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Concussion in youth rugby union and rugby league: a systematic review

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ABSTRACT

Background Children and adolescents who play rugby are at increased risk of concussion and its effects. Competitive rugby union and rugby league feature as major sports in the school sport curriculum in the UK. There is a need for a thorough understanding of the epidemiology of concussion in youth rugby, the mechanisms involved in injuries and predisposing risk factors.

Data Sources The publication databases Pubmed, Embase and SportDISCUS were searched in April 2014 for primary research studies of child and adolescent rugby union and rugby league (under 20 years) in English language with data on concussion injuries. The review was conducted within a larger all injury systematic review on rugby union and rugby league where key words used in the search included rugby, injury and concussion with child, adolescent, paediatric and youth.

Results There were 25 studies retrieved with data on child or adolescent rugby and concussion, 20 were on rugby union, three on rugby league and in two the code of rugby was unspecified. There was significant heterogeneity in the definitions of injuries and of concussion. The incidence of child and adolescent match concussion ranged from 0.2 to 6.9 concussions per 1000 player-hours for rugby union and was 4.6 and 14.7 concussions per 1000 player-hours for rugby league, equivalent to a probability of between 0.3% and 11.4% for rugby union and of 7.7% and 22.7% for rugby league.

Conclusions There is a significant risk of concussion in children and adolescents playing rugby union and rugby league evident from the studies included in this systematic review. There is a need for reliable data through routine monitoring and reporting in schools and clubs and in hospital emergency departments in order to inform prevention. Concussion protocols should be implemented and tested.

INTRODUCTION

Concussion is a frequently reported injury in rugby union and rugby league.^{1,2} It is now the most commonly recorded injury in professional rugby union in England and is increasing in incidence.³ Concern about the long-term consequences of multiple sport related concussions and associated repetitive head trauma have been growing.^{4,6} World Rugby (formerly the International Rugby Board (IRB)), the world rugby union governing body, acknowledges the risks associated with head injury and concussion 'even if this risk is unquantifiable and unknown'.⁷ An association has been found between repeat concussions and poorer cognitive function in

young adult male rugby players, at least 3 months after their last concussion.⁸ There is also evidence of an association between repeat concussions and depression, mild cognitive impairment, poorer memory and verbal fluency and electrophysiological abnormalities diagnosed in later life among former American football and ice hockey players.⁹⁻¹² There have also been multiple autopsy findings of chronic traumatic encephalopathy (CTE), similar to that found in ex-boxers and military veterans, in the brains of former professional athletes in American football, ice hockey and wrestling^{4-6,13} and in the brains of former rugby players.^{6,14,15}

Children are more likely to experience concussion than adults and take longer to recover.¹⁶⁻¹⁸ There is evidence that concussion is a relatively more common injury among rugby playing children and adolescents than it is among adult players.¹⁹ Youth players are at increased risk of what is known as 'second impact syndrome', a potentially fatal phenomenon where a player sustains a second head injury without fully recovering from the effects of the first.²⁰

UK government policy is to have at least 6000 partnerships in place between schools and local sports clubs by 2017, and rugby union and rugby league are among the five sports selected to increase the prominence of competitive sport in schools in England.²¹ This is despite evidence from Australia that rugby union and rugby league are the two sports most likely to be discouraged by parents concerned about injury.²² There are two codes of rugby, union and league, with rugby union the more popular of the two, played in 119 countries with around 40 countries playing rugby league.^{23,24}

The aim of this review was to better understand the epidemiology of concussion in youth rugby union and rugby league. The primary objective was to systematically review the literature for primary research studies on concussion in both codes of youth rugby. Variables of interest were the incidence of concussion and concussion as a proportion of all rugby injury. Secondary objectives were to review the literature for data on any association between sustaining a concussion and phase of play, position of play and sex of the player.

METHODS

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Statement.²⁵ The reference databases Pubmed, Embase and SPORTDiscus were searched in April 2014 for primary research studies published in English in peer review journals within a larger



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systematic review of rugby injury studies. The reference lists of key systematic reviews and other papers from prior work on rugby were also hand searched. Our inclusion criteria were studies which reported data on child or adolescent (under 20 years of age) rugby union or rugby league players with data on incidence of concussion and concussion as a proportion of all rugby injury. All types of study design (ie, prospective, retrospective, observational and ecological) were eligible for inclusion in this review. No date or other restrictions were imposed on our searches.

