									STILL PRESENT?						
Identify any symptom you have experienced since the injury or following the Game which is not usually noted with Rugby.			Identify the maximum intensity of each symptom.						Identify when you started to feel each symptom identified.				Please identify how long each of these symptoms lasted.									Confirm the intensity of any unusual symptom that is still present from 1 to 6.						
			Mild		Moderate		Severe																Mild		Moderate		Severe	
	No	Yes	1	2	3	4	5	6	A*	B**	C***	D****	< 1 min	< 15 min	< 30 min	< 1 hour	< 3 hrs	< 1 day	< 2 days	< 1 week	> 1 week	0	1	2	3	4	5	6
Headaches																												
'Pressure in head'																												
Neck pain																												
Nausea or vomiting																												
Dizziness																												
Blurred vision																												
Balance problems																												
Sensitivity to light																												
Sensitivity to noise																												
Feeling slowed down																												
Feeling like 'in a fog'																												
'Don't feel right'																												
Difficulty concentrating																												
Difficulty remembering																												
Fatigue or low energy																												
Confusion																												
Drowsiness																												
Trouble falling asleep/disturbed sleep																												
More emotional																												
Irritability																												
Sadness																												
Nervous or anxious																												

ANTEROGRADE AMNESIA (amnesia after the injury)? ☐ No ☐ Yes, duration: ____

RETROGRADE AMNESIA (amnesia before the injury)? ☐ No ☐ Yes, duration: ____

A* = During match, immediately
B** = During match, later
C*** = Post-match, same day
D**** = Post-match, days later

Please send pages 1 and 2 PLUS all HIA forms to your Competition Co-ordinator

Appendix 2: Scottish Rugby Contract: Injury Data Clause

1 Data Protection/ Confidential Information

1.1 The Player acknowledges and agrees that the SRU (*sic: now Scottish Rugby)* is permitted to hold personal information about the Player as part of its personnel and other business records and may use such information in the course of its business. The Player agrees that the SRU may disclose such information to third parties in the event that such disclosure is in the SRU's view required for the proper conduct of the SRU's business. This Paragraph applies to information held, used or disclosed in any medium.

1.2 The Player hereby accepts that the medical records kept by the SRU are owned by the SRU and that the Medical Team will be free at any time without the Player's prior consent to discuss any aspect of the Player's medical condition with, and to disclose his medical records to, any party who may reasonably require in the context of the SRU's business, discussion or disclosure of the same.

1.3 Except where disclosure is required by law or otherwise permitted by this Agreement or where a prohibited drug or substance has been detected as a result of tests carried out by the Medical Team or by any doctor acting on the instructions of World Rugby, the SRU agrees not to unreasonably publicise or disclose the Player's medical records to any third party.

1.4 By signing this Agreement, the Player authorises the SRU, acting reasonably, to make contact with and to obtain from his doctor (or such other persons as the Player or any previous employer of the Player, may have consulted in relation to medical or fitness matters concerning the Player) details of the Player's medical history, fitness and condition which relate to the Player's ability to perform his obligations, duties and responsibilities under this Agreement and the Player hereby authorises and consents to such doctor and/or other persons releasing any such details to the SRU and/or the Medical Team and the Player shall sign any release, waiver or other document that may be required in order for the SRU to obtain such information and/or records.

1.5 Except in the performance of his duties under this Agreement, the Player shall not during the Employment or at any time after the termination of the Employment or after expiration of the Term (howsoever caused or arising) without the prior written consent of the SRU use for his own benefit or for the benefit of any person, firm, club, company or organisation (other than the SRU) or directly or indirectly divulge or disclose to any person (other than another employee of the SRU who is aware of the same), any Confidential Information which has come or may come to his knowledge during the Employment or previously or otherwise.

1.6 During the Employment, the Player shall use his best endeavours to prevent the publication, divulgence or disclosure by third parties of any Confidential Information.

1.7 The restrictions contained in this Paragraph shall cease to apply to any Confidential Information, which may, otherwise than through the default of the Player, become available to or within the knowledge of, the public generally.

1.8 The restrictions in this Paragraph will not prevent the Player from making a protected disclosure in accordance with the Public Interest Disclosure Act 1998 insofar as the Player makes such disclosure in accordance with the procedure stipulated in that Act.

Appendix 3: Configurable Team Report example

Player Code	Period Name	Period Number	Start Time	End Time	Duration	Field Time	Odometer
[redacted]	Session	0	15:56:44	16:47:13	00:45:10	00:45:09	4262.95
[redacted]	Session	0	15:56:44	16:47:13	00:45:10	00:45:09	4178.7
[redacted]	Session	0	15:56:44	16:47:13	00:45:10	00:45:09	4020.83
[redacted]	Session	0	15:56:44	16:47:13	00:45:10	00:45:09	3962.25
[redacted]	Session	0	15:56:56	16:15:52	00:18:55	00:18:55	2548.12
[redacted]	Session	0	15:56:44	16:47:13	00:45:10	00:45:09	3988.05
[redacted]	Session	0	16:05:04	16:31:49	00:26:44	00:26:44	2172.62
[redacted]	Session	0	15:56:44	16:47:13	00:45:10	00:45:09	4196.29
[redacted]	NL - Conditioning	1	15:56:44	16:04:57	00:08:13	00:08:13	827.69
[redacted]	NL - Conditioning	1	15:56:44	16:04:57	00:08:13	00:08:13	781.144
[redacted]	NL - Conditioning	1	15:56:44	16:04:57	00:08:13	00:08:13	704.351
[redacted]	NL - Conditioning	1	15:56:44	16:04:57	00:08:13	00:08:13	766.59
[redacted]	NL - Conditioning	1	15:56:44	16:04:57	00:08:13	00:08:13	755.704
[redacted]	NL - Conditioning	1	15:56:44	16:04:57	00:08:13	00:08:13	753.968
[redacted]	Concussion Test	1	15:56:56	16:15:52	00:18:55	00:18:55	2548.12
[redacted]	NL - Sprints	2	16:05:04	16:31:49	00:26:44	00:26:44	1900.28
[redacted]	NL - Sprints	2	16:05:04	16:31:49	00:26:44	00:26:44	1924.57
[redacted]	NL - Sprints	2	16:05:04	16:31:49	00:26:44	00:26:44	1926.4
[redacted]	NL - Sprints	2	16:05:04	16:31:49	00:26:44	00:26:44	1826.91
[redacted]	NL - Sprints	2	16:05:04	16:31:49	00:26:44	00:26:44	1832.6
[redacted]	NL - Sprints	1	16:05:04	16:31:49	00:26:44	00:26:44	2172.62
[redacted]	NL - Sprints	2	16:05:04	16:31:49	00:26:44	00:26:44	2100.1
[redacted]	NL - Conditioning Games	3	16:34:22	16:39:24	00:05:02	00:05:02	748.072
[redacted]	NL - Conditioning Games	3	16:34:22	16:39:24	00:05:02	00:05:02	725.204
[redacted]	NL - Conditioning Games	3	16:34:22	16:39:24	00:05:02	00:05:02	702.236
[redacted]	NL - Conditioning Games	3	16:34:22	16:39:24	00:05:02	00:05:02	666.225
[redacted]	NL - Conditioning Games	3	16:34:22	16:39:24	00:05:02	00:05:02	685.48
[redacted]	NL - Conditioning Games	3	16:34:22	16:39:24	00:05:02	00:05:02	613.917
[redacted]	NL - Conditioning Games	4	16:42:03	16:47:13	00:05:10	00:05:10	786.91
[redacted]	NL - Conditioning Games	4	16:42:03	16:47:13	00:05:10	00:05:10	747.787
[redacted]	NL - Conditioning Games	4	16:42:03	16:47:13	00:05:10	00:05:10	687.852
[redacted]	NL - Conditioning Games	4	16:42:03	16:47:13	00:05:10	00:05:10	702.516
[redacted]	NL - Conditioning Games	4	16:42:03	16:47:13	00:05:10	00:05:10	714.269
[redacted]	NL - Conditioning Games	4	16:42:03	16:47:13	00:05:10	00:05:10	728.304

Appendix 4: Informed Consent for previous/current exiled players to access concussion history information

PhD Research Project: Concussion in Elite Scottish Rugby Union

PhD Student: Stuart Bailey (stuart.bailey@napier.ac.uk)

Institution: Edinburgh Napier University

Study Supervisors: Dr Debbie Palmer (d.palmer@napier.ac.uk); *Dr Russell Martindale* (r.martindale@napier.ac.uk)

Scottish Rugby Contact: Dr James Robson (james.robson@sru.org.uk)

Background

As part of the afore-titled PhD project in partnership with the Scotland Rugby Union (SRU), we are attempting to conduct a study to identify certain factors which may increase the risk of players sustaining a concussive injury. This will attempt to establish the relative risk of certain extrinsic and intrinsic risk factors pertinent to the game of rugby.

Extrinsic risk factors relate to features within the game, such as body position before contact, speed approaching contact situations, tackle types etc., and can be identified through video analysis. Intrinsic risk factors are specific to each individual, and in this research will involve information surrounding the concussive history of each player. We would like to investigate how certain intrinsic factors interact with extrinsic factors, attempting to provide a more coherent estimate of the risk of concussive injury amongst players representing the SRU.

This study requires information of concussive injuries sustained from August 2014 – June 2019. The data required is detailed below. For players contracted to Scottish Rugby through playing for Glasgow or Edinburgh for this entire duration (or whilst representing Scotland), concussive history information can be obtained through historical injury records held by these teams. However, for players who are/have been contracted to clubs outwith Scottish Rugby between August 2014 – June 2019, we require the player's permission to approach the medical staff at the respective club(s)/country to ask for concussive injury data (from concussions sustained whilst playing for that club/country) to be shared with us.

