A systematic review of concussion in rugby league

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ABSTRACT

Objectives Concussion remains one of the inherent risks of participation in rugby league. While other injuries incurred by rugby league players have been well studied, less focus and attention has been directed towards concussion.

Review method The current review examined all articles published in English from 1900 up to June 2013 pertaining to concussion in rugby league players.

Data sources Publications were retrieved via six databases using the key search terms: rugby league, league, football; in combination with injury terms: athletic injuries, concussion, sports concussion, sports-related concussion, brain concussion, brain injury, brain injuries, mild traumatic brain injury, mTBI, traumatic brain injury, TBI, craniocerebral trauma, head injury and brain damage. Observational, cohort, correlational, cross-sectional and longitudinal studies were all included.

Results 199 rugby league injury publications were identified. 39 (20%) were related in some way to concussion. Of the 39 identified articles, 6 (15%) had the main aim of evaluating concussion, while the other 33 reported on concussion incidence as part of overall injury data analyses. Rugby league concussion incidence rates vary widely from 0.0 to 40.0/1000 playing hours, depending on the definition of injury (time loss vs no time loss). The incidence rates vary across match play versus training session, seasons (winter vs summer) and playing position (forwards vs backs). The ball carrier has been found to be at greater risk for injury than tacklers. Concussion accounts for 29% of all injuries associated with illegal play, but only 9% of injuries sustained in legal play.

Conclusions In comparison with other collision sports, research evaluating concussion in rugby league is limited. With such limited published rugby league data, there are many aspects of concussion that require attention, and future research may be directed towards these unanswered questions.

INTRODUCTION

Originating in the north of England in the late 19th century, rugby league has become a popular team collision sport played throughout the world at a variety of competition levels.[1] It is a physical sport involving numerous collisions and tackles. Each team, consisting of 13 players on the field, is allowed six tackles with the ball. The ball cannot be thrown forward but must be carried forward or kicked downfield. At the completion of each set of six tackles, the ball is immediately given to the opposing team to commence their set of six tackles. The same players therefore engage in offensive and defensive roles, depending on which team is in possession of the ball. The game is played non-stop, except for a serious player injury, for two 40 min halves. The overall objective of the game is to carry the ball over the goal line of the opponent to score a try.[2] In Australia, rugby league is a popular contact sport. There are approximately 167 533 registered players with 368 869 involved in school competition and 893 965 involved in development club programmes.[3]

With the improvements in professionalism and commercialisation of sports such as rugby league, an increase in the value of the athlete as a commodity has occurred. Injuries sustained by players are now of considerable financial importance to the individual player and to their club. Participation in rugby league, at any level, carries inherent risk for injury,[4] including concussion.

Sport-related concussion is a common injury,[5–7] and these injuries might be more prevalent than initially thought because some concussions go unrecognised.[8] Approximately 90% of concussions in sport occur without loss of consciousness[9–12]; thus, they can be difficult to detect and might be underdiagnosed. Concussions are caused by accelerations or decelerations of the head involving linear (translational) and/or rotational forces, and there is tremendous interest in trying to better understand the biomechanics of this injury.[13–17] Concussions have a large adverse effect on cognition and balance in the first 24 h following injury, with resolution of these deficits occurring within about 1 week according to group studies.[18 19] There is evidence that a minority of athletes do not experience rapid recovery in cognitive functioning,[20] and this subgroup might be obscured in statistical analyses applied to larger groups of athletes.[21] Younger athletes might take longer to recover. In a prospective study of high school football players,[22 23] approximately 42–47% were deemed functionally recovered by 1 week (see figure 1, p.503)[23] and it was not until 4 weeks that 84–94% were considered recovered.

Concussion in sport has been the topic of media attention recently, thus raising awareness in the participants of collision sports, parents and the general community, and also sports medicine physicians and researchers. The aim of this review was to systematically evaluate the available evidence on concussion in rugby league.

METHODS

The review was conducted in two stages. In stage 1, articles were retrieved via online database searching, hand-searching reference lists and performing cited reference searches (see figure 1). The current review examined all articles published in English from 1900 up to June 2013 pertaining to concussion in rugby league athletes. The online databases of PubMed, PsycINFO, MEDLINE, EMBASE, SPORTDiscuss and Web of Science were searched, using the key

search terms: rugby league, league, football; in combination with injury terms: athletic injuries, concussion, sports concussion, sports related concussion, brain concussion, brain injury, brain injuries, mild traumatic brain injury, mTBI, traumatic brain injury, TBI, craniocerebral trauma, head injury and brain damage. The reference lists of articles retrieved for inclusion in the review were searched to identify other relevant articles. Key articles retrieved via online databases and through hand-searching reference lists were also used for further searches using the Web of Science Cited Reference function. During stage 2, the titles and abstracts of articles were reviewed to assess eligibility for inclusion in this review. Articles were regarded as relevant and warranting inclusion if they were experimental studies examining concussed rugby league players. Studies were included whether they were conducted with acute or long-term concussed athletes (ie, there were no restrictions placed on time elapsed since injury) and independent of examination techniques used to assess these players (eg, neuroimaging, symptom checklist, balance testing or neuropsychological testing). Where there was uncertainty about whether a study should be included based on the review of the title and abstract, the full article was retrieved. Only observational, cohort, correlational, cross-sectional and longitudinal studies were included.