The following search strategy was used for Pubmed and then adapted for Embase and SPORTDiscus:

((rugby[tiab]) AND ((injury OR injur* OR accident OR accident* OR concussion OR concuss* OR fracture OR sprain OR strain OR contusion OR bruise OR dislocation OR dis-location OR haematoma OR hematoma OR laceration OR cut OR break OR broken))) AND ((child OR child* OR adolescent OR adolesc* OR pediatric OR paediatric OR youth OR young OR boy OR girl OR teenage OR teen* OR minor OR school OR college OR university OR student OR pupil)).

The studies retrieved by our search were initially screened on the inclusion criteria by title and abstract by one reviewer (GK) with a second reviewer (AF) double-checking studies rejected at this stage. The full text of these selected studies was then retrieved either online or if necessary from the British Library and read, leading to the final selection of studies for the systematic review. (AF, R O-A, SS) Data were extracted from our final group of studies on the topic of concussion (R A-O, GK). Where match concussion incidence was given per 1000 player-hours, the methods developed by Parekh *et al*²⁶ were used to calculate post-hoc probabilities of injury over a season for a player on the basis of two assumptions: first, that game duration was 70 min as per Under 19 World Rugby (IRB) regulations²⁷ and second, that the number of games played per season was 15.

Similar recommended definitions of injury exist in rugby union²⁸ and rugby league²⁹ and the definitions used in the studies found were extracted in line with these. In particular definitions of injury were analysed to see if medical attention was required and/or if the definition was graded according to time lost from matches and training. Definitions of concussion used in the studies were compared to the Zurich Consensus Statement on Concussion in Sport 2012.³⁰

From "Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012"³⁰

The suspected diagnosis of concussion can include one or more of the following clinical domains:

- ▶ Symptoms—somatic (eg, headache), cognitive (eg, feeling like in a fog) and/or emotional symptoms (eg, lability);
- ▶ Physical signs (eg, loss of consciousness (LOC), amnesia);
- ▶ Behavioural changes (eg, irritability);
- ▶ Cognitive impairment (eg, slowed reaction times);
- ▶ Sleep disturbance (eg, insomnia).

If any one or more of these components are present, a concussion should be suspected and the appropriate management strategy instituted.

RESULTS

There were 1579 studies found via the publication database and hand searching (minus duplicates), of which 25 met the inclusion criteria. Details and reasons for exclusion are given in the

flow diagram below (see online supplementary figure S1). Of the 25 studies selected for review: five were from Australia,^{31–35} four each were from South Africa,^{36–39} England^{40–43} and New Zealand,^{44–47} two each were from Scotland,^{48 49} the USA^{50 51} and Ireland^{52 53} and one was from Canada,⁵⁴ in addition to an international study⁵⁵ (see online supplementary table S1).

There were 20 studies on rugby union,^{32–45 48–52 55} three were on rugby league^{31 46 47} and in two studies, the code of rugby was not specified.^{53 54} Nineteen studies included men only,^{31–40 42–46 48 52 53 55} three included both men and women^{49 50 54} and in three the sex of the players was not provided.^{41 47 51}

Of the 25 studies, 21 collected data prospectively from matches or training over the course of a season or several seasons or during tournaments,^{31–38 40–45 47–51 53 55} three studies collected data retrospectively from rugby players using surveys or questionnaires^{39 46 52} and one study analysed hospital emergency department data collected via an injury surveillance system.⁵⁴

Four studies reported injuries "irrespective of the need for medical attention or time-loss from rugby activities";^{33 44 45 53} four studies reported injuries using 'medical-attention' injury definitions;^{35 38 41 47} 11 studies used 'time-loss' injury definitions;^{31 34 36 37 40 42 43 48 49 51 55} two studies used both 'time-loss' and 'medical attention' injury definitions;^{32 50} and the three surveys and the emergency department study did not require any such restrictions on injuries reported.^{39 46 52 54}