Required Data

To complete this investigation, we would need access to the following information for each player:

- The date of each concussion sustained (from August 2014 – June 2019)
- The severity of each concussion (time from injury to passing RTP protocols)
- The immediate symptomology of each concussion (HIA forms 1, 2, & 3)
- Dates of passed HIAs (from August 2014 – June 2019)

No action is required on your part for us to access and analyse this data. We only require your permission, which would allow us to approach your club's medical team and ask for access to the data. No other injury/illness/medical data will be asked for or viewed.

Data Confidentiality

The confidentiality of all data will be ensured throughout all investigations. Concussive data will only be saved and analysed using coded identification numbers. Data will never be analysed or reported on an individual basis. Any HIA forms which are analysed may contain player names, however, these will be saved under identification numbers.

Once all data required has been saved under unique identification numbers, all uses of player's names will be deleted. This will result in no player being identifiable throughout data management, analysis, and reporting of results. All data will be stored on a password protected computer at Edinburgh Napier University.

Withdrawal from the Study

As an exiled player, if you agree to participate and for us to contact your club's medical team in order to view concussive history data, you are completely entitled to withdraw from the study at any time without discrimination, by contacting the primary researcher (Stuart Bailey) or James Robson on the contact details displayed above. Data from that point on will no longer be accessed, but the data that has already been provided by that individual up until the declaration to withdraw will still be used for data analysis.

Questions

If you have any questions or queries about the study, please feel free to contact the primary researcher (Stuart Bailey), or the study supervisors on the details above.

It is hoped that this research will increase our understanding of concussive injury mechanisms, improving medical care of Scottish Rugby players in the future, and therefore your assistance in this matter would be greatly appreciated.

Kind regards,

Stuart Bailey

To Whom it May Concern,

I……………………………………………., freely and voluntarily consent for the medical team at my current/previous clubs to be contacted with the aim of sharing concussive injury data (described above) for the current study.

The research aims to elucidate details around causes of concussion within elite level rugby union in Scotland. I do not have to complete any task or procedure but have been asked to allow my concussion injury details to be accessed.

I understand that my data will be anonymised, my name will not be linked to the investigation in anyway and may data will be unidentifiable as to be belonging to me.

I comprehend that I am free to withdraw at any time without prejudice or negative consequences. However, the data I have provided up until that time may still be used.

I have been made aware that I am free to ask questions about the research at any time.

I……………………………………………, give consent for data surrounding my concussion injury records to be shared with Stuart Bailey, conducting research on behalf of Scottish Rugby. Concussion injury records include date and severity of all concussions from August 2014 - June 2019 and all Head Injury Assessment paperwork during this timeframe.

Signed (player)……………………………………………Date:…………………………….

Signed (researcher)………………………………………Date:…………………………….

Stuart Bailey
Office 1B.29
Edinburgh Napier University
Sighthill Court
Edinburgh
EH11 4BN

stuart.bailey@napier.ac.uk

Appendix 5: Extrinsic categorical variables within each contact type

TABLE A.1: Extrinsic categorical variables assessed as concussion risk factors for the tackling player

Risk Factor	Categories	Definition
Match Quarter	Q1	Tackle is made between 0-20 mins
	Q2	Tackle is made between 21-40 mins
	Q3	Tackle is made between 41-60 mins
	Q4	Tackle is made between 61-80 mins
Playing Position	Forward	Playing as a forward
	Back	Playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap whilst tackling
	No	Not wearing a scrum cap whilst tackling
Tackler Speed into Tackle	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Ball Carrier Speed into Tackle	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Accelerating Player	Ball Carrier	Ball carrier accelerates into tackler's body (not arms), attempting to dominate the collision
	Tackler	Tackler accelerates into the ball carrier's body, attempting to dominate the collision
	Both	Both players attempt to dominate the collision
	Neither	Neither player attempts to dominate the collision
Direction of Tackle	Front-On	Tackler makes contact from in-front of ball carrier's path of movement
	Side-On	Tackler makes contact from beside ball carrier's path of movement
	Behind	Tackler makes contact from behind ball carrier's path of movement
Ball Carrier Fend	None	No arm is extended to fend tackler away, or it has no effect in obstructing the tackler
	Moderate	Arm is extended away from ball carrier's body, and reduces effectiveness of the tackle
	Strong	Arm is extended away from ball carrier's body, and prevents tackler completing the tackle

TABLE A.1 Continued: Extrinsic categorical variables assessed as concussion risk factors for the tackling player

Risk Factor	Categories	Definition
Body Region Struck on the Ball Carrier	Head	Tackler's first contact with the ball carrier is to the ball carrier's head
	Neck	Tackler's first contact with the ball carrier is to the ball carrier's neck
	Shoulder/Arm	Tackler's first contact with the ball carrier is to the ball carrier's shoulder/arm
	Torso	Tackler's first contact with the ball carrier is to the ball carrier's torso
	Lower Limb	Tackler's first contact with the ball carrier is to the ball carrier's lower limb
	Inconclusive	Body region struck on the ball carrier is inconclusive
Body Region Used to Strike Ball Carrier	Head	Tackler's first contact with the ball carrier is the tackler's head
	Neck	Tackler's first contact with the ball carrier is the tackler's neck
	Shoulder/Arm	Tackler's first contact with the ball carrier is the tackler's shoulder/arm
	Torso	Tackler's first contact with the ball carrier is the tackler's torso
	Lower Limb	Tackler's first contact with the ball carrier is the tackler's lower limb
	Inconclusive	Body region used by the tackler is inconclusive
Tackler Head Position	Beside	Tackler places their head alongside the ball carrier
	Above	Tackler places their head above the projected path of the ball carrier
	Behind	Tackler places their head behind the path of the ball carrier
	In-Front	Tackler places their head in the projected path of the ball carrier
Tackle Type	Shoulder	Tackler attempts to impede ball carrier with the use of their shoulder, followed by use of arms
	Smother	Tackler attempts to impede ball carrier by use of their torso, followed by use of arms
	Arm	Tackler attempts to impede the ball carrier by the initial use of their arm(s)
	Tap	Tackler attempts to use their hand to trip the ball carrier on the lower limb below the knee
	Jersey	Tackler attempts to impede ball carrier by initially grasping the ball carrier's jersey
	Collision	Tackler attempts to impede ball carrier without using their arms to grasp/wrap
	High	Tackler makes contact with the ball carrier above the line of the shoulders
	Lift	Tackler raises the ball carrier's hips above their head

TABLE A.1 Continued: Extrinsic categorical variables assessed as concussion risk factors for the tackling player

Risk Factor	Categories	Definition
Tackle Sequence	One on One	A single tackler attempts to impede the ball carrier
	Two on One Sequential	Two tacklers attempt to impede the ball carrier. The time between the initial contact of tackler one and tackler two is greater than 0.2 s
	Two on One Simultaneous	Two tacklers attempt to impede the ball carrier. The time between the initial contact of tackler one and tackler two is less than 0.2 s
Ball Carrier Body Position	Low	Height of shoulders level with/below hips
	Medium	Height of shoulders above hips, yet demonstrating moderate flexion of hips and/or knees
	Upright	Demonstrating near maximal extension of hips and knees
Tackler Body Position	Low	Height of shoulders level with/below hips
	Medium	Height of shoulders above hips, yet demonstrating moderate flexion of hips and/or knees
	Upright	Demonstrating near maximal extension of hips and knees
Tackle Impact Force	Low	Minimal rate of change of velocity of tackler's centre of mass
	Moderate	Moderate rate of change of velocity of tackler's centre of mass
	High	Large rate of change of velocity of tackler's centre of mass
Tackler Legality	Legal	Referee deems the tackler performed a legal tackle
	Illegal	Referee deems the tackler performed an illegal tackle
Body Region to Strike Ground	Head	The tackler's head is the first body region to strike the ground after making the tackle
	Neck	The tackler's neck is the first body region to strike the ground after making the tackle
	Shoulder/Arm	The tackler's shoulder/arm is the first body region to strike the ground after making the tackle
	Torso	The tackler's torso is the first body region to strike the ground after making the tackle
	Lower Limb	The tackler's lower limb is the first body region to strike the ground after making the tackle
	Stays on Feet	The tackler remains on their feet after making the tackle
	Inconclusive	The tackler's body region which strikes the ground first is inconclusive

TABLE A.2: Extrinsic categorical variables assessed as concussion risk factors for the tackled player

Risk Factor	Categories	Definition
Match Quarter	Q1	Tackle is made between 0-20 mins
	Q2	Tackle is made between 21-40 mins
	Q3	Tackle is made between 41-60 mins
	Q4	Tackle is made between 61-80 mins
Playing Position	Forward	Playing as a forward
	Back	Playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap whilst being tackled
	No	Not wearing a scrum cap being tackled
Player Speed into Tackle	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Tackler Speed into Tackle	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Accelerating Player	Tackled Player	Ball carrier accelerates into tackler's body (not arms), attempting to dominate the collision
	Tackler	Tackler accelerates into the ball carrier's body, attempting to dominate the collision
	Both	Both players attempt to dominate the collision
	Neither	Neither player attempts to dominate the collision
Direction of Tackle	Front-On	Tackler makes contact from in-front of ball carrier's path of movement
	Side-On	Tackler makes contact from beside ball carrier's path of movement
	Behind	Tackler makes contact from behind ball carrier's path of movement

TABLE A.2 Continued: Extrinsic categorical variables assessed as concussion risk factors for the tackled player

