

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

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

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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.

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		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

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		<p>season).</p> <p>58.1% of cases were involved in 'rugby' (league and union).</p> <p>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.</p> <p>Concussion incidence is likely to be considerably higher, because these statistics are only for those injuries resulting in an admission to hospital.</p>
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	<p>204 total injuries equating to one injury per 3.6 hours of play.</p> <p>Concussion (n=13) 3.6% of injuries, 10 occurred to front-row players.</p>
Lingard, Sharrock, & Salmond (1976)	To identify the incidence, nature, and severity of sports injuries during the winter in New Zealand	<p>Overall a total of 2,529 cases were documented across a variety of sports [rugby league n=192 (7.6%)].</p> <p>A total of 124 central nervous system head injuries were recorded across all sports, only 87 resulted in a hospital admission.</p> <p>In rugby league, 4.2% of injuries were central nervous system head injuries (n=7).</p>
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.	<p>Overall 85% of all playing injuries and 82% of all training injuries are non-time loss injuries.</p> <p>Non-time loss concussions accounted for 71% of all concussions.</p> <p>Note: prior to 2012 it was possible to be classified as having a concussion and not miss any playing time.</p>
O'Connor (2011) ^{REF}	NRL injury report 2010	<p>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.</p> <p>All incidences were recorded in games, with neither level recording a single incidence of concussion at training.</p> <p>Concussion represented 6.4% and 4.6% of the overall injury incidence in the NYC and NRL, respectively.</p> <p>31 NYC games (mean: 1.3) were missed during the 2010 season as a result of a concussion (1.9 missed games per club).</p> <p>55 NRL games (mean: 1.8) were missed during the 2010 season as a result of a concussion (3.4 missed games per</p>

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O'Connor (2012)	NRL injury report 2011	<p>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.</p> <p>On average 1.7 (NYC) and 2.2 (NRL) concussions occurred per club during the 2011 season.</p> <p>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.</p> <p>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.</p>
King, Hume, & Clark (2010)	Player perspectives on return to play after a match or training injury in amateur rugby league	<p>In 2008, concussion resulted in missed matches (n=8; i.e., 17.0% of overall match injuries) but not training (n=0).</p> <p>Incidence of concussion match injury was 17.8 per 1,000 playing hours.</p> <p>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).</p> <p>Incidence of concussion match injury was 10.7 per 1,000 playing hours, and 0.2 per 1,000 training hours.</p> <p>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.</p> <p>75% of players felt that time off for rehabilitation was too long, especially for concussion with the three week mandatory stand-down period.</p>
King, Hume, Milburn, & Gianotti (2009)	Injury surveillance, claims, and costs by ethnicity and other demographics in New Zealand rugby league	<p>Concussion represented 0.5% ($\pm 0.4\%$) of all injury claims but 1.3% ($\pm 2.4\%$) of the overall injury costs.</p> <p>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).</p> <p>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).</p>

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King (2006)	Incidence of injuries in the 2005 NZ national junior rugby league competition	<p>74 total injuries were recorded with an overall incidence rate of 217.3 per 1,000 playing hours.</p> <p>Total recorded concussions (n=5) represented an incidence of 14.7 per 1,000 playing hours and 6.8% of the overall injury data.</p> <p>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.</p> <p>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.</p>
King & Gabbett (2009)	Injuries in NZ semi-professional rugby league	<p>Limited concussion details, beyond graphical representation of incidence of injury, approximately 6.0 per 1,000 playing hours.</p>
Norton & Wilson (1995)	Rugby league injuries and patterns	<p>352 injuries in 313 players, equivalent to 621 injuries per 1,000 players and 4.8 injuries per 1,000 playing hours.</p> <p>Concussion represented 11.8% of the total injury data.</p> <p>Restricted teams reported somewhat higher proportion of concussions compared with other grades.</p> <p>All concussions were reported to have been sustained in tackles.</p> <p>Of all injuries associated with illegal play, 29% were concussions. Only 9% of injuries sustained in legal play were concussions.</p> <p>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.</p>
Hume & Marshall (1994)	Sports injuries in NZ: an exploratory analysis	<p>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.</p> <p>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.</p> <p>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.</p>