Eighteen studies did not give any detail on the definition of concussion used^{31 33–37 39 43–50 53–55} although most of these studies were on general injury, six studies defined concussion if players had at least one of the clinical domains from the Zurich Consensus Statement on Concussion in Sport 2012 described above although not all clinical domains were included in each study^{32 38 40 41 51 52} and one study required LOC in its definition of concussion.⁴²

The incidence of match concussion was reported per 1000 player-hours by seven studies^{31 32 35 40 44 47 55} and ranged from 0.2³⁵ to 6.9 (95% CI 4.4 to 9.4)³² concussions per 1000 player-hours for rugby union and was reported by two studies as 4.6 (0.6 to 8.6)³¹ and 14.7 (4.8 to 34.2)⁴⁷ concussions per 1000 player-hours for rugby league (see online supplementary table S2). Using the method developed by Parekh *et al*,²⁶ these incidences convert to a probability for a player over a season of sustaining a concussion of between 0.3% and 11.4% for rugby union and of 7.7% and 22.7% for rugby league. Three rugby union studies reported concussion using alternative denominators, 10.6 (5.7 to 15.4) concussions per 1000 player-seasons,⁴⁸ 11.1 (4.8 to 17.4) concussions per 1000 player-games⁵¹ and 5.9 concussions per 1000 player-exposures.³⁴ Only two studies, both rugby union, reported concussion incidence during training, giving figures of zero concussions⁴⁴ and 1.5 (0.2 to 2.8)⁵¹ concussions per 1000 player-practices.

Nine studies gave figures for both concussions and all injuries sustained during matches (see online supplementary table S2)^{31–33 35 40 44 47 48 55} and the proportion of all injuries classified as concussions ranged from 1.1%³⁵ to 12.2%⁴⁸ of all rugby union injuries and was 6.8%⁴⁷ and 8.1%³¹ of all rugby league injuries. Two rugby union studies reported training concussions and injuries with concussions accounting for zero⁴⁴ and 1.9%³³ of all injuries sustained in training. Finally, 12 studies, all on rugby union, gave figures for matches and training combined^{33 36 37 41–45 49–51 53} (table 1); in these studies the proportion of all injuries classified as concussions ranged from 2.2%⁴⁴ to 24.6%⁵¹ of all injuries.

Table 1 Concussion as a proportion of all injuries sustained where figures are reported for matches and training combined

Author/year of publication	Number of players included in study	Total exposure	Number of injuries	Number of concussions	Concussion as a percentage of all injury
Collins <i>et al</i> (2008) ⁵⁰	Not given	32 014 player-matches and 81 627 player-practices	594	94	15.8
Durie and Munroe (2000) ⁴⁴	442	6880 player match-hours+23 868 player practice-hours	270	6	2.2
Junge <i>et al</i> (2004) ⁴⁵	123	1734 player match-hours+5141 player training-hours	340	10	2.9
Lewis and George (1996) ⁴¹	45	Not given	Not given	Not given	7.1
Marshall and Spencer (2001) ⁵¹	Not given	1081 player-matches+3333 player- training sessions	69	17	24.6
Nathan, Goedeke and Noakes (1983) ³⁶	Not given	6075 player match-hours+25 110 player training-hours	79	17	21.5
Nicol <i>et al</i> (2010) ⁴⁹	470	2406 player match-hours; training exposure not given	37	6	16.2
Roux <i>et al</i> (1987) ³⁷	Not given	50 126 player match-hours+259 150 player training-hours	495	59	12.0
Sparks (1981) ⁴³	Not given	Match+training total=500 000 player-hours	9885	513	5.2
Sparks (1985) ⁴²	Not given	22 776 player match-hours+17 090 player training-hours	772	49	6.3
Sugerman (1983) ³³	Not given	Match+training total=45 885 player-games	574	48	8.4
Watson (1997) ⁵³	40	Not given	118	8	6.6