RESULTS

A total of 8639 articles were identified using the search strategy outlined in figure 1. The initial search strategy was far-reaching and had limited restrictions, in order to identify all articles eligible for inclusion. Owing to the nature of the initial search, a considerable number of citations were not relevant largely due to the use of the term 'football', which yielded over 7500 citations pertaining to American football, rugby union, Australian football and/or 'soccer' research. After all identified citations were screened, 199 were retrieved and screened for eligibility. Of the 199 articles, 125 were not research studies (ie, conference presentation, abstract only and commentary), 28 were excluded on the basis that the participants were not athletes (ie, they were not sports-related concussion cases) and 7 duplicates were identified on closer inspection. The final outcome following this screening process resulted in the inclusion of 39 articles for this review (33 related to concussion incidence[1 24–54] and 6 specifically examining concussion).[55–60]

There were 18 published articles that reported the incidence of concussion per 1000 playing hours[1 25 27–31 36 37 39 40 47 48 51 55 61–63] (see online supplementary table S2). Incidence rates varied widely from 0.0[27 31] to

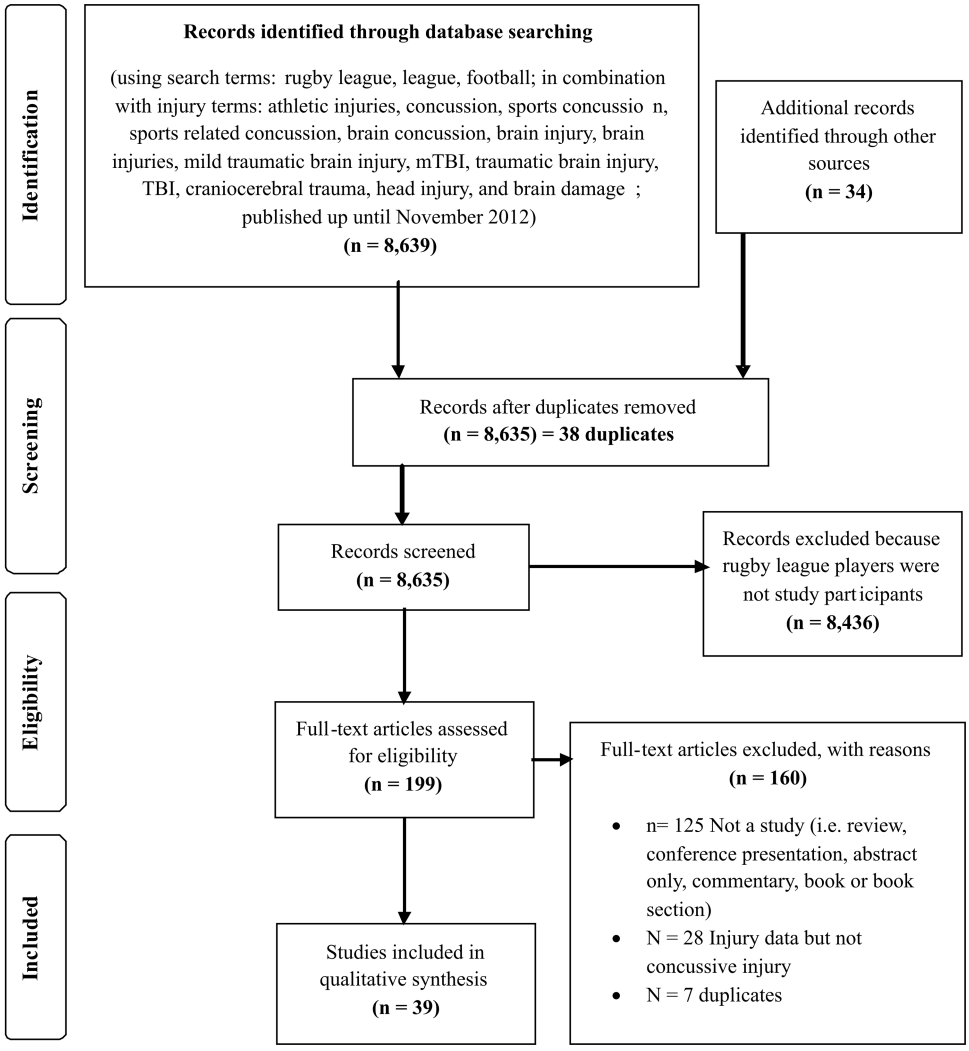

Figure 1 PRISMA flow diagram.

approximately 40.0, with differences in sampling and methodology most likely explaining a large amount of this variation.[37] Concussions are less common in rugby league than other types of injuries such as contusions, muscular strains, joint injuries, abrasions and lacerations.[4 24 28 33 61] The incidence of concussion has been observed to remain consistent over consecutive seasons. Between 13% and 17% of all players sustained a concussion over three consecutive seasons.[55] However, studies on the incidence of injuries in rugby league are confounded by inconsistencies in the injury definitions used. Initial attempts at a standard definition for injury were not achieved, yet recently an international consensus opinion on the definition of injury has been accepted.[4] Some studies used the strict criterion of a missed match (time loss) as the injury definition, and others used a medical treatment (non-time loss) to define the injury. These variations in the definition of injury are highlighted by considering that up to 85% of all playing injuries, and up to 82% of all training injuries, are 'non-time loss' injuries. Non-time loss concussions account for approximately 71% of all concussions,[46] suggesting that the most reliable studies in this body of literature estimate concussion incidence between 8.0 and 17.5 injuries/1000 playing hours.[1 62]

Tackling has been identified as the most common cause of concussion in rugby league,[30 36 53] with the tackled player reportedly more vulnerable to injury than those players making the tackle.[61] It is therefore not surprising, given the reported forces induced on the bodies of players involved in the tackle,[64] and the high number of tackles that occur in each game,[61] that the incidence of concussion in rugby league is relatively high (see supplementary tables S1 and S2 for a review). Playing position (forwards vs backs) might also influence the risk for concussion. The forwards (who typically possess a bigger physique and are involved in more contact/tackles during the game) might be at greater risk for injury than backs.[28 40] King *et al*[61] reported that the tackle-related concussion occurred most frequently to the ball carrier when tackled at the shoulder or mid-torso height, in their blind vision, when involving two or more tacklers, and in the final quarter of matches. Of all injuries associated with illegal play, 29% were concussions, whereas only 9% of injuries sustained in legal play were concussions.[53]