Risk Factor	Categories	Definition
Body Region Struck by Tackler	Head	Tackler's first contact with the tackled player is to the tackled player's head
	Neck	Tackler's first contact with the tackled player is to the tackled player's neck
	Shoulder/Arm	Tackler's first contact with the tackled player is to the tackled player's shoulder/arm
	Torso	Tackler's first contact with the tackled player is to the tackled player's torso
	Lower Limb	Tackler's first contact with the tackled player is to the tackled player's lower limb
	Inconclusive	Body region struck on the tackled player is inconclusive
Body Region Used by Tackler to Strike Tackled Player	Head	Tackler uses their head to make first contact with tackled player
	Neck	Tackler uses their neck to make first contact with tackled player
	Shoulder/Arm	Tackler uses their shoulder/arm to make first contact with tackled player
	Torso	Tackler uses their torso to make first contact with tackled player
	Lower Limb	Tackler uses their lower limb to make first contact with tackled player
	Inconclusive	Body region used by tackler is inconclusive
Tackle Sequence	One on One	A single tackler attempts to impede the tackled player
	Two on One Sequential	Two tacklers attempt to impede the tackled player. The time between the initial contact of tackler one and tackler two is greater than 0.2 s
	Two on One Simultaneous	Two tacklers attempt to impede the tackled player. The time between the initial contact of tackler one and tackler two is less than 0.2 s
Tackle Type	Shoulder	Tackler attempts to impede ball carrier with the use of their shoulder, followed by use of arms
	Smother	Tackler attempts to impede ball carrier by use of their torso, followed by use of arms
	Arm	Tackler attempts to impede the ball carrier by the initial use of their arm(s)
	Tap	Tackler attempts to use their hand to trip the ball carrier on the lower limb below the knee
	Jersey	Tackler attempts to impede ball carrier by initially grasping the ball carrier's jersey
	Collision	Tackler attempts to impede ball carrier without using their arms to grasp/wrap
	High	Tackler makes contact with the ball carrier above the line of the shoulders
	Lift	Tackler raises the ball carrier's hips above their head

TABLE A.2 Continued: Extrinsic categorical variables assessed as concussion risk factors for the tackled player

Risk Factor	Categories	Definition
Tackle Impact Force	Low	Minimal rate of change of velocity of tackled player's centre of mass
	Moderate	Moderate rate of change of velocity of tackled player's centre of mass
	High	Large rate of change of velocity of tackled player's centre of mass
Tackled Player Body Position	Low	Height of shoulders level with/below hips
	Medium	Height of shoulders above hips, yet demonstrating moderate flexion of hips and/or knees
	Upright	Demonstrating near maximal extension of hips and knees
Tackler Body Position	Low	Height of shoulders level with/below hips
	Medium	Height of shoulders above hips, yet demonstrating moderate flexion of hips and/or knees
	Upright	Demonstrating near maximal extension of hips and knees
Tackler Legality	Legal	Referee deems the tackler performed a legal tackle
	Illegal	Referee deems the tackler performed an illegal tackle

TABLE A.3: Extrinsic categorical variables assessed as concussion risk factors for players entering an attacking ruck

Risk Factor	Categories	Definition
Match Quarter	Q1	Ruck is formed between 0-20 mins
	Q2	Ruck is formed between 21-40 mins
	Q3	Ruck is formed between 41-60 mins
	Q4	Ruck is formed between 61-80 mins
Playing Position	Forward	Player entering ruck is playing as a forward
	Back	Player entering ruck is playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap when approaching ruck
	No	Not wearing a scrum cap when approaching ruck
Player Speed into Approaching Ruck	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Player Role	Protecting Ball	Player approaches ruck with no intention of clearing out and protects the ball.
	Clear Out Low	Clear out from a low body position: Shoulders level/below hips
	Clear Out Med	Clear out from a medium body position: Shoulders above hips, yet with hip/knee flexion
	Clear Out High	Clear out from an upright body position: Extended knees and hips
	Other	Other role not covered by the above
Body Region Used by Player to Strike Ruck	Head	Player’s first contact with the ruck is with their head
	Neck	Player’s first contact with the ruck is with their neck
	Shoulder/Arm	Player’s first contact with the ruck is with their shoulder/arm
	Torso	Player’s first contact with the ruck is with their torso
	Lower Limb	Player’s first contact with the ruck is with their lower limb
	Inconclusive	Body region used by player upon entering ruck is inconclusive

TABLE A.3 Continued: Extrinsic categorical variables assessed as concussion risk factors for players entering an attacking ruck

Risk Factor	Categories	Definition
Body Region Struck on Player in Ruck	Head	Player makes first contact with the head of a player in the ruck/entering the ruck
	Neck	Player makes first contact with the neck of a player in the ruck/entering the ruck
	Shoulder/Arm	Player makes first contact with the shoulder/arm of a player in the ruck/entering the ruck
	Torso	Player makes first contact with the torso of a player in the ruck/entering the ruck
	Lower Limb	Player makes first contact with the lower limb of a player in the ruck/entering the ruck
	Inconclusive	Body region struck on player in ruck is inconclusive
Ruck Speed	Fast	Ruck time (from tackle completion to the ball being played from the ruck) less than 3 s
	Slow	Ruck time (from tackle completion to the ball being played from the ruck) more than 3 s
Player Penalised	No	Player entering ruck did not give away a penalty
	Yes	Player entering ruck gave away penalty

TABLE A.4: Extrinsic categorical variables assessed as concussion risk factors for players entering a defensive ruck

Risk Factor	Categories	Definition
Match Quarter	Q1	Ruck is formed between 0-20 mins
	Q2	Ruck is formed between 21-40 mins
	Q3	Ruck is formed between 41-60 mins
	Q4	Ruck is formed between 61-80 mins
Playing Position	Forward	Player entering ruck is playing as a forward
	Back	Player entering ruck is playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap when approaching ruck
	No	Not wearing a scrum cap when approaching ruck
Player Speed into Approaching Ruck	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Player Role	Jackal	Player attempts a jackal position to steal the ball
	Protecting Ball	Player approaches ruck with no intention of clearing out and protects the ball.
	Clear Out Low	Clear out from a low body position: Shoulders level/below hips
	Clear Out Med	Clear out from a medium body position: Shoulders above hips, yet with hip/knee flexion
	Clear Out High	Clear out from an upright body position: Extended knees and hips
	Other	Other role not covered by the above
Body Region Used by Player to Strike Ruck	Head	Player's first contact with the ruck is with their head
	Neck	Player's first contact with the ruck is with their neck
	Shoulder/Arm	Player's first contact with the ruck is with their shoulder/arm
	Torso	Player's first contact with the ruck is with their torso
	Lower Limb	Player's first contact with the ruck is with their lower limb
	Inconclusive	Body region used by player upon entering ruck is inconclusive

TABLE A.4 Continued: Extrinsic categorical variables assessed as concussion risk factors for players entering a defensive ruck

Risk Factor	Categories	Definition
Body Region Struck on Player in Ruck	Head	Player makes first contact with the head of a player in the ruck/entering the ruck
	Neck	Player makes first contact with the neck of a player in the ruck/entering the ruck
	Shoulder/Arm	Player makes first contact with the shoulder/arm of a player in the ruck/entering the ruck
	Torso	Player makes first contact with the torso of a player in the ruck/entering the ruck
	Lower Limb	Player makes first contact with the lower limb of a player in the ruck/entering the ruck
	Inconclusive	Body region struck on player in ruck is inconclusive
Ruck Speed	Fast	Ruck time (from tackle completion to the ball being played from the ruck) less than 3 s
	Slow	Ruck time (from tackle completion to the ball being played from the ruck) more than 3 s
Player Penalised	No	Player entering ruck did not give away a penalty
	Yes	Player entering ruck gave away penalty

TABLE A.5: Extrinsic categorical variables assessed as concussion risk factors for players entering an attacking maul

Risk Factor	Categories	Definition
Match Quarter	Q1	Maul is formed between 0-20 mins
	Q2	Maul is formed between 21-40 mins
	Q3	Maul is formed between 41-60 mins
	Q4	Maul is formed between 61-80 mins
Playing Position	Forward	Player entering maul is playing as a forward
	Back	Player entering maul is playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap when approaching maul
	No	Not wearing a scrum cap when approaching maul
Maul Formation	Lineout	Maul is formed from a lineout
	Open Play	Maul is formed in open play
Player Speed Approaching Maul	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Body Region Used when Making Contact with Maul	Head	Player joining maul makes first contact with the maul with their head
	Neck	Player joining maul makes first contact with the maul with their neck
	Shoulder/Arm	Player joining maul makes first contact with the maul with their shoulder/arm
	Torso	Player joining maul makes first contact with the maul with their torso
	Lower Limb	Player joining maul makes first contact with the maul with their lower limb
	Inconclusive	Body region used by player joining maul is inconclusive
Player Role	Tackled Player	Player who was in possession of the ball when the maul was formed
	Ball Carrier	Primary role of securing the ball in the maul
	Pushing	Primary role of attempting to push the maul forward
Maul Status	Collapsed	Maul collapses before ball is played
	Non-Collapsed	Players remain on their feet until ball is played
Penalised	No	Player is not penalised
	Yes	Player is penalised

TABLE A.6: Extrinsic categorical variables assessed as concussion risk factors for players entering a defensive maul

Risk Factor	Categories	Definition
Match Quarter	Q1	Maul is formed between 0-20 mins
	Q2	Maul is formed between 21-40 mins
	Q3	Maul is formed between 41-60 mins
	Q4	Maul is formed between 61-80 mins
Playing Position	Forward	Player entering maul is playing as a forward
	Back	Player entering maul is playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap when approaching maul
	No	Not wearing a scrum cap when approaching maul
Maul Formation	Lineout	Maul is formed from a lineout
	Open Play	Maul is formed in open play
Player Speed Approaching Maul	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Body Region Used when Making Contact with Maul	Head	Player joining maul makes first contact with the maul with their head
	Neck	Player joining maul makes first contact with the maul with their neck
	Shoulder/Arm	Player joining maul makes first contact with the maul with their shoulder/arm
	Torso	Player joining maul makes first contact with the maul with their torso
	Lower Limb	Player joining maul makes first contact with the maul with their lower limb
	Inconclusive	Body region used by player joining maul is inconclusive
Player Role	Tackler	Player is involved in maul due to tackling the initial ball carrier
	Grapple	Primary role of attempting to work through the maul to disrupt
	Pushing	Primary role of attempting to push against the maul
	Collapse	Primary role of attempting to collapse the maul
Maul Status	Collapsed	Maul collapses before ball is played
	Non-Collapsed	Players remain on their feet until ball is played
Penalised	No	Player is not penalised
	Yes	Player is penalised