There were two surveys which collected data on players' prior concussion experience (table 2). A survey of under 20-year-old club and national academy elite rugby union players in Ireland found 48.1% players reported at least one concussion in their career while 27.1% had sought medical attention for concussion.⁵² In a large survey across 25 South African high-schools involving 3330 rugby union players, 14.1% of players reported at least one prior concussion with concussions accounting for 15% of all injuries reported.³⁹ There was also one study which retrospectively analysed routinely administered pre-competition medical questionnaires in New Zealand amateur rugby league⁴⁶ finding an average of 4.1 (SD 2.8) concussive incidents among the 42 under 15-year-old rugby league players surveyed and 3.8 (SD 2.5) among the 47 under 17-year-olds surveyed.⁴⁶ Finally, one study retrospectively analysed data collected by the Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) at emergency departments across Canada and found that 11.0% of all rugby injury diagnoses among 5–19-year-olds were concussions.⁵⁴

There was only one study, on rugby union, with data on concussion and phase of play. Most of the 94 concussions reported (87.2%) were associated with being tackled, tackling and

rucks.⁵⁰ Only two studies, both on rugby union, had data on position of play and concussion. Fuller and Molly report that of the nine concussions sustained during four international under 20 years tournaments, five were sustained by backs and four by forwards⁵⁵ while Marshall and Spencer report that out of the 17 concussions they found, eight were to backs and nine to forwards.⁵¹

The study by Collins *et al*⁵⁰ on rugby union was the only one with data on concussion and the sex of the player concerned. They report that the boys and girls in their study sustained concussions as a proportion of all injury in a similar fashion, with 83 concussions among the boys (16.1% of all injuries) and 11 concussions among the girls (14.3% of all injuries).

DISCUSSION

There is evidence of a significant risk of concussion in children and adolescents playing rugby union and rugby league. The incidence of youth rugby union match concussion ranged from 0.2 to 6.9 concussions per 1000 player-hours, equivalent to a probability for a player over a season of sustaining a concussion of between 0.3% and 11.4%. For rugby league there were two studies which reported 4.6 and 14.7 concussions per 1000

Table 2 Results of questionnaire surveys on injuries and concussion

Study	Total respondents	Number of rugby injuries reported	Number of concussions reported
Baker <i>et al</i> (2013) ⁵²	133	Concussion only study	64 players (48.1% of respondents) reported at least one prior concussion while 36 players (27.1%) sought medical attention for concussion
Fridman <i>et al</i> (2013) ⁵⁴	56 691 sport related injury attendances analysed	1651	182
King <i>et al</i> (2013) ⁴⁶	42 under 15 years; 47 under 17 years (213 all ages including adults)	Concussion only study	Under 15-year-olds, 4.1 (SD 2.8) concussive incidents; 1.3 (0.5) loss of consciousness Under 17-year-olds 3.8 (2.5) concussive incidents, 1.1 (0.3) loss of consciousness
Upton <i>et al</i> (1996) ³⁹	3330	5920	888 concussions (15.0% of all injuries reported) 471 players (14.1% of respondents) reported at least one prior concussion

player-hours equivalent to a 7.7% and 22.7% probability of concussion over a season. Surveys found a high prevalence of prior concussion among young rugby union players with 48.1% of 133 interviewees in Ireland and 14.1% of 3330 respondents in a South African survey reporting at least one prior concussion. There is very little research on phase of play, player position or sex in relation to concussion risk. What little there is suggests that being tackled, tackling and rucks are the phases of play most associated with concussion, that forwards and backs have similar levels of risk as do boys compared to girls.

No meta-analysis was possible due to a large degree of study heterogeneity, the largest of all the prospective studies was that by McIntosh *et al* on rugby union with 28 902 player-hours which found an incidence of 6.9 (4.4 to 9.4) concussions (requiring on field treatment or removal from the game) per 1000 player-hours, equivalent to an 11.4% (7.4% to 15.2%) risk of a child or adolescent rugby union player being concussed over the course of a season, or one or two players sustaining a concussion every season in every school or club rugby team of 15 players.

Most of the studies in this review, 19 of 25, came from just four countries, Australia, New Zealand, South Africa and the UK. Kaplan *et al*⁵⁶ also found that the vast majority of research on rugby injuries comes from these main rugby playing countries. Similarly it was no surprise that most studies were on rugby union given the differences in popularity of the two codes of rugby.^{23 24} The fact that most studies were on men is also not surprising, however, there are now estimated to be 1.5 million female rugby union players in the world, representing around 23% of all registered and unregistered rugby union players worldwide.²³ There is therefore a need for more targeted research on the epidemiology of injury among female rugby players and whether their mechanisms of injury, types of injuries sustained and their severity are similar or different to their male counterparts.