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<i>Rugby League Studies with a Concussion Focus</i>		
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.	<p>Concussion incidence remained relatively stable across the three seasons; 13-17% of all players.</p> <p>Loss of consciousness occurred in only 12% cases.</p> <p>16% of recorded concussions were repeat injuries.</p> <p>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.</p> <p>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.</p> <p>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.</p> <p>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).</p> <p>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).</p> <p>Most common self-reported post-concussion symptoms: headache (n=35), unsteadiness (n=22), visual disturbance (n=19), dizziness (n=11), and nausea (n=10).</p>
Hinton-Bayre & Geffen (2002)	Severity of concussion and neuropsychological assessment results	<p>No relationship was observed between concussion severity grade and cognitive impairment for the severity grading systems used (AAN, Cantu, or Colorado Medical Society).</p> <p>Cognitive deficits were observed regardless of the severity rating within 2 days post-concussion.</p> <p>The percentage of rugby league footballers impaired at 10 days post-concussion was consistent across severity classifications.</p> <p>PTA was the only salient predictor of impairment at 2 days, although neither its presence nor duration was related to recovery.</p>

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		<p>Players experiencing a loss of consciousness did not appear more likely to demonstrate impairment.</p> <p>The overemphasis of grading systems/classifications on loss of consciousness requires greater consideration and the effects of the mildest concussion may be underestimated.</p>
Hinton-Bayre, Geffen, & McFarland (1997)	<p>Study 1: examine alternate form equivalence, test-retest reliability, and practice effects on standardised measures of processing speed.</p> <p>Study 2: examine the sensitivity of the selected psychometric measure to the acute effects of concussion.</p>	<p>Study 1: Established alternate forms and test-retest reliability of measures expected to be sensitive to the effects concussion on cognitive functioning.</p> <p>Study 2: Illustrated that timed tasks (silly sentences, Symbol Digit, and Digit Symbol) were performed more poorly following concussion.</p> <p>Silly sentences was found to be most sensitive.</p>
McCrory, Bladin, & Berkovic (1997)	Retrospectively studied concussive convulsions in elite Australia rules and rugby league footballers	<p>Only two cases of elite rugby league concussive convulsion during 15 playing seasons.</p> <p>Outcomes for a player experiencing a concussive convulsion were universally good.</p> <p>Concussive or impact convulsions are a non-epileptic phenomenon, and are not associated with structural brain injury.</p> <p>Antiepileptic medication is not indicated and prolonged absence from sport is unwarranted.</p>
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	<p>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.</p> <p>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.</p> <p>Concussion incidence 12.1 per 1,000 match hours.</p> <p>Internal consistency of the three King-Devick testing cards was: card 1: 0.72, card 2: 0.78, and card 3: 0.76.</p> <p>Player cohort (n=50) self-reported history of concussion:</p>

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		<p>30% (n=15) of players sustained a concussion in the current playing season.</p> <p>62% (n=31) reported a previous concussion history.</p> <p>31 players (25.8%) were removed from play, with five (16.1%) receiving a subsequent medical clearance to return-to-play.</p> <p>Median number of days that players were removed from play was 17.5 (range 2-21) days.</p>
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	<p>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.</p> <p>95 people (50 coaches, 13 managers, 15 trainers/medics, 14 club committee personnel and 3 referees) completed the questionnaire.</p> <p>Male:Female ratio 83%:17%, mean age 38 years (± 10 years), 55% (n=52) had a current first-aid certificate.</p> <p>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.</p> <p>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.</p> <p>85% identified that playing while recovering from a concussion could lead to long-term complications.</p> <p>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.</p> <p>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.</p> <p>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.</p> <p>Only 33% ($\pm 14\%$) of respondents correctly identified concussive symptoms.</p>

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		<p>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%).</p> <p>Loss of consciousness was reported to be required for a concussion to have occurred by 39% of responses.</p> <p>Overall concussion knowledge was low at 42% ($\pm 20\%$). Trainers/medics recorded the highest overall concussion knowledge.</p> <p>Misconceptions regarding SRC appear to be common.</p>
<p>Note, NYC: national youth competition; NRL: National Rugby League; NZ: New Zealand; ED: emergency department.</p>		