TABLE A.7: Extrinsic categorical variables assessed as concussion risk factors for players in a lineout

Risk Factor	Categories	Definition
Match Quarter	Q1	Lineout occurs between 0-20 mins
	Q2	Lineout occurs between 21-40 mins
	Q3	Lineout occurs between 41-60 mins
	Q4	Lineout occurs between 61-80 mins
Scrum Cap Use	Yes	Wearing a scrum cap in lineout
	No	Not wearing a scrum cap in lineout
Player Role	Lifter	Player responsible for lifting a jumper
	Jumper	Player jumps to contest ball
	Other	Player is not a lifter or jumper
Lineout Contested	Yes	Opposition makes a realistic effort to win the ball
	No	Opposition do not make a realistic effort to win the ball
Lineout Winners	Scottish Rugby	Scottish Rugby team win the ball from lineout
	Opponents	Opponents win the ball from the lineout
Penalised	No Penalty	No team is penalised
	Scottish Rugby	Scottish Rugby team is penalised
	Opponents	Opponent team is penalised

TABLE A.8: Extrinsic categorical variables assessed as concussion risk factors for players in a scrum

Risk Factor	Categories	Definition
Match Quarter	Q1	Scrum occurs between 0-20 mins
	Q2	Scrum occurs between 21-40 mins
	Q3	Scrum occurs between 41-60 mins
	Q4	Scrum occurs between 61-80 mins
Scrum Cap Use	Yes	Wearing a scrum cap in scrum
	No	Not wearing a scrum cap in scrum
Wheel	Clockwise	Scrum wheels clockwise
	Anti-Clockwise	Scrum wheels anti-clockwise
	No Wheel	No wheel
Scrum Dominance	Equal	No team demonstrates scrum dominance
	Scottish Rugby	Scottish Rugby team demonstrates scrum dominance
	Opponents	Opposing team demonstrates scrum dominance
Scrum Status	Non-collapsed	Scrum collapses
	Collapsed	Players remain on feet
Penalised	Neither	Neither team are penalised (includes free kick)
	Scottish Rugby	Scottish Rugby team are penalised (includes free kick)
	Opponents	Opposing team is penalised (includes free kick)

TABLE A.8: Extrinsic categorical variables assessed as concussion risk factors for players in kick contests

Risk Factor	Categories	Definition
Match Quarter	Q1	Contest occurs between 0-20 mins
	Q2	Contest occurs between 21-40 mins
	Q3	Contest occurs between 41-60 mins
	Q4	Contest occurs between 61-80 mins
Playing Position	Forward	Player in contest is playing as a forward
	Back	Player in contest is playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap
	No	Not wearing a scrum cap
Scottish Rugby Player Speed Approaching Contest	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Opponent Speed Approaching Contest	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Scottish Rugby Player Body Region Struck in Contest	Head	First point of contact in contest is to Scottish Rugby player's head
	Neck	First point of contact in contest is to Scottish Rugby player's neck
	Shoulder/Arm	First point of contact in contest is to Scottish Rugby player's shoulder/arm
	Torso	First point of contact in contest is to Scottish Rugby player's torso
	Lower Limb	First point of contact in contest is to Scottish Rugby player's lower limb
	Inconclusive	First point of contact is inconclusive
Opponent Player Body Region Struck in Contest	Head	Scottish Rugby player makes first contact with the head of opponent in contest
	Neck	Scottish Rugby player makes first contact with the neck of opponent in contest
	Shoulder/Arm	Scottish Rugby player makes first contact with the shoulder/arm of opponent in contest
	Torso	Scottish Rugby player makes first contact with the torso of opponent in contest
	Lower Limb	Scottish Rugby player makes first contact with the lower limb of opponent in contest
	Inconclusive	First point of contact is inconclusive

TABLE A.8 Continued: Extrinsic categorical variables assessed as concussion risk factors for players in kick contests

Risk Factor	Categories	Definition
Scottish Rugby Player Anticipated Impact	Yes	Player appears to notice opposing player pre-contest
	No	Player shows no sign of noticing opposing player pre-contest
Contest Impact Force	Low	Minimal rate of change of velocity of player's centre of mass
	Moderate	Moderate rate of change of velocity of player's centre of mass
	High	Large rate of change of velocity of player's centre of mass
Relative Height	Same Height	Scottish Rugby player and opponent at the same height at point of impact
	Higher	Scottish Rugby player higher than opponent at point of impact
	Lower	Scottish Rugby player lower than opponent at point of impact
Body Region Struck on Ground	Head	Post-contest, Scottish Rugby player lands on the ground on their head
	Neck	Post-contest, Scottish Rugby player lands on the ground on their neck
	Shoulder/Arm	Post-contest, Scottish Rugby player lands on the ground on their shoulder/arm
	Torso	Post-contest, Scottish Rugby player lands on the ground on their torso
	Lower Limb	Post-contest, Scottish Rugby player lands on the ground on their lower limbs
	Stays on Feet	Post-contest, Scottish Rugby player lands on the ground on their feet
	Inconclusive	Post-contest, it is inconclusive which body region Scottish Rugby player lands on
Penalised?	Neither	Neither player is penalised
	Scottish Rugby	Scottish Rugby player is penalised
	Opponent	Opponent is penalised

TABLE A.9: Extrinsic categorical variables assessed as concussion risk factors for players in off the ball collisions

Risk Factor	Categories	Definition
Match Quarter	Q1	Collision occurs between 0-20 mins
	Q2	Collision occurs between 21-40 mins
	Q3	Collision occurs between 41-60 mins
	Q4	Collision occurs between 61-80 mins
Playing Position	Forward	Player in collision is playing as a forward
	Back	Player in collision is playing as a back
Scrum Cap Use	Yes	Wearing a scrum cap
	No	Not wearing a scrum cap
Scottish Rugby Player Speed Approaching Collision	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Opponent Speed Approaching Collision	Slow	Static or minimal foot movement, minimal knee lift
	Medium	Running with moderate knee lift
	Fast	High speed running with high knee lift
Scottish Rugby Player Body Region Struck in Collision	Head	First point of contact in collision is to Scottish Rugby player's head
	Neck	First point of contact in collision is to Scottish Rugby player's neck
	Shoulder/Arm	First point of contact in collision is to Scottish Rugby player's shoulder/arm
	Torso	First point of contact in collision is to Scottish Rugby player's torso
	Lower Limb	First point of contact in collision is to Scottish Rugby player's lower limb
	Inconclusive	First point of collision is inconclusive
Opponent Player Body Region Struck in Collision	Head	Scottish Rugby player makes first contact with the head of opponent in collision
	Neck	Scottish Rugby player makes first contact with the neck of opponent in collision
	Shoulder/Arm	Scottish Rugby player makes first contact with the shoulder/arm of opponent in collision
	Torso	Scottish Rugby player makes first contact with the torso of opponent in collision
	Lower Limb	Scottish Rugby player makes first contact with the lower limb of opponent in collision
	Inconclusive	First point of collision is inconclusive

TABLE A.9 Continued: Extrinsic categorical variables assessed as concussion risk factors for players in off the ball collisions

Risk Factor	Categories	Definition
Scottish Rugby Player Anticipated Impact	Yes	Player appears to notice opposing player pre-collision
	No	Player shows no sign of noticing opposing player pre-collision
Collision Impact Force	Low	Minimal rate of change of velocity of player's centre of mass
	Moderate	Moderate rate of change of velocity of player's centre of mass
	High	Large rate of change of velocity of player's centre of mass
Body Region Struck on Ground	Head	Post-collision, Scottish Rugby player lands on the ground on their head
	Neck	Post-collision, Scottish Rugby player lands on the ground on their neck
	Shoulder/Arm	Post-collision, Scottish Rugby player lands on the ground on their shoulder/arm
	Torso	Post-collision, Scottish Rugby player lands on the ground on their torso
	Lower Limb	Post-collision, Scottish Rugby player lands on the ground on their lower limbs
	Stays on Feet	Post-collision, Scottish Rugby player lands on the ground on their feet
	Inconclusive	Post-collision, inconclusive which body region Scottish Rugby player lands on
Penalised?	Neither	Neither player is penalised
	Scottish Rugby	Scottish Rugby player is penalised
	Opponent	Opponent is penalised

Appendix 6: Informed consent for participants in study in Chapter 5

Neck Function and Concussive Risk:

Informed Consent

Part of a collaborative research project between the

Scottish Rugby Union and Edinburgh Napier University

Key Personnel:

Primary Researcher:

- **Stuart Bailey** (PhD Research Student – Edinburgh Napier University).
  Email: stuart.bailey@napier.ac.uk

Study Supervisors:

- **Dr Debbie Palmer** (Edinburgh Napier University) Email: d.palmer@napier.ac.uk
- **Dr Russell Martindale** (Edinburgh Napier University)
  Email: r.martindale@napier.ac.uk

Scottish Rugby Representatives:

- **Dr James Robson** (Scottish Rugby Chief Medical Officer)
  Email: James.Robson@sru.org.uk
- **Stuart Paterson** (National Team Lead Physiotherapist)
  Email: Stuart.Paterson@sru.org.uk

Background Information

Rugby union is a contact sport with an inherent risk to players of a multitude of different types of injury. Concussion is a specific injury that has previously been shown to be the most frequent injury in Rugby, with many negative short and long-term consequences. Reducing the risk of this injury is of utmost interest to Scottish Rugby. One possible method that has been suggested to reduce the risk of sustaining a concussion is improving neck strength and function.

If a player can anticipate a forthcoming collision, and has the chance to tense neck musculature, they can limit the acceleration of the head upon impact. However, this requires neck muscles which are strong enough to limit this acceleration. By improving neck strength and function, the chance that players are able to limit head acceleration should increase.