LIMITATIONS

There was a high degree of variation between studies in the reported estimates of incidence of concussion and of concussion as a proportion of all injury sustained during child and adolescent rugby. This variation is likely to be, at least partly, due to heterogeneity in study methodology and in particular in the different definitions of injury used between studies.^{1 2 29 56} There were also variations between studies in the denominators used for incidence reporting and a failure in some studies to separate matches from training. This high level of heterogeneity between studies meant there were no two studies which collected data in a similar enough fashion to conduct a meaningful meta-analysis of the results.

There can be an under-reporting of concussion by players or coaches which needs to be considered when interpreting the results of this review. Concussions which don't involve LOC or convulsions can be difficult to diagnose, symptoms may be inaccurately reported by athletes or they may withhold information in order to continue playing.⁵⁷ There may be signs of some improvement, at least in the professional game, where the higher incidence figures recorded by the English Rugby Football Union (RFU) study may be in some degree due to increased awareness of concussion and a greater focus on understanding of diagnosis.³ Preliminary data from a Pitch Side Concussion Assessment trial (results due late 2014) show a 25% increase in the number of concussed players being removed from play compared to previous seasons.³

CONCLUSIONS AND RECOMMENDATIONS

The association found between contact sports, concussion and cognitive deficits, depression and other health problems among current and former contact sport players along with the multiple autopsy findings of CTE in professional contact sport athletes should ring alarm bells among sports governing bodies and politicians. There is no hard evidence for protective equipment in protecting against concussion.^{30 58} As children are more vulnerable to concussion and its effects than adults, it is therefore urgent that rugby and other contact sports are made safer for children and adolescents to play.

1. Rule changes and prevention strategies require evidence to both inform and evaluate them but in the UK the data required for this are lacking. Data collection systems need improvement, there should be injury data collected at every school and club rugby match involving young players and hospital emergency departments need to be able to distinguish between different sports and to collect data on mechanisms involved in injuries.
2. First aiders with knowledge of concussion and full awareness of current concussion protocols such as the RFU return to play guidance should be available pitch side at every school and club rugby match involving children and adolescents. The RFU recommend under 19s in school or college rugby with a suspected or confirmed concussion are only allowed to return to competitive play after clearance by a doctor and that this should not happen before 23 days after the injury.⁵⁹
3. Public health approaches to injury prevention should be adopted by the government, rugby authorities, schools and local authorities to raise awareness among parents and school authorities on the risks of concussion, its management and prevention.
4. Given that rugby is a compulsory sport in many schools in the UK and young rugby players have a significant risk of concussion, there should be no compulsion to play rugby as part of school education.

What is already known?

- Playing rugby is a major cause of injury in children and adolescents.
- Concussion is the most common injury in professional rugby union in England.

What are the new findings?

- Studies show the probability of concussion to a child or adolescent rugby player over the course of a season to be between 0.3% and 11.4% in rugby union and 7.7% or 22.7% in rugby league.
- The largest prospective study available estimates a probability of 11.4% of a child or adolescent rugby union player sustaining a concussion over a season, equivalent to between one and two players in every school or club youth rugby team sustaining a concussion every season on average.

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Competing interests None.

