



LEEDS
BECKETT
UNIVERSITY

Citation:

Eastwood, D and Owen, C and Phillips, G and Williams, S and Brown, JC and Gardner, A and Hendricks, S and Johnston, RD and Stokes, K and Tadmor, D and Till, K and Whitehead, S and Jones, B (2023) Incidence of Concussion in Men's Super League, Championship, and Academy Rugby League Matches Between 2016 and 2022. *Journal of Science and Medicine in Sport*. pp. 1-6. ISSN 1440-2440 DOI: <https://doi.org/10.1016/j.jsams.2023.09.001>

Link to Leeds Beckett Repository record:

<https://eprints.leedsbeckett.ac.uk/id/eprint/9918/>

Document Version:

Article (Published Version)

Creative Commons: Attribution 4.0

The aim of the Leeds Beckett Repository is to provide open access to our research, as required by funder policies and permitted by publishers and copyright law.

The Leeds Beckett repository holds a wide range of publications, each of which has been checked for copyright and the relevant embargo period has been applied by the Research Services team.

We operate on a standard take-down policy. If you are the author or publisher of an output and you would like it removed from the repository, please [contact us](#) and we will investigate on a case-by-case basis.

Each thesis in the repository has been cleared where necessary by the author for third party copyright. If you would like a thesis to be removed from the repository or believe there is an issue with copyright, please contact us on openaccess@leedsbeckett.ac.uk and we will investigate on a case-by-case basis.



Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Incidence of concussion in men's Super League, Championship, and Academy rugby league matches between 2016 and 2022

David Eastwood^{a,b}, Cameron Owen^{c,d}, Gemma Phillips^{c,d,e}, Sean Williams^{a,l}, James Brown^{c,f,h}, Andrew J. Gardner^{c,g}, Sharief Hendricks^{c,h}, Rich D. Johnston^{c,i,j}, Keith Stokes^{a,k,l}, Daniel Tadmor^{c,m}, Kevin Till^{c,m}, Sarah Whitehead^c, Ben Jones^{c,d,h,i,n,*}

^a Centre for Health and Injury and Illness Prevention in Sport, University of Bath, United Kingdom^b Wakefield Trinity Rugby League Club, United Kingdom^c Carnegie Applied Rugby Research (CARR) Centre, Carnegie School of Sport, Leeds Beckett University, United Kingdom^d England Performance Unit, Rugby Football League, United Kingdom^e Hull Kingston Rovers, United Kingdom^f Division of Orthopaedic Surgery, Department of Surgical Sciences, Faculty of Medicine and Health Sciences, Institute of Sport and Exercise Medicine, Stellenbosch University, South Africa^g Sydney School of Health Sciences, Faculty of Medicine and Health, The University of Sydney, Australia^h Division of Physiological Sciences and Health through Physical Activity, Lifestyle and Sport Research Centre (HPALS), Department of Human Biology, Faculty of Health Sciences, University of Cape Town, South Africaⁱ School of Behavioural and Health Sciences, Faculty of Health Sciences, Australian Catholic University, Australia^j Sport Performance Recovery Injury and New Technologies (