A training programme has been designed in collaboration with Scottish Rugby medical staff to improve multiple aspects of neck function, in order to possibly reduce concussive risk during rugby union contact situations. The current study aims to answer the following questions:

- Whether the training programme can improve neck proprioception, strength, and endurance in elite rugby players
- Investigate whether those that adhere to and complete the programme reduce their concussive risk in matches in comparison to a control group

It is hoped that the current research will inform and improve current medical practice throughout Scottish Rugby and lead to reduced concussive risk, improving player welfare in the future.

Study Methodology

The current study aims to take place over the 2018/19 pre-season and in-season. Two groups will exist throughout the study: an intervention group; and a control group. Players will be matched between intervention group and control group on playing position and concussive history. Concussive history will be determined by questionnaire for both groups.

Players in the intervention group will complete exercises as part of a training programme designed to improve neck proprioception, strength and endurance two times per week throughout pre-season and in-season. Players in the control group are to complete no systematic neck work throughout the season.

Players in both groups will go through neck function tests at the start of pre-season, mid-season, and the end of season. Tests will include basic player data (body mass, height) as-well as the tests outlined below:

Neck Proprioception

- A test designed to assess the ability of the player to relocate their head to a neutral position.
- Players will rotate their head maximally, before attempting to relocate their head to a neutral position. This will be completed ten times with a prior rotation to the left, and ten times with a rotation to the right.

Neck Strength

- A test designed to find neck strength in four directions.
- Players will be asked to perform a maximal contraction of the neck against an immovable force in a forward, backward, and left and right directions. Force will be measured by a hand-held dynamometer.

Neck Endurance

- A test designed to measure the endurance of neck muscles
- Players will be asked to maintain $80 \pm 5\%$ of their maximal force produced during strength testing pushing forward and backwards until the pre-prescribed force cannot be maintained.

A testing session will not last longer than 15-20 minutes. Although these tests will require motivation to produce maximum effort, there should be no difference to what is experienced in a resistance training session or competitive situation. These tests should monitor whether the programme for the intervention group is improving neck function.

In order to assess concussive risk, player match time for each player in both the control and intervention group will be recorded throughout the season, alongside the number of concussions. Concussions in each group will then be expressed per 1,000 player match hours, with statistical analysis determining whether the intervention group possess a reduced risk of concussion in comparison to the control group.

How will this impact individuals taking part?

For those players in the control group, aside from testing dates, no extra participation is required. For those in the intervention group, exercises as part of the programme will be integrated into weekly training sessions. It is aimed that exercises as part of this programme will be completed within 5-10 minutes.

Will the data be identifiable to each individual?

No, all scientific reports of data will contain no name or identification of players. Once players agree participation, they will each be assigned unique player identification numbers, and therefore any data collected will be anonymous.

Can I withdraw from the study?

You are free to withdraw from the study at any time without prejudice. You are not compelled to take part in the study, and your decision to take part will not affect your chances of selection throughout the season. However, if you withdraw, the data that has been provided up until that point in time may still be used for analysis.

How can I find out about the results of the study?

The results of the study are to be presented to the Scottish Rugby medical staff, and medical/coaching staff of any BT Premiership clubs taking part as the control group upon completion of data collection and results analysis. The details of the exercise programme will be shared with clubs agreeing to be part of the control group, for use during the subsequent season if the club so wishes.

If individual players would like to be debriefed on the key findings of the study, please request this by signing the attached debrief form, and return it to the primary researcher (Stuart Bailey).

How can I find out more about the study?

To find out more about the study, please contact the primary researcher (Stuart Bailey) using the contact details above.

To Whom It May Concern,

I………………………………………………….………., freely and voluntarily consent to be a participant in the studies described above, conducted by Scottish Rugby and Stuart Bailey.

The research aims to elucidate the effectiveness of a neck programme aiming to reduce concussive risk. I have been asked to be available for a battery of tests to assess my neck proprioception, strength, and endurance at the start of pre-season for the 2018/19 season, midway through the season, and at the end of the season. I have also been asked to agree to data pertaining to the number of minutes I play in matches, and the date and injury severity of any concussions I sustain to be provided to Stuart Bailey.

I understand that my data will be anonymised, my name will not be linked to the investigation in any way, and my data will be unidentifiable as to be belonging to me.

I comprehend that I am free to withdraw at any time without prejudice or negative consequences. However, the data that I have provided up until that time may still be used.

I have been made aware that I am free to ask questions about the research at any time.

I ……………………………………………………… have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand I will be able to keep a copy of this form for my records.

Signed
(Participant)……………………………………...…………Date……………………

Signed
(Researcher)…………………………………………..….Date……….……..........

Please forward all records to:

Stuart Bailey
Edinburgh Napier University
Sighthill Court
Edinburgh
EH11 4BN
stuart.bailey@napier.ac.uk

Appendix 7: Concussion History Questionnaire for participants in study in Chapter 5

CONCUSSION HISTORY QUESTIONNAIRE

PhD Research Study: Neck Function and Concussive Risk
PhD Student: Stuart Bailey (stuart.bailey@napier.ac.uk)
Institution: Edinburgh Napier University
Study Supervisors: Dr Debbie Palmer (d.palmer@napier.ac.uk); *Dr Russell Martindale* (r.martindale@napier.ac.uk)
Scottish Rugby Contacts: Stuart Paterson (stuart.paterson@sru.org.uk); Dr James Robson (james.robson@sru.org.uk)

Participant Questionnaire

The following questionnaire is designed to collate basic information about your concussive injury history. Some people have the misconception that concussions only happen when you black out after a hit to the head or when the symptoms last for a while. However, a concussion has occurred anytime you have had a blow to the head that caused you to experience the symptoms below for any amount of time:

☐ Blurred or double vision	☐ Headache	☐ Nausea
☐ Seeing Stars	☐ Dizziness	☐ Vomiting
☐ Sensitivity to light or noise	☐ Balance Problems	☐ Trouble sleeping
☐ Fatigue	☐ Confusion	☐ Difficulty remembering
☐ Difficulty concentrating	☐ Loss of consciousness	☐ Feeling 'dinged' or dazed

Using the definition/symptoms of concussions listed above, please answer the questions below to the best of your knowledge.

Name:……………………………………………………..……..DoB:…………………..

1. What is your preferred playing position? ....
2. How long have you been playing rugby?...
3. How many concussions have you sustained throughout the last 3 years?...............................
4. How long ago was your most recent concussion?...
5. With your most recent concussion, how long afterwards did you continue to experience symptoms listed above?...

Signed (Participant)…………..………………..…..………Date…………………………

Please forward all records to:

Stuart Bailey
Edinburgh Napier University
Sighthill Court
Edinburgh
EH11 4BN
stuart.bailey@napier.ac.uk

Appendix 8: Exercise Guidance Sheets for Neck Training Programme

Cranio-Cervical Flexion

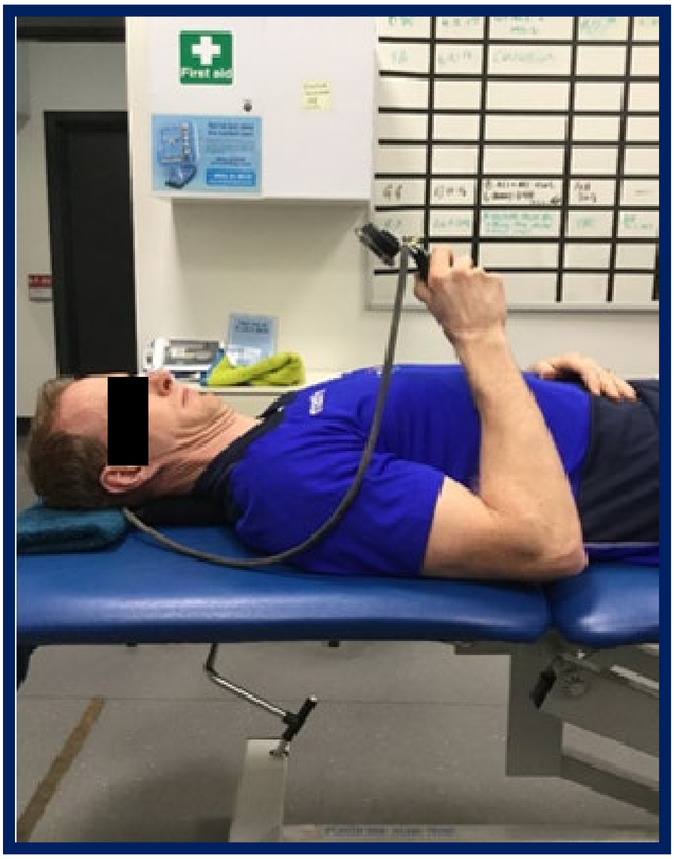
Set Up

- Supine lying on floor/physio bed
- Neck in neutral position. Folded towel can be used to achieve neutral position if required (do not use a pillow)
- Gentle, slow head nodding action 'as if saying yes'- feel back of head slide up floor/towel
    - This is Cranio-Cervical Flexion (CCF) or "chin tucked" position

Cranio-Cervical Flexion

Cranio-Cervical Flexion

- Lie on back on floor/physio bed
- Neck in neutral position. Folded towel can be used to achieve neutral position if required
- Place uninflated pressure cuff behind neck so that the back of the head rests on it
- Inflate cuff to 20 mmHg
- Gentle, slow head nodding action as if saying "yes"- feel back of head slide up floor/towel
- Gauge will move with pressure – control to correct pressure for level
    - If breathing with large movements of the upper chest then attempt to nod during exhalation - correct breathing pattern is important
- Hold pressure for appropriate duration and adhere to appropriate rest