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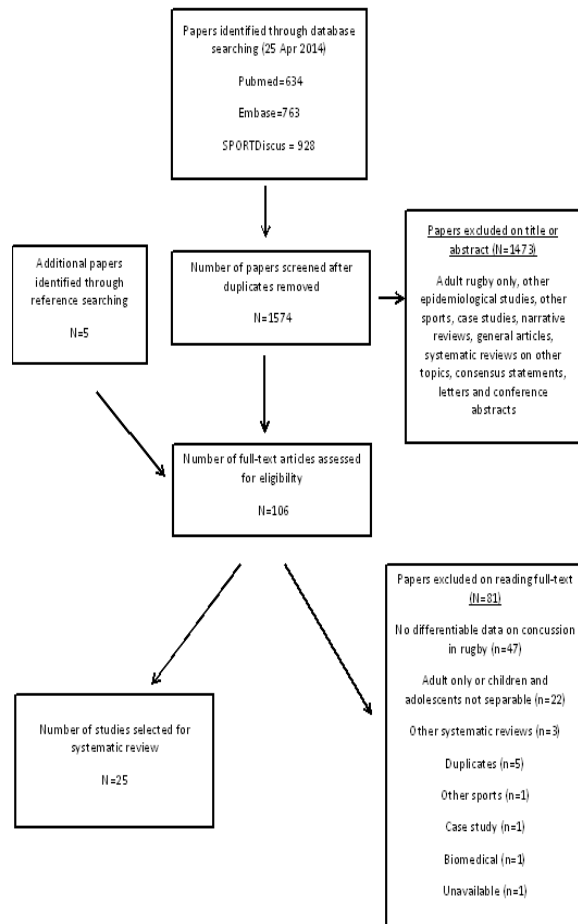
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Supplementary Figure

Concussion in youth rugby union and rugby league – a systematic review. Kirkwood et al

Figure one. Flow diagram for study selection



Supplementary Table 1 – Description of included studies

Author / Year of publication	Data collection details	Definition of injury	Definition of concussion	Who carried out the injury assessment	Age	Gender	Time / Period	Country	Rugby Code
Baker et al (2013)	Retrospective questionnaire survey on club and national academy elite youth rugby players, no time limit for recall	Self-reported concussion	Self-reported concussion symptoms checked against Sports Concussion Assessment Tool version 2 (SCAT-2)	Self-reported	<20 years	Male	2009-10 season	Ireland	Union
Collins et al (2008)	Clubs completed weekly reports including injury details	Requiring medical attention by physician, trainer or emergency department; one or more days missed play	Not defined	Most were assessed by a doctor or other medical personnel such as an athletic trainer (93.0%)	13-19 years Mean age 16.5 years	Male and female	2005 and 2006 seasons	USA	Union
Davidson (1987)	Data collected prospectively at a casualty station during inter-school matches at a large private school	Any injury however minor reported to casualty station	Not defined	Trained nurse and if appropriate by doctor	11-18 years	Male	1969-86	Australia	Union
Durie and Munroe (2000)	Data collected at the injury clinic at a boys high school on the Monday following matches	Unable to continue playing or reported injury at the end of a game: minor (able to play again in 7 days); moderate (unable to play for 1-3 weeks); severe (unable to play for more than three weeks)	Not defined	Doctor assessment at injury clinic	<19 years	Male	1998 season	New Zealand	Union

Fridman et al (2013)	Data collected routinely at Canadian emergency departments	Sport related injury diagnosis	Not defined	Medical diagnosis	5 to 19 years	Male and Female	1 April 2007 to 31 March 2010	Canada	Not Specified
Fuller and Molloy (2011)	Data collected prospectively during four international competitions, two in 2008 and two in 2010	Time-loss match injuries	Not defined	Team physician responsible for recording injury location and type	<20 years, mean age 19 years	Male	2008 and 2010 tournaments	International	Union
Gabbett (2008)	Prospective match data collection over four seasons, junior rugby league	Player misses subsequent match	Not defined	Head trainer accredited in injury assessment	17-19 years	Male	2003 – 06 seasons	Australia	League
Haseler, Carmont and England (2010)	Prospective data collection from one community rugby club	Unable to return to play for at least two days	Concussion described to form completers as “suffering from transient loss of consciousness, confusion, dizziness, nausea or visual disturbance following a head injury”	Injuries form completed by coaches or first aid staff. Formal diagnoses obtained for those players who attended GP or emergency department	<17 years	Male	2008-09 season	England	Union
Junge et al (2004)	Data collected prospectively via weekly player interview with doctor from 10 school rugby teams	Any physical complaint caused by rugby during training or match	Not defined	Doctor visited teams weekly to record injuries. No on-site team physician or physiotherapist responsible for looking after the players	14-18 years	Male	March to August 2001	New Zealand	Union
King et al (2013)	Retrospective analysis of medical pre-competition questionnaires	Self-reported concussion	Concussion history items not defined, compared to post concussion symptom scale to establish baseline data	Self-reported	Under 15 years and under 17 years	Male	2010 to 2012 competition period	New Zealand	League
King (2006)	Data collected prospectively during	Any pain or disability suffered by a player during	Not defined	Recorded by accredited team trainer	Under 16 years and under 18	Not given	March to April 2005	New Zealand	League