Compared with the rates of concussion during match play (34.6/1000 playing hours), one study reported that the rates of concussion during training were 0.3/1000 playing hours.[33] A reduction in training loads (ie, reduced by 1.7 vs 0.7/1000 training hours) was also found to reduce the injury rates in rugby league players and resulted in greater improvements in maximal aerobic power.[31] Another study reported 32–37 injuries/1000 playing hours compared with 1.0/1000 training hours by reducing training loads.[37] Variations in concussion rates were also observed across seasons, with winter injuries occurring at a rate of 3.35/1000 playing hours and summer injuries at a rate of 2.51/1000 playing hours, with a winter/summer risk ratio of 0.75.[39] Despite little attention being given to the possible effects of history of concussion, one study reported that 62% of concussed athletes had sustained a previous concussion. This study also found that 30% of players sustained a concussion in the current playing season.[59] As a comparison, the rates of injuries during match play have been estimated to range between 1.68[36] and 104.8[27] for contusions, 9.2[36] and 261.9[27] for muscular strains, 12[61] and 65.5[27] for joint injuries, and 0[27] and 40[37] for concussions during 1000 h of match play.

In a New Zealand (NZ) economics study, concussions were associated with the highest mean cost per injury type, accounting for 6.3% of total injury costs, despite representing only 1.8% of the total injury entitlement claims.[61] The incidence of concussion varied among ethnicity, with NZ Maori (n=62; 10.4 injuries/1000 playing hours) recording significantly more concussions than other ethnic groups (NZ European: n=41; 6.9 injuries/1000 playing hours; Pacific people: n=17; 2.9 injuries/1000 playing hours; Asian: n=0 and others/unknown: n=31; 5.2 injuries/1000 playing hours). Total cost and mean cost per concussion was found to vary across ethnic groups in this study (NZ Maori: $2 363 000 N Z dollars (mean cost per concussion $38 118); NZ European: $86 000 (mean cost per concussion $2097); Pacific people: $44 000 (mean cost per concussion $2588); Asian: $0 and others/unknown: $239 000 (mean cost per concussion $7709).[50]

With respect to the level of knowledge among players and officials regarding concussion and the opinion of players regarding the importance of management, researchers reported that 54% knew of a concussion policy in rugby league but only 8% could identify the 3-week mandatory stand-down requirement, and 78% reported a 7-day stand-down as the requirement for recovery from concussion. Loss of consciousness was reported to be required in the definition of concussion by 39% of respondents. Overall concussion knowledge was low at 42% (±20%). Trainers/medics recorded the highest overall concussion knowledge. Misconceptions regarding this injury appear to be common.[60] King *et al*[49] reported that fewer than 34% of injured athletes sought medical clearance for return to sports participation for match play, and fewer than 25% for return to training. It was also reported that up to 75% of players felt that time off for rehabilitation was too long, especially for concussion with the 3-week mandatory stand-down period.[49] Interestingly, a survey of club coaches found that 55% of respondents who had a player with a concussion (n=52) had not sought medical clearance for a concussed player before returning them to match or training activities.[60]

The most thorough study until now has been conducted by Hinton-Bayre *et al*[55] who examined the epidemiology and consequence of concussion in rugby league. The authors found that the incidence of concussion remained relatively stable across the three seasons of observation. They reported 9.84 concussions/1000 playing hours in first grade (the highest level of club competition); 7.87 concussions/1000 playing hours in reserve grade (the second tier of club competition) and 5.90 concussions/1000 playing hours in age-group (u/21 s and u/19 s) competitions. Loss of consciousness occurred in only six cases (12%), and individual players sustaining a subsequent injury accounted for seven (16%) of all concussive injuries. Unlike previous studies, Hinton-Bayre, Geffen, and Friis did not observe any playing positions that were more vulnerable to concussion. Players in possession of the ball (players being tackled) were not concussed significantly more frequently than defensive players (players making the tackle). There were two recorded concussions that occurred when neither player in the collision had possession of the ball. The reported mechanisms of injury were as follows: 40% (n=17) head high tackles, 35% (n=15) head contact with the ground and head contact with opposing player's body (n=5). The most common self-reported postconcussion symptoms were as follows: headache (n=35), unsteadiness (n=22), visual disturbance (n=19), dizziness (n=11) and nausea (n=10).

DISCUSSION

Concussions in rugby league are common. The incidence rates vary dramatically in large part due to how the injury has been defined across studies. However, using the more liberal injury definition, there appear to be between 8.0 and 17.1 injuries/

1000 playing hours. One study suggested that a substantial minority of athletes (eg, 13–17%) will sustain this injury at least once over the course of three playing seasons.[55] The rate of injury is much higher in match play than in training.[33 37] There is some evidence that forwards are at greater risk for injury[28 40]; the ball carrier appears to be statistically more likely to get injured than the tackling player.[61] Concussion rates are disproportionately high for illegal play.[53] This finding provides governing bodies of the sport with an opportunity to modify risk by implementing greater sanctions, which hopefully would modify the playing behaviour of participants and reduce concussion rates.

The definitions of concussion in past rugby league studies have not been consistent with international recommendations.[65] Over the past decade, several agreement statements and consensus statements have set out standardised injury definitions for injury.[66–71] In contrast, most rugby league studies have used a strict criterion of a missed match (time loss) as the injury definition, and a number of other studies have incorporated a less strict injury definition that includes the player merely receiving medical treatment (non-time loss). Future researchers are encouraged to use consensus-based definitions of this injury.[71]

The majority of rugby league studies addressed injury rates. There were only six studies that addressed other issues. The topics of these studies were diverse and mostly non-overlapping, including a comprehensive audit of concussion in rugby league,[55] examination of the psychometric properties of screening[59] and cognitive tests in concussed rugby league footballers,[56 57] retrospectively examining concussive convulsions[58] and assessing concussion knowledge among rugby league club stakeholders.[60] King *et al*[60] found that misconceptions about concussion appear to be common in players, trainers and coaches. This highlights a weakness in the education of rugby league stakeholders and the importance of widespread education. Education dissemination could be a collaborative effort between the governing bodies and the elite level, which plays a crucial role in the filtering of all educational messages to the community and the grass-roots levels.

Research focused on studying the acute consequences and best management strategies in current players, and the potential longer term outcomes of concussion in retired players is needed. Future research could, for example, use video analysis to determine whether certain playing styles (eg, tackling, ball carrying or running techniques) or playing positions are associated with increased risk for injury.[72–76] Future research in the areas of prevention, injury identification and medical management, and risk for long-term outcomes will be of benefit to current athletes, trainers and coaches.

What are the new findings?

- The incidence of concussion in rugby league varies considerably due to the lack of consensus regarding a 'definition of injury'.
- The rate of injury is much higher in match play than in training; the ball carrier appears to be statistically more likely to get injured than the tackling player, and injury rates are disproportionately high for illegal play.
- The current rugby league concussion literature is small, and further research is required across numerous areas and levels of competition.

Contributors AG developed the concept and methodology and also conducted the literature search and structure of the review. He wrote the entire content included in the manuscript, figures and tables. GLI assisted with the development of the concept and methodology. He also provided considerable editing assistance and comment on all sections, the figures and tables to finalise the manuscript. CRL, PWS, FK-L, RMNK and PS provided expert input to the final draft of the manuscript.

Competing interests AG has a clinical practice in neuropsychology involving individuals who have sustained sports-related concussion (including current and former athletes). He has received travel funding from the Australian Football League (AFL) to present at the Concussion in Football Conference in 2013. Previous grant funding includes the NSW Sporting Injuries Committee, the Brain Foundation and the Hunter Medical Research Institute, supported by Jennie Thomas. GLI has been reimbursed by the government, professional scientific bodies and commercial organisations for discussing or presenting research relating to mild traumatic brain injury (TBI) and sport-related concussion at meetings, scientific conferences and symposiums. He has a clinical and consulting practice in forensic neuropsychology involving individuals who have sustained mild TBIs. He has received research funding from several test publishing companies, including ImPACT Applications, Inc, CNS Vital Signs and Psychological Assessment Resources (PAR, Inc). He is a coinvestigator, collaborator or consultant on grants relating to mild TBI funded by several organisations, including, but not limited to, the Canadian Institute of Health Research, Alcohol Beverage Medical Research Council, Rehabilitation Research and Development (RR&D) Service of the US Department of Veterans Affairs, Vancouver Coastal Health Research Institute and Roche Diagnostics Canada.

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Supplementary Table 1. Studies examining concussion in rugby league players

Author (year)	Aims Purpose	Findings
King, Hume, & Clark (2012)	To examine the nature of rugby league tackles associated with injuries	The majority of injuries occurred in the tackle situation. More injuries occurred to the ball carrier than the tackler. Tackle-related injuries occurred most frequently to the ball carrier when tackled at the shoulder or mid torso height, in their blind vision, when involving two or more tacklers, and in the fourth quarter of matches.
King, Hume, Milburn, & Gianotti (2009)	To provide an epidemiological overview of rugby league injuries and associated costs in NZ over 8 years.	Although the cost of concussion over the study period only accounting for 1.8% of the total injury entitlement claims, concussion accounted for 6.3% of the total costs and had the highest mean cost per injury type ($25,347).
King & Gissane (2009)	To describe differences in injury risk between different amateur participation levels.	No significant differences were observed between division 1 and division 2 teams for concussions.
Gabbett (2008)	Incidence of injury in junior rugby league.	The overall incidence of injury was 56.8 per 1,000 playing hours. Incidence of concussion was 4.6 per 1,000 playing hours.
Hodgson, Standen & Batt (2006)	Analysis of injury rates after the seasonal change in rugby league	The incidence of injuries in summer remained higher than that found in winter. The increase observed in concussion did not reach significance.
King, Gabbett, Dreyer, & Gerrard (2006)	To examine the incidence of injury in NZ rugby league sevens tournament	Over the two days of competition 76 injuries were observed. One concussion was recorded; equated to 6.5 per 1,000 playing hours.
Gabbett (2005a)	Playing position & injuries in rugby league	The hooker and props were found to have the highest incidence of injury of any playing positions. Concussion incidence was 5 per 1,000 playing hours in forwards versus 3 in backs; props recorded an incidence of 6 per 1,000 playing hours, backrowers and outside backs 4, and hookers and halves 2.
Gabbett (2005b)	To examine the influence of the limited interchange rule on the	A 30% reduction in overall risk of injury was reported during matches played under the limited interchange rule

Author (year)	Aims Purpose	Findings
	Incidence of injury	in comparison to matches played under the unlimited interchange rule. Concussion (which also included 'open wound injuries to the head' in this study) had an increased risk of 0.59 under the limited interchange rule versus the unlimited interchange rule.
Gabbett & Domrow (2005)	Investigate the risk factors for injury in sub-elite rugby league	The incidence of injury was 55.4 per 1,000 playing hours. Injuries were most commonly sustained while being tackled and while tackling. The rate of concussion was 3 per 1,000 playing hours.
Gabbett (2004)	Investigate if reductions in pre-season training loads reduced the incidence of training injuries in rugby league footballers	A reduction in training loads reduced training injury rates in rugby leagues players and resulted in greater improvements in maximal aerobic power. Concussion rates were reduced from 1.7 versus 0.7 per 1,000 training hours.
Hrysomallis (2004)	To evaluate the impact energy attenuation of headgear using a yielding headform and no-rigid impact surface	When compared to the Head Injury Criterion (HIC) values for the bare headform drops, the headgear on average reduced the HIC values by approximately 50%. 1/7 headgear tested generated HIC values below 1,000 for side of the head impacts. It appears that headgear thickness on the front and sides should be at least 15mm in order to offer adequate impact energy attenuation.
Gabbett (2004)	Influence of training and match intensity on injury rates in rugby league	Match-play injury-rate (any type of injury) was highly correlated with the intensity, duration, and load of matches. A significant positive relationship was present between the incidence of overall training injury (any type of injury) and the intensity, duration, and load of training sessions. Concussive injuries: Match (n=36) 34.8 per 1,000 playing hours; Training (n=1) 0.3 per 1,000 training hours.
McIntosh, McCrory, & Finch (2004)	To examine the impact energy attenuation performance of foam	Attenuation of impact energy could be increased by increasing foam thickness. The 16mm thick Honeycomb headgear model performed significantly better than the 10mm standard model.

Author (year)	Aims Purpose	Findings
Gissane et al. (2003)	To determine the incidence of injury in professional rugby league, in terms of major injuries and over 3 day injuries.	Very high injury rates; 563 per 1,000 players. Concussive injuries: Minor (n=10); over 3 days (n=2), and major (n=2).
Gissane, Jennings, Kerr, & White (2003)	To report the injury incidences over a period of five summer seasons and four winter seasons to examine the shift in playing seasons	Professional rugby league footballers doubled their risk of being injured; up to a 100% increase. Both forwards and backs demonstrated an increase in injury. The tackle is the most common mechanism for injury. Concussive injuries: summer (n=10) 4.02 per 1,000 playing hours; winter (n=8) 3.35 per 1,000 playing hours; Summer/winter risk ratio 1.20.
Gabbett (2003)	To document the incidence of injury in semi-professional rugby league footballers over two consecutive seasons	Overall playing incidences of injury of 824.7 per 1,000 player-position game hours, with First grade players having the highest incidence of injury (1055.3 per 1,000 player-position game hours). Rates of missed matches were higher in the present cohort (67.7 per 1,000). Concussive injuries: Playing injuries approximately 32-37 per 1,000 playing hours; Training injuries approx. 1 per 1,000 training hours.
Gabbett (2002)	Document the incidence of injuries in amateur rugby league sevens	Overall injury rate was 283.5 per 1,000 playing hours. This represents a 76.5% increase in rates of injury from the same cohort participating in conventional rugby league. Incidence of injury increased significantly when participating in consecutive matches. No concussions were observed in the study cohort.
Gissane, Jennings, White, & Cumine (1998)	To ascertain different injury rates from winter to summer seasonal play	Increased rates and risk of injury associated with summer competition in both forwards and backs. Injury rates in summer increased despite exposure decrease by one-third.

Author (year)	Aims Purpose	Findings
		Concussion: winter (n=8) 3.35 per 1,000 playing hours; summer (n=1) 2.51 per 1,000 playing hours; winter/summer risk ratio 0.75.
Gissane, Jennings, Cumine et al. (1997)	To document the differences in the incidence of injury between rugby league forwards and backs	The forwards/backs overall injury risk ratio was 1.50; 492 injuries [277 (56.3%) forwards, 215 (43.7%) backs]. Concussion: forwards (n=22) 11.1 per 1,000 playing hours; backs (n=13) 5.60 per 1,000 playing hours; total (n=35) 8.10 per 1,000 playing hours.
Stephenson, Gissane, & Jennings (1996)	To describe the incidence of injury in one professional rugby league club over a period of four seasons	Overall injury rate of 114 injuries per 1,000 playing hours. This incidence was reduced to 34 injuries per 1,000 playing hours, if injury definition restricted to those that miss a subsequent game due to the injury. Most common site of injury head and neck (33.3%) of the overall injury incidence. Concussion: first team (n=18) 8.0 per 1,000 playing hours; A team (n=17) 9.0 per 1,000 playing hours; total (n=35) 8.0 per 1,000 playing hours.
Gibbs (1993)	To study the incidence and nature of injuries sustained by players in all three teams of a professional rugby league football club over three seasons	Over the three playing seasons 141 injuries were observed, 44.9 injuries per 1,000 playing hours. Concussion (n=5 players) made up 6% of all injuries. Four concussions were minor (only missed one subsequent game), the other was a player who had three injuries. Games missed following each incident: 1, 4, and the rest of the season (2 games), respectively. 23 other players were treated on the field for mild concussion that did not require removal from play or missing subsequent games.
Seward, Orchard, Hazzard, & Collinson (1993)	To establish a comparative injury profile across the major football competitions in Australia at the elite level	Rugby league reported a total of 1,214 injuries during the season. The most common injury reported was head and facial lacerations (11.4%), followed by concussion at 8.5% of all reported injuries. These injuries were particularly common among forwards.
McKenna et al. (1986)	Public hospital admissions due to sporting injuries in New Zealand	A total of 5,108 admission due to sporting injuries were recorded during 1981-82. The overwhelming majority of injuries (80%) were sustained participating in winter sports (i.e., the warm

Author (year)	Aims Purpose	Findings
		season). 58.1% of cases were involved in 'rugby' (league and union). 504 'rugby' concussions were documented, which represents 70% of all documented concussions, 17% of all injuries in 'rugby' (the second most common behind fractures), and 10% of the overall injuries recorded. Concussion incidence is likely to be considerably higher, because these statistics are only for those injuries resulting in an admission to hospital.
Alexander, Kennedy, & Kennedy (1979)	Describe the pattern and incidence of one season of injuries in the top three grades of a NSW rugby league club	204 total injuries equating to one injury per 3.6 hours of play. Concussion (n=13) 3.6% of injuries, 10 occurred to front-row players.
Lingard, Sharrock, & Salmond (1976)	To identify the incidence, nature, and severity of sports injuries during the winter in New Zealand	Overall a total of 2,529 cases were documented across a variety of sports [rugby league n=192 (7.6%)]. A total of 124 central nervous system head injuries were recorded across all sports, only 87 resulted in a hospital admission. In rugby league, 4.2% of injuries were central nervous system head injuries (n=7).
Gissane, Hodgson, & Jennings (2012)	Describe the injury rates in rugby league in terms of those injuries that require players to miss matches and those that do not.	Overall 85% of all playing injuries and 82% of all training injuries are non-time loss injuries. Non-time loss concussions accounted for 71% of all concussions. Note: prior to 2012 it was possible to be classified as having a concussion and not miss any playing time.
O'Connor (2011)[REF]	NRL injury report 2010	Concussions were sustained at an injury rate of 3.3 per 1,000 playing hours (n=27) at the NYC level, and 4.3 per 1,000 playing hours (n=30) at the NRL level. All incidences were recorded in games, with neither level recording a single incidence of concussion at training. Concussion represented 6.4% and 4.6% of the overall injury incidence in the NYC and NRL, respectively. 31 NYC games (mean: 1.3) were missed during the 2010 season as a result of a concussion (1.9 missed games per club). 55 NRL games (mean: 1.8) were missed during the 2010 season as a result of a concussion (3.4 missed games per

Author (year)	Aims Purpose	Findings
		club).
O'Connor (2012)	NRL injury report 2011	Concussions were sustained at an injury rate of 3.4 per 1,000 playing hours at the NYC level, and 4.2 per 1,000 playing hours at the NRL level. On average 1.7 (NYC) and 2.2 (NRL) concussions occurred per club during the 2011 season. Concussion represented 5.5% and 5.3% of the overall injury incidence in the NYC and NRL, respectively, and 6.8% and 6.4% of game injuries, respectively. An average of 1.0 NYC and 1.7 NRL games were missed during the 2011 season as a result of a concussion, equating to 1.7 and 3.8 games missed per club, respectively.
King, Hume, & Clark (2010)	Player perspectives on return to play after a match or training injury in amateur rugby league	In 2008, concussion resulted in missed matches (n=8; i.e., 17.0% of overall match injuries) but not training (n=0). Incidence of concussion match injury was 17.8 per 1,000 playing hours. In 2009, concussion resulted in missed matches (n=5; 11.4% of overall match injuries) and training (n=1; 5.0% of overall training injuries). Incidence of concussion match injury was 10.7 per 1,000 playing hours, and 0.2 per 1,000 training hours. Less than 33.3% of athletes sought medical clearance for return to sports participation for match play, and less than 25% for return to training post-injury. 75% of players felt that time off for rehabilitation was too long, especially for concussion with the three week mandatory stand-down period.
King, Hume, Milburn, & Gianotti (2009)	Injury surveillance, claims, and costs by ethnicity and other demographics in New Zealand rugby league	Concussion represented 0.5% (±0.4%) of all injury claims but 1.3% (±2.4%) of the overall injury costs. NZ Maori (n=62; 10.4 injuries per 1,000 playing hours) recorded significantly more concussions than other ethnic groups (NZ European: n=41; 6.9 injuries per 1,000 playing hours; Pacific People: n=17; 2.9 injuries per 1,000 playing hours; Asian: n=0; others/unknown: n=31; 5.2 injuries per 1,000 playing hours). Total cost and mean cost per concussion varied by ethnic group (NZ Maori: $2,363,000 (mean cost per concussion $38,118); NZ European: $86,000 (mean cost per concussion $2,097); Pacific People: $44,000 (mean cost per concussion $2,588); Asian: $0; others/unknown: $239,000 (mean cost per concussion $7,709).

Author (year)	Aims Purpose	Findings
King (2006)	Incidence of injuries in the 2005 NZ national junior rugby league competition	74 total injuries were recorded with an overall incidence rate of 217.3 per 1,000 playing hours. Total recorded concussions (n=5) represented an incidence of 14.7 per 1,000 playing hours and 6.8% of the overall injury data. At the under 16s level (n=1 concussion) incidence of 4.3 per 1,000 playing hours and 2.0% of the overall injury data. At the under 18s level (n=4 concussions) incidence of 18.5 per 1,000 playing hours and 17.4% of the overall injury data.
King & Gabbett (2009)	Injuries in NZ semi-professional rugby league	Limited concussion details, beyond graphical representation of incidence of injury, approximately 6.0 per 1,000 playing hours.
Norton & Wilson (1995)	Rugby league injuries and patterns	352 injuries in 313 players, equivalent to 621 injuries per 1,000 players and 4.8 injuries per 1,000 playing hours. Concussion represented 11.8% of the total injury data. Restricted teams reported somewhat higher proportion of concussions compared with other grades. All concussions were reported to have been sustained in tackles. Of all injuries associated with illegal play, 29% were concussions. Only 9% of injuries sustained in legal play were concussions. Headgear was worn by 10.4% of players who sustained a head injury or concussion. Headgear was worn by 8.4% of players who did not sustain a head injury or concussion.
Hume & Marshall (1994)	Sports injuries in NZ: an exploratory analysis	Reported 3 fatal injuries in rugby league (not specifying cause), representative of 4.3% of all fatal injuries with an incidence of 0.41 per 100,000 players per year. A total of 102 injuries in rugby league, representative of 2.3% of all sporting injuries recorded, with an incidence of 137.82 per 100,000. Across all sports, hospitalisation due to concussion (n=421) represented 9.6% of all injuries, ED presentation (n=47) represented 1.5% of all injuries and sports injury clinic appointments (n=24) represented 3.9% of all injuries.

Author (year)	Aims Purpose	Findings
Rugby League Studies with a Concussion Focus		
Hinton-Bayre, Geffen, & Friis (2004)	Record the incidence of concussion in rugby league including the circumstances leading to concussion, injury incidence, mechanism leading to concussion, how the injury was recognised and the frequency of presenting signs and symptoms, across three seasons.	Concussion incidence remained relatively stable across the three seasons; 13-17% of all players. Loss of consciousness occurred in only 12% cases. 16% of recorded concussions were repeat injuries. All playing position were vulnerable to concussion, although the incidence of injury was not significantly different between forwards and backs in contrast to results from other studies. 9.84 concussions per 1,000 playing hours in first grade; 7.87 concussions per 1,000 playing hours in reserve grade; 5.90 concussions per 1,000 playing hours in age-group (u/21s & u/19s) competitions. Offensive players were not concussed significantly more frequently than defensive players (9.68 v 6.45 per 1,000 playing hours); only two concussions occurred when neither player in the collision had possession of the ball. Identification of a concussion was most frequently made when a player remained motionless on the ground (n=21); a player admitted problems subsequently (n=10); and observed unsteadiness (n=7). Mechanism of injury: 40% (n=17) head high tackles, but only 7 resulted in a penalty; 35% (n=15) head contact with the ground; and head contact with opposing players body (n=5). Most common self-reported post-concussion symptoms: headache (n=35), unsteadiness (n=22), visual disturbance (n=19), dizziness (n=11), and nausea (n=10).
Hinton-Bayre & Geffen (2002)	Severity of concussion and neuropsychological assessment results	No relationship was observed between concussion severity grade and cognitive impairment for the severity grading systems used (AAN, Cantu, or Colorado Medical Society). Cognitive deficits were observed regardless of the severity rating within 2 days post-concussion. The percentage of rugby league footballers impaired at 10 days post-concussion was consistent across severity classifications. PTA was the only salient predictor of impairment at 2 days, although neither its presence nor duration was related to recovery.

Author (year)	Aims Purpose	Findings
		Players experiencing a loss of consciousness did not appear more likely to demonstrate impairment. The overemphasis of grading systems/classifications on loss of consciousness requires greater consideration and the effects of the mildest concussion may be underestimated.
Hinton-Bayre, Geffen, & McFarland (1997)	Study 1: examine alternate form equivalence, test-retest reliability, and practice effects on standardised measures of processing speed. Study 2: examine the sensitivity of the selected psychometric measure to the acute effects of concussion.	Study 1: Established alternate forms and test-retest reliability of measures expected to be sensitive to the effects concussion on cognitive functioning. Study 2: Illustrated that timed tasks (silly sentences, Symbol Digit, and Digit Symbol) were performed more poorly following concussion. Silly sentences was found to be most sensitive.
McCrory, Bladin, & Berkovic (1997)	Retrospectively studied concussive convulsions in elite Australia rules and rugby league footballers	Only two cases of elite rugby league concussive convulsion during 15 playing seasons. Outcomes for a player experiencing a concussive convulsion were universally good. Concussive or impact convulsions are a non-epileptic phenomenon, and are not associated with structural brain injury. Antiepileptic medication is not indicated and prolonged absence from sport is unwarranted.
King, Clark, & Gissane (2012)	To determine whether the King-Devick sideline test and the Sports Concussion Assessment Tool (SCAT-2) could identify concussions in amateur rugby league footballers	12 games (414.5 match exposure hours) of a 24 game season were observed, three concussions were identified by team medics and two were found post-match by King-Devick testing. Three players identified on-field had significantly longer King-Devick test times (median increase greater than 5s) and reported greater post-concussion symptoms compared with their own baseline performance. Concussion incidence 12.1 per 1,000 match hours. Internal consistency of the three King-Devick testing cards was: card 1: 0.72, card 2: 0.78, and card 3: 0.76. Player cohort (n=50) self-reported history of concussion:

Author (year)	Aims Purpose	Findings
		30% (n=15) of players sustained a concussion in the current playing season. 62% (n=31) reported a previous concussion history. 31 players (25.8%) were removed from play, with five (16.1%) receiving a subsequent medical clearance to return-to-play. Median number of days that players were removed from play was 17.5 (range 2-21) days.
King, Hume, & Clark (2010)	Assess the knowledge of first aid, concussion recognition and management, and injury prevention of local rugby league club administrators, coaches, and other team management in NZ	Concussion knowledge questionnaire Part III: "concussion recognition, management and prevention knowledge" consisted of 38 closed- and open-ended questions on concussion recognition, management, and prevention knowledge. 95 people (50 coaches, 13 managers, 15 trainers/medics, 14 club committee personnel and 3 referees) completed the questionnaire. Male:Female ratio 83%:17%, mean age 38 years (±10 years), 55% (n=52) had a current first-aid certificate. Only 54% of coaches had a rugby league coaching qualification; 54% of managers had a rugby league manager's qualification, 13% of trainer's had a rugby league trainer's qualification, and 100% of referees had a rugby league refereeing qualification. All respondents indicated that they knew what the term concussion meant; 98% responded that sports-related concussion could influence players' social and work activities. 75% knew how to recognise a concussion in players but only 58% had discussed the consequences of a concussion with a player. 85% identified that playing while recovering from a concussion could lead to long-term complications. 70% insist a concussed player should see a doctor before returning to play or train, and 26% of non-coaches would check with the coach before they could return a player to play or training. 54% knew of a concussion policy in rugby league but only 8% could identify the three week mandatory stand-down requirement. 78% reported a seven day stand-down as the requirement for recovery from concussion. 55% of respondents who had a player with a concussion (n=52) had not sought a medical clearance for a concussed player before returning them to match or training activities. Only 33% (±14%) of respondents correctly identified concussive symptoms.

Author (year)	Aims Purpose	Findings
		53% endorsed the wearing of head gear as a means to aid concussion prevention. More trainers (80%) supported this statement than coaches (62%) or managers (54%). Loss of consciousness was reported to be required for a concussion to have occurred by 39% of responses. Overall concussion knowledge was low at 42% (±20%). Trainers/medics recorded the highest overall concussion knowledge. Misconceptions regarding SRC appear to be common.
Note, NYC: national youth competition; NRL: National Rugby League; NZ: New Zealand; ED: emergency department.		

Supplementary Table 2. Studies reporting on concussion incidence

Author (year)	Concussion incidence	Injury Definition	Level of Play	Number of teams and seasons	Ranking of concussion frequency among all other injuries, rates of overall injury, and rates of concussion
King et al (2012)	Ball carrier 6 per 10,000 tackle events & 12 per 1,000 match hours; Tackler 4 per 10,000 tackle events & 8 per 1,000 match hours. Concussion Risk ration Ball Carrier:Tackler = 1.4	An injury that rendered the player unavailable for selection in the next match	Professional	One team, two seasons (48 matches; 830 playing hours)	Equal 4th; 18 concussions / 266 total injuries
King et al (2009)	Division 1: 12.9; Division 2: 27.2; overall 17.5.	Injuries defined as both: transient (did not miss a game), and missed game injuries.	Amateur	Two teams, two seasons (53 matches; 951 hours)	Least frequent injury category recorded
Gabbett (2008)	4.6	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent match.	Junior	One team, four seasons (84 matches)	5th most frequent type of injury
King et al (2006)	Total 6.5; Semi-Professional 10.6; Amateur 0.	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent match.	Semi-Professional & Amateur	20 teams, 1 ‘sevens’ tournament (47 games)	Equal 6th; 1 concussion / 76 total injuries
Gabbett (2005)	Forwards: 5; Backs: 3; Outside Backs: 4; Halves & Hooker: 2; Backrowers: 4; Props: 6.	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent match.	Semi-Professional	156 players over two seasons	Forwards equal 5th, 5 / 80 total injuries; Backs equal 5th, 3 / 57 total injuries.
Gabbett (2005)	Unlimited Interchange: 5.1; Limited Interchange: 3.0; Limited/Unlimited	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent	Semi-Professional	One club, three seasons (two under Unlimited Interchange; one under Limited Interchange	Unlimited Interchange equal 4th, Limited Interchange equal 5th.

Author (year)	Concussion incidence	Injury Definition	Level of Play	Number of teams and seasons	Ranking of concussion frequency among all other injuries, rates of overall injury, and rates of concussion
	Interchange RR: 0.59	match.		rules)	
Gabbett et al (2005)	3.0	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent match.	Semi-Professional	One club, four seasons	5th
Gabbett (2004)	Training injuries: Year 2001: 0; Year 2002: 1.7 Year 2003: 0.7	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent match.	Semi-Professional	One club, three seasons	2001: 10th; 2002: 8th; 2003: 10th.
Hinton-Bayre et al (2004)	1st Grade: 9.84; Res. Grade: 7.87; Age-Grade: 5.90	The team physician made a clinical diagnosis of concussion	Professional	Two clubs, three seasons	NR: Concussion only
Gissane et al (2003)	Summer: 4.02; Winter: 3.35 Summer:Winter RR: 1.20	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent match.	Professional	One club, nine seasons (five summer and four winter seasons)	Summer: 6th Winter: equal 4th
Gabbett (2003)	NR graphically represented. Match: Forward: slightly less than 40.0; Backs: slightly less than Forwards total. Training: Forwards: less than 1; Backs: 0.	Any pain or disability suffered by a player during a match that resulted in the player missing a subsequent match.	Semi-Professional	156 players, two seasons	Match: Forwards: 7th; Backs: 6th. Training: Forwards: 11th; Backs: 13th.
Gissane et al	Winter: 3.35	A physical impairment received during a competitive match which	Professional	One club, four seasons	Winter: Equal 4th, (8 / 72 total

Author (year)	Concussion incidence	Injury Definition	Level of Play	Number of teams and seasons	Ranking of concussion frequency among all other injuries, rates of overall injury, and rates of concussion
(1998)	Summer: 2.51	prevented a player from being available for selection for the next competition game.			injuries) Summer: equal 5th (1 / 20 total injuries)
Jennings et al (1997)	Forwards: 11.1 Backs: 5.6 Total: 8.1	The onset of pain or a disability that occurred while playing.	Professional	One club, four seasons	Forward: 6th (22 / 277 injuries) Backs: 7th (13 / 215 injuries) Total: 6th (35 / 492 injuries)
Stephenson et al (1996)	All players: 8 1st team: 8 A team: 9	The onset of pain or disability that occurred while playing rugby league football	Professional	Four seasons (249 games)	All players: 8th (35 / 492 injuries) 1st team: 8th (8 / 297 injuries) A team: 7th (17 / 195 injuries)
O'Connor (2011)	NRL: 4.3 NYC: 3.3	Any injury that was sustained during a first grade NRL game (or NYC game) or training session that resulted in missed game time.	Professional	Sixteen clubs, one season	NRL: 5th; NYC: 7th
O'Connor (2012)	NRL: 4.2 NYC: 3.4	Any injury that was sustained during a first grade NRL game (or NYC game) or training session that resulted in missed game time.	Professional	Sixteen clubs, one season	NRL: Equal 5th NYC: 5th
King (2006)	Total: 14.7 u/16: 4.3 u/18: 18.5	Any pain or disability suffered by a player during a match that required advice and/or treatment	Junior	Four teams, one season	Total: 6th (5 / 74 total injuries) u/16: equal 9th (1 / 49 total injuries) u/18: 2nd (4 / 23 total injuries)

Author (year)	Concussion incidence	Injury Definition	Level of Play	Number of teams and seasons	Ranking of concussion frequency among all other injuries, rates of overall injury, and rates of concussion
King & Gabbett (2009)	NR, graphically represented, approx. 6.	Any pain or disability suffered by a player during a match that required advice and/or treatment	Semi-Professional	Eight teams, one season	7th
Note. Incidence reported as number of injuries per 1,000 playing (or training) hours; RR: risk ratio; Res: Reserve; NR: not reported; NYC: national youth competition; u/: under; approx.: approximately.					