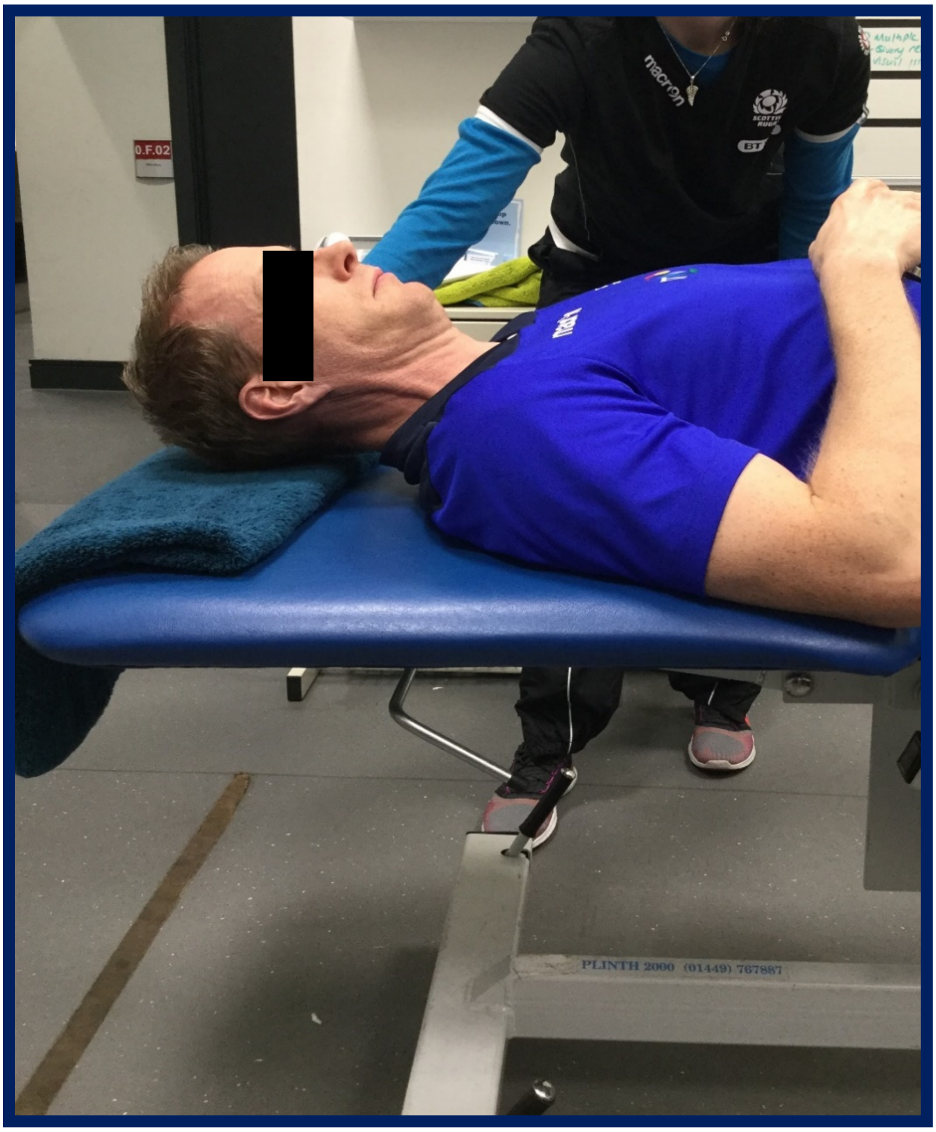
Key points:

- Avoid retraction movement
- Avoid lifting head
- Slow speed
- Return to 20mmhG during rest periods

Cranio-Cervical Flexion

Cranio-Cervical Flexion & Head Lift

- Reach the "Chin Tuck" position
- Lift head off the towel, enough to allow a flat hand underneath
    - Avoid any big movement in this position - this will cause other large muscle groups to take over
- Adhere to appropriate duration and rest periods



Neck Extension (Endurance)

- Lie prone on high weights bench
- Head harness on with appropriate weight attached
- Gentle, slow head nodding action as if saying "yes", then extend head into a neutral position
    - Complete isometric hold from here
    - Adhere to appropriate hold and rest duration

Isometric Bodyweight Neck Extension

Level I

- Create supine bridge with head on exercise box
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Shoulders, hips and knees aligned
    - Heels directly under knees
    - (30 s on; 30 s rest) x 3

Isometric Bodyweight Neck Extension

Level 2

- Create supine bridge with head on exercise box
  - Head in neutral position
  - Chin “tucked” to activate deep cervical flexors
  - Shoulders, hips and knees aligned
  - Heels beyond knees
  - (30 s on; 30 s rest) x 3

Isometric Bodyweight Neck Extension

Level 3

- Create supine bridge between two exercise boxes.
  - Place head on first exercise box, and use another box to support the back of thighs
  - Head in neutral position
  - Chin "tucked" to activate deep cervical flexors
  - Maintain tight core, with whole body stiff and aligned in neutral posture
  - (30 s on; 30 s rest) x 3

Isometric Bodyweight Neck Flexion

Level 1

- Create prone bridge with head on exercise box
  - Head in neutral position
  - Chin "tucked" to activate deep cervical flexors
  - Knees on floor beyond hips
  - (30 s on; 30 s rest) x 3

Isometric Bodyweight Neck Flexion

Level 2

- Create prone bridge with head on exercise box
    - Head in neutral position
    - Chin “tucked” to activate deep cervical flexors
    - On toes with knees in front of hips
    - (30 s on; 30 s rest) x 3

Isometric Bodyweight Neck Flexion

Level 3

- Create prone bridge between two exercise boxes:
    - Place head on first exercise box, and use another box to support front of thighs
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Maintain tight core, with whole body stiff and aligned in neutral posture
    - (30 s on; 30 s rest) x 3

Isometric Bodyweight Lateral Neck Flexion

Level 1

- Create standing bridge against wall with head on pad
    - Pad level with shoulder when standing upright
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Maintain tight core, with whole body stiff and aligned in neutral posture
    - (30 s on; 30 s rest) x 3
- Repeat for alternate side during rest periods

Isometric Bodyweight Lateral Neck Flexion

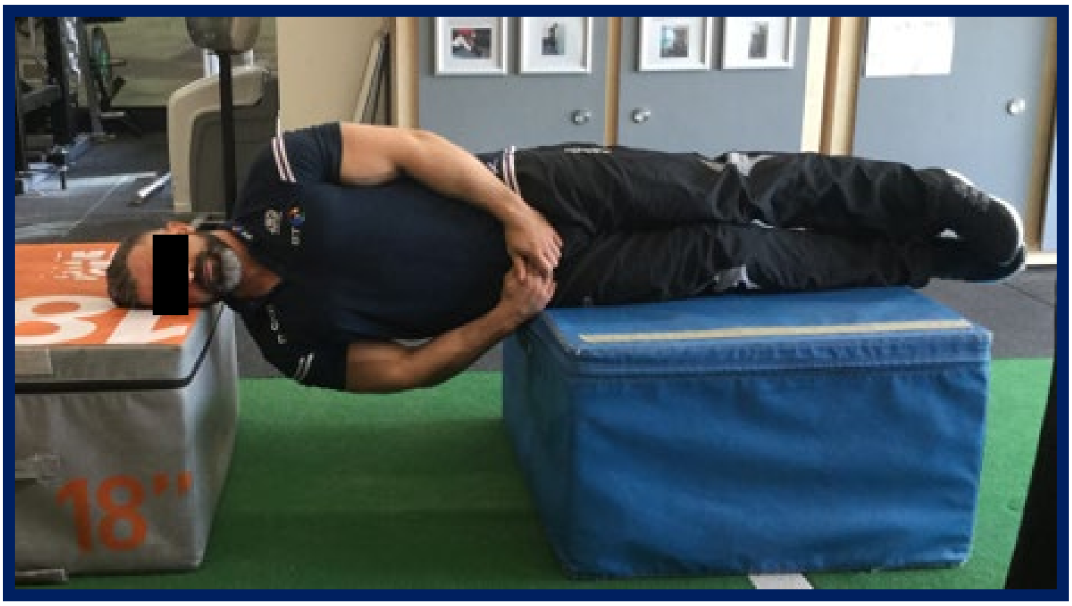
Level 2

- Create standing bridge against wall with head on pad
    - Pad level with elbow when standing upright
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Maintain tight core, with whole body stiff and aligned in neutral posture
    - (30 s on; 30 s rest) x 3
- Repeat for alternate side during rest periods

Isometric Bodyweight Lateral Neck Flexion

Level 3

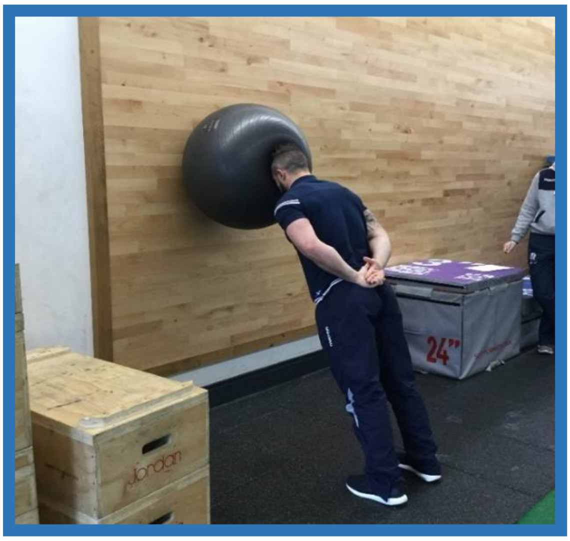
- Create lateral bridge between two exercise boxes:
    - Place head on first exercise box, and use a second box to support upper thighs
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Maintain tight core, with whole body stiff and aligned in neutral posture
    - (30 s on; 30 s rest) x 3
- Repeat for alternate side during rest periods