	competition	a match that required advice and / or treatment			years				
Lee and Garraway (1996)	Prospective data collection over a season from nine state or private rugby playing schools	Sustained during training or match resulting in inability to play or train. Coded using International Classification of Diseases, ICD-9 classifications	Not defined	Injury recorded by teacher, school nurse or matrons. Additional information gained from parents and General Practitioner or hospital if appropriate	11-19 years	Male	1993-94 season	Scotland	Union
Lewis and George (1996)	Data collected prospectively from games from three youth rugby clubs	Requiring attention on the pitch or after game or training session	Following a blow to the head, one or more of: loss of consciousness, loss of memory, confusion and disorientation; double/blurred/abnormal vision; giddiness or unsteadiness; vomiting; or headache OR within 24 hours of blow to head one or more of: persistent headache; drowsiness leading to unconsciousness; irritability; confusion and loss of concentration; vomiting; or convulsions	Questionnaire completed by club doctor or physiotherapist	< 19 years Mean age 17 years	Not given	September 1992 to April 1994 (two seasons)	England	Union
Marshall and Spencer (2001)	Data collected prospectively onto a custom made database from one high school rugby programme	Injuries resulting in time lost from games or practice, all fractures and concussions recorded	Graded using Cantu Scale, loss of consciousness, disorientation, convulsions, dizziness, amnesia, disorientation or headache	Doesn't say who records them during game or training Concussions are monitored and reviewed by team physician	Not given (high school)	Not given	1998-2000 three seasons	USA	Union
McIntosh (2001)	Prospective data collection during	A traumatic event resulting in a	"Medically verified concussion"	Team nominated "recording officer".	< 15 years	Male	Single competitive	Australia	Union

	inter school competitions	missed game or missed training		Team medical officers were contacted to verify injury diagnosis			season (doesn't give dates)		
McIntosh et al (2010)	Data collected prospectively from matches, participants were from schools or clubs	Game injury – requiring on-field treatment or removal from game Missed game injury - player misses a game the following week, usually at least 7 days absence from competition	Defined by at least one of a list of “concussion descriptors” on injury form including loss of consciousness, headaches, dizziness and post-traumatic amnesia	Injury data collected at games by university students trained in injuries, typically studying medicine, physiotherapy or sports science supplemented with information from players treating doctor or team physiotherapist	<20 years	Male	2002 and 2003 seasons	Australia	Union
Nathan, Goedeke and Noakes (1983)	Injury data collected weekly from matches in one school via missed game reports	Severe enough to prevent player from play for at least 7 days	Not defined	Self-reported player questionnaire, interviewed by study personnel	<19 years	Male	1982 season	South Africa	Union
Nicol et al (2011)	Data collected prospectively by school “data champion” at five secondary schools (state and private)	Player unable to take a full part in future training or match play (taken from IRB definition)	Not defined	Injury recorded/assessed by school-based data collector (majority were non-medical)	11-18 years	Male and female	Second half of 2008-09 season	Scotland	Union
Roux et al (1987)	Data collected weekly following matches from 26 schools (20 closely monitored)	Severe enough to prevent the player from returning to rugby for at least seven days	All concussion injuries had to be reported regardless of ability to continue playing, concussion not defined	Teacher/coaches completed one weekly form for all injuries, injured players completed individual injury report forms	<19 years	Male	1983, one 18-week season	South Africa	Union
Shuttleworth-Edwards et al (2008)	Data collected prospectively for all concussed players referred to school medical centre from five	Concussion study	Any alteration in neurological status occurring as a result of head-jarring trauma with or without loss of consciousness	Doctor (four schools) and nurse (one school)	South African school grades 8 to 12	Male	2002-06	South Africa	Union

	schools from matches								
Sparks (1981)	Data collected routinely by school doctor from one private school	At least one week's absence from the game	Not defined	Doesn't say, the paper is written by the school doctor	13-18 years	Male	1950-79	England	Union
Sparks (1985)	As above (follow-up study to Sparks 1981)	No definition given for injury, it was defined in prior study (see above Sparks 1981)	Loss of consciousness, however transient, caused by a blow to the head or neck	Doesn't say, the paper is written by the school doctor	13-18 years	Male	1980-83, four seasons	England	Union
Sugerman (1983)	Data collected from matches at 33 schools and centralised monthly	As reported by a player to the teacher, generally after a match	Not defined	Teacher	Secondary school ages (11 to 18 years)	Male	1981 school season (April to July)	Australia (Australian Capital Territory, New South Wales and Queensland)	Union
Upton, Roux and Noakes (1996)	Data collected retrospectively via questionnaire survey to 25 high schools	No definition of injury or concussion given	No definition of injury or concussion given	Self-completed player questionnaires	Not given (high school)	Male	1991	South Africa	Union
Watson (1997)	Data collected prospectively from schools	Required medical treatment or disrupted training or matches	Not defined	Physical education teachers	14 to 19 years	Male	12 month period	Ireland	Not Specified

Supplementary Table 2 –Incidence of concussion and concussions as a proportion of all injuries sustained where figures are reported for matches and training separately

Author / Year of publication	Number of players included in study	Matches only						Training only				
		Number of injuries	Number of concussions	Total exposure	Incidence of concussion (95% confidence interval where given)	Probability of a match concussion to a player in a season *	Concussion as a percentage of all injury	Number of injuries	Number of concussions	Total exposure	Incidence of concussion (95% confidence interval where given)	Concussion as a percentage of all injury
Davidson (1987)	Over 1000 boys attended the school	1444	16	82107 player-hours	0.2 concussions per 1000 player-hours	0.3%	1.1%	Study was matches only				
Durie and Munroe (2000)	442	189	6	6880 player-hours	0.9 concussions per 1000 player-hours	1.5%	3.2%	81	0	23868 player-hours	0	0
Fuller and Molloy (2011)	941	190	9	3320 player-hours	2.7 concussions per 1000 player-hours	4.6%	4.7%	Study was matches only				
Gabbett (2008)	80	62	5	1092 player-hours	4.6 (0.6, 8.6) concussions per 1000 player-hours	7.7%	8.1%	Study was matches only				
Haseler, Carmont and England (2010)	210	39	3	1636 player-hours	1.8 concussions per 1000 player-hours	3.1%	7.7%	Study was matches only				
King 2006	68	74	5	340 player-hours	14.7 (4.8, 34.2) per 1000 player-	22.7%	6.8%	Study was matches only				

					hours							
Lee and Garraway (1996)	1705	148	18	1705 player-seasons	10.6 (5.7, 15.4) concussions per 1000 player-seasons [given as period prevalence]	n/a	12.2%	62	Not given	Not given	Not given	Not given
Marshall and Spencer (2001)	Not given	Not given	12	1081 player-games	11.1 (4.8-17.4) concussions per 1000 player-games	n/a	Not given	Not given	5	Not given	1.5 (0.2-2.8) per 1000 player-practices	Not given
McIntosh (2001)	294	Not given	9 (7 with headgear, 2 without headgear)	1536 player-exposures (1179 with headgear, 357 without headgear)	5.9 concussions per 1000 player-exposures	n/a	Not given	Study was matches only				
McIntosh et al (2010) <i>Game injuries</i>	3277	1841	199	28902 player-hours	6.9 (4.4-9.4) concussions per 1000 player-hours	11.4%	10.8%	Study was matches only				
McIntosh et al (2010) <i>Missed game injuries</i>	3277	604	47	28902 player-hours	1.6 (0.4-2.9) concussions per 1000 player-hours	2.8%	7.8%	Study was matches only				
Shuttleworth-Edwards et al (2008)	1147	Not given	135	Not given	Not given	n/a	Not given	Study was matches only				

Sugerman (1983)	Not given	468	46	Not given †	Not given	n/a	9.8%	105	2	Not given	Not given	1.9%
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* - calculated using the Poisson distribution model of Parekh et al ¹ assuming a player plays a whole season of 15 games with each game 70 minutes in duration (as per under 19 IRB regulations ²); † 45885 player-games overall

n/a = not applicable

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