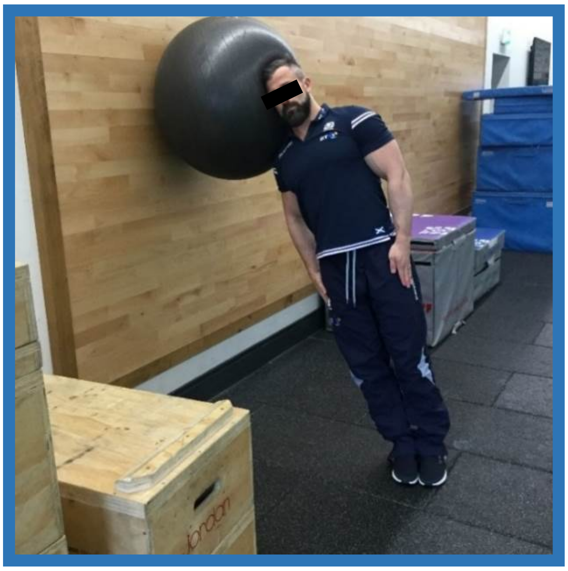


Perturbation Exercises

Level 1

- Create standing wall bridge with head against Swiss ball
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Maintain tight core, with whole body stiff and aligned in neutral posture
- Perform in extension, flexion, left flexion and right flexion
- 4 x 10-20 s in each position





Perturbation Exercises

Level 2

- Take a rolled up towel, placed around the back of the head and held out in front, so that the towel covers the ears
- Maintain head in neutral position with chin "tucked" to activate deep cervical flexors whilst resisting self-applied movements to head using towel
- 4 reps of 10-20 s duration (10 s rest)

Perturbation Exercises

Level 3

- Assume a four point kneeling position
- Maintain head in neutral position with chin "tucked" to activate deep cervical flexors whilst resisting movements applied to head and neck by partner
- 4 reps of 10-20 s duration (10 s rest)

Perturbation Exercises

Level 4

- Create standing wall bridge with head against Swiss ball
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Maintain tight core, with whole body stiff and aligned in neutral posture
        - Maintain head/neck/body in neutral position with chin "tucked" whilst resisting perturbations applied to Swiss ball by partner
- Perform in extension, flexion, left flexion and right flexion
- 4 x 10-20 s in each position

Perturbation Exercises

Level 5

- Player to stand approximately two metres away from partner
- Partner to feed Swiss ball through the air for player to header back to partner
- 4 x 10 headers (10-20 s rest)

Perturbation Exercises

Level 6

- Stand as a group of three with all players facing inward
  - Place a hand on the lateral aspect of each of the other players' heads to create a triangle
  - Chin "tucked"
  - Players are to apply perturbations to others' heads, whilst aiming to keep their own head in neutral and chin "tucked"
- 4 x 10-20 s (10-20 s rest)

Proprioception Exercises

Level 1

- Seated laser maze with eyes open
    - Sit 3 m away from wall
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Wearing cap and laser pen, trace the path through the maze
- Choose the difficulty of maze based on current ability
- Complete the task as accurately as possibly, without worrying about speed. If a mistake is made, reset from where the mistake was made rather than starting again
- Complete 3 routes through maze

Proprioception Exercises

Level 2

- Lateral lying laser clock with eyes open
    - Lie laterally 3 m away from the wall
    - Head in neutral position
    - Chin “tucked” to activate deep cervical flexors
        - Wearing cap and laser pen, the clock should be placed on the wall so that the laser falls in the centre of the clock face
    - Trace the laser from the centre of the clock face to each number around the clock
        - 5 – 10 s rest between each number
    - Complete 2 laps of clock face per side

Proprioception Exercises

Level 3

- Walking on the spot laser maze with eyes open
    - Stand 3 m away from the wall
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - Wearing cap and laser pen, trace the path through the maze
- Choose the difficulty of maze based on current ability
- Complete the task as accurately as possibly, without worrying about speed. If a mistake is made, reset from where the mistake was made rather than starting again
- Complete 3 routes through maze

Proprioception Exercises

Level 4

- Seated laser target with eyes closed
    - Sit 3 m away from wall
    - Head in neutral position
    - Chin “tucked” to activate deep cervical flexors
        - Wearing cap and laser pen, the target should be placed on the wall so that the laser falls in the centre of the target
    - With eyes closed, laterally rotate neck maximally in one direction, before aiming to return to a neutral position (with the laser in the centre of the target)
        - Open eyes to readjust neutral position
- Perform through lateral rotation left and right, and flexion and extension
- Complete 3 rotations in each direction

Proprioception Exercises

Level 5

- Lateral lying laser clock with eyes closed
    - Lying laterally 3 m away from the wall
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
    - With eyes closed and wearing cap and laser pen, trace the laser from the centre of the clock face to each number around the clock
        - 5 – 10 s rest between each number
    - Complete 2 laps of clock face per side

Proprioception Exercises

Level 6

- Seated random laser clock with eyes closed
    - Sit 3 m away from wall
    - Head in neutral position
    - Chin "tucked" to activate deep cervical flexors
        - Wearing cap and laser pen, the clock should be placed on the wall so that the laser falls in the centre of the clock face
    - With eyes closed, physio will call a random number
        - Trace from centre of clock to number, and then back to centre
        - Open eyes to re-adjust, then repeat
    - Trace path to 10 different numbers

Appendix Nine: Published Abstract: Effects of a strength and proprioceptive training programme on neck function and concussion injury risk in elite Scottish rugby union players

Effects of a strength and proprioceptive training programme on neck function and concussion injury risk in elite Scottish Rugby Union players

Bailey, S. J.[1], Martindale, R.[1], Sweeting, J.[2], Deacon, J.[2], Laing, F.[2], Leck, C.[2], Palmer, D.[1,3]

[1]School of Applied Sciences, Edinburgh Napier University, Edinburgh, UK; [2]Scottish Rugby Union; [3]Division of Rheumatology, Orthopaedics and Dermatology, University of Nottingham, Nottingham, UK.

Background

Cervical musculature function (strength, endurance, and proprioception) may be a modifiable risk factor for concussion in contact sports. The ability to enhance neck function and reduce concussive risk needs to be determined.

Objective

To assess the efficacy of a training programme to enhance neck function and lower match concussion injury risk in rugby union players.

Design

Repeated-measures intervention with control.

Setting

Premiership rugby union players in Scotland during the 2018/19 season.

Patients (or Participants)

Premiership players selected for Scotland Rugby academies (intervention group; INT; n = 30) or those with their clubs (control group; CON; n = 20).

Interventions (or assessment of risk factors)

A neck training programme was implemented twice per week during the 2018/19 season for INT, while CON performed no systematic neck training.

Main Outcome Measures

For both INT and CON neck strength (maximal voluntary contraction; MVC), endurance (exercise capacity; TTF) and proprioception pre- and post-season, and match concussion injury incidence were recorded.

Results

Left and right cervical flexion MVC force and flexion TTF all significantly increased in the intervention group ($p < 0.001$), with no significant change in the control group. While there were increases in cervical flexion and extension MVC force in both groups from pre to post-season, there was a significantly greater increase amongst the intervention group ($p < 0.05$). Concussion incidence was lower in INT versus CON (INT: 7.7/1000

match hours; CON: 18.4/1000 match hours). However, this was not a significant alteration in risk (relative risk: 0.4; 95% CI: 0.1-2.1).

Conclusions

The neck function programme increased cervical MVC force and flexion exercise capacity, beyond any changes induced by a season of rugby union. The intervention group also had a lower incidence of concussion across the season. This pilot study shows good promise and highlights the need for further investigation.

Appendix Ten: Published Abstract: Epidemiology of injuries in Scottish male professional rugby union

Epidemiology of injuries in Scottish male professional rugby union

Bailey, S. J.[1], Martindale, R.[1], Robson, J.[2], Palmer, D.[1, 3]

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Background

The rate of injury in men's professional rugby union tends to be greater than other team/field based sports. Epidemiological studies are required to demonstrate the magnitude of the injury situation and to inform future injury prevention measures.

Objective

To analyse injuries sustained by male professional rugby union players in Scotland.

Design

Prospective observational study.

Setting

Match and training time-loss injuries sustained by players in their professional club (Edinburgh Rugby and Glasgow Warriors) and Scotland International Men's team during the 2017/18 season were recorded by Scotland Rugby medical staff. Exposure (hours) during training or match play was recorded by GPS device (on-pitch) or player-RPE (off-pitch).

Patients (or Participants)

229 players (24.7 ± 4.1 years) were involved in the study (professional club n = 149; Scotland international n = 80). Sixty-two players were present in both cohorts.

Interventions (or assessment of Risk Factors)

Match and training injuries and level of play (professional club vs. international) were compared.

Main Outcome Measures

Injury incidence, severity, type and location.

Results

Match injury incidence was 128.7/1000 player match hours (severity: 19.4 ± 30.7 days) and 118.2/1000 player match hours (severity: 43.3 ± 50.4 days) for professional club and international rugby, respectively. Training injury incidence was 4.7/1000 player hours (severity: 29.1 ± 56.2 days) and 4.6/1000 player hours (severity: 24.2 ± 35.6 days) for professional club and international rugby, respectively. Concussion (professional club: 32.0/1000 player match hours; international: 31.8/1000 player match hours) and lower limb muscle/tendon injuries (professional club: 1.9/1000 player hours; international: 1.9/1000 player hours) were the most frequent match and training injuries respectively.

Conclusions

Match injury incidence is higher than training injury incidence in professional Scottish rugby union, with concussion and lower limb muscle/tendon injuries the most common match and training injury diagnoses, respectively. These findings are in agreement with previous studies.

<u>Appendix Eleven: Poster Presentation at The Edinburgh Sport & Exercise Medicine Conference 2019</u>

Effects of a strength and proprioceptive training programme on neck function and concussion injury risk in elite Scottish Rugby Union players

Edinburgh Napier UNIVERSITY

Bailey, S. J.[1], Martindale, R.[1], Sweeting, J.[2], Deacon, J.[2], Laing, F.[2], Leck, C.[2], Palmer, D.[1],

[1]School of Applied Sciences, Edinburgh Napier University, Edinburgh, UK; [2]Scottish Rugby Union

SCOTTISH RUGBY

Introduction

Concussion is defined as a traumatic brain injury, and will occur as a result of direct or indirect force applied to the head, causing sudden acceleration/deceleration of the brain[(5)]. The risk of concussion is related to the magnitude of cranial acceleration that is experienced[(4)]. Neck musculature is responsible for controlling the acceleration of the head during impulsive loading[(3)]. Cervical musculature function (strength, endurance and proprioception) has been postulated to present as a modifiable risk factor for concussion in contact sports[(1,2)]. Before implementation of a neck function training programme across an entire sporting institution, the efficacy of the programme should first be determined.

Aim

Assess the efficacy of a training programme designed to enhance neck function and lower concussive risk in rugby union players.

Methods

Fifty male rugby union players (Tennent's Premiership) took part in an experimental controlled trial during the 2018/19 season. A neck-training programme was developed based on suggestions from previous literature, designed to enhance cervical proprioception, strength and endurance. Thirty Tennent's Premiership players who were also enlisted in the Scotland Rugby academy received the neck-training programme (INT;18 forwards; 12 backs; 19.0 ± 1.0 yrs; 1.85 ± 0.08 m; 97.7 ± 12.4 kg; 1.1 ± 1.0 previous concussions). Twenty other premiership players acted as controls with no access to a neck training programme (CON; 13 forwards; 7 backs; 24.2 ± 2.6 yrs; 1.83 ± 0.05 m; 99.7 ± 12.4 kg; 1.2 ± 1.4 previous concussions). Neck function was assessed pre- and post-season, with match concussion incidence recorded.

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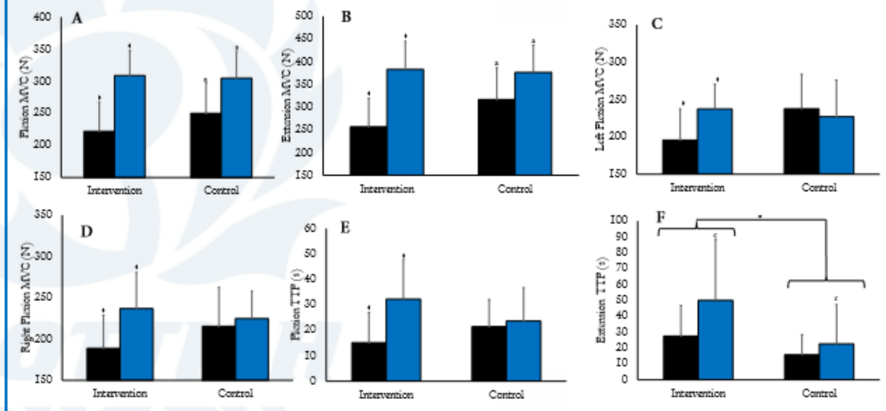
Results

Neck function improved and match concussion injury incidence decreased during the season for INT compared with CON. Specifically, left and right cervical flexion maximal voluntary contraction (MVC) force and flexion exercise capacity all significantly increased in the intervention group ($p < 0.001$), with no significant change in the control group. While there were increases in cervical flexion and extension MVC force in both groups from pre to post-season, there was a significantly greater increase amongst the intervention group ($p < 0.05$). Concussion incidence was lower in INT versus CON (INT: 7.7/1000 match hours; 95% CI: 3.5 - 14.4; CON: 18.4/1000 match hours 95% CI: 11.5 – 28.3). However, this was not a significant alteration in risk (relative risk: 0.4; 95% CI: 0.1 – 2.1; $p = 0.148$). Although proprioception improved during the season, no difference was found between INT and CON.



Figures A - F ■ Pre ■ Post

Mean INT and CON group scores for pre- and post- intervention for A) Neck Flexion MVC; B) Neck Extension MVC; C) Neck Left Flexion MVC; D) Neck Right Flexion MVC; E) Neck Flexion Exercise Capacity (TTF); F) Neck Extension Exercise Capacity

ǂ) Significant difference pre-to-post in intervention group ($p < 0.001$); a Significant difference pre-to-post in control group ($p < 0.001$); c Significant effect of time ($p < 0.001$); * Significant difference between groups ($p < 0.01$)

Conclusion

The neck function programme increased cervical MVC force and flexion exercise capacity, beyond changes induced by a season of rugby union. The intervention group also had a lower incidence of concussion. This pilot study of a new neck training programme provides positive early results and highlights the need for further investigation.

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Appendix Twelve: British Journal of Sports Medicine Blog: Rugby Union injuries: Future Research

Rugby Union Injuries: Future research

Stuart Bailey (Twitter: @stujohnbailey)

Edinburgh Napier University & Scottish Rugby PhD Student

As the 2018/19 rugby union season continues, player welfare is once again a hot topic for discussion amongst pundits, the media, and fans. While as a form of physical activity, rugby at community level can be expected to have overall physical health and wellness benefits, what health issues arise for elite players taking part? Last season, there were revelations from professional players calling for a reduction in the number of competitive matches in order to limit injury risk, alongside increasing reports of players retiring early due to injury (BBC News, 2018; BBC Sport, 2017). Early into the current season, we have already seen a player retire due to repeated concussive injuries (BBC Sport, 2018). Echoing conclusions from Williams et al. (2017) who suggested that players exposed to 35 or more matches in a 12 month period were significantly more susceptible to injury, the Rugby Football Union (RFU) has recently declared an upper limit of 35 matches per season for elite players in England. Due to these retirements and the RFU's attempt to limit game time, this raises the question of whether the impact of injuries is getting worse in elite rugby?

The RFU report into injuries during the 2016/17 English Aviva Premiership season demonstrated that injury incidence and severity had increased from the previous season, and were both greater than the mean for the whole data collection period (2002/03 season onwards; RFU, 2018). Among one of the most concerning findings was that concussion was again the most commonly reported match injury, with an incidence of 20.9/1000 player match hours (RFU, 2018). There has been a dramatic rise in match concussion incidence reported by the RFU season-by-season since 2009/10. This has been reflected in other research, with Rafferty et al. (2018) demonstrating that concussion incidence increased across a four-year period to 21.5/1000 player match hours by 2015/16 in elite Welsh men's rugby (figure 1). This recent rise in concussion frequency suggests one of two scenarios – either concussion incidence is truly rising in elite rugby union; or widespread historical under-reporting has caused false incidences in previous data, and as recognition of the injury improves, a true incidence is gradually being reached. Taking into account the amount we still do not know about its various short- and long-term consequences, either of these circumstances is highly perturbing. The more studies of elite groups of players that are performed investigating injuries in general and concussion specifically, the closer we will get to fully understanding the aetiology of injuries, and the magnitude of the injury problem.

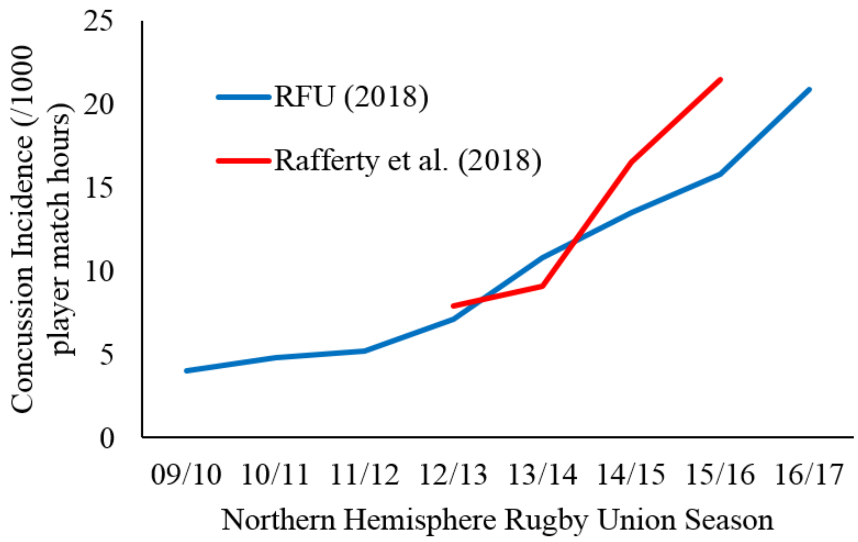

FIGURE 1: Rise in match concussion incidence in rugby union. Data taken from RFU (2018) and Rafferty et al. (2018).

There is an identical need for similar contemporary research into women's rugby. In the elite game, injury aetiology was examined amongst the England international squad for the 2001/02 season, and injury epidemiology studies were produced from the Women's Rugby World Cup in 2006 and 2010 (Doyle & George, 2004; Schick, Molloy, & Wiley, 2008; Taylor, Fuller, & Molloy, 2011). However, no research appears to have been published in the 15-a-side format of game since these studies. As a greater magnitude of professionalism is established for the elite women's game, it would be expected that players being paid to train full-time would result in increased training volumes, altered physical characteristics, and greater match collision frequency and intensity (Quarrie & Hopkins, 2004; Sedaud, Vidalin, Tafflet, Marc, & Toussaint, 2013). In order to better comprehend the injury aetiology, and therefore be able to start to mitigate injury risk, contemporary research studies into women's rugby injuries in a variety of settings are necessary.

A PhD research project aiming to investigate injuries and concussion in elite Scottish Rugby over the 2017/18 and 2018/19 seasons commenced in April 2017, joint-funded by the Scottish Rugby Union (SRU) and Edinburgh Napier University. Due to an attitude prioritising player welfare, Edinburgh Napier University and the SRU have collaborated to fund this research to further the scientific understanding of injuries in general and concussion specifically across elite rugby union in Scotland. The PhD project in question will report on match and training injuries sustained by Glasgow Warriors, Edinburgh Rugby, Scotland Men and Scotland Women over the 2017/18 and 2018/19 seasons, as well as a meticulous analysis of concussions sustained during this period. This will provide an up-to-date epidemiology on all injuries and concussion in elite men and women's rugby, establishing the groundwork to later attempt to reduce concussive risk in Scottish rugby.

Athlete welfare is of the greatest concern for all those involved in rugby union, and the current research will provide an opportunity to increase the understanding of the nature of injuries in Scottish rugby union players as well as adding to the scientific evidence-base available in elite rugby union, benefitting the worldwide rugby union community.

Competing Interests

None

END OF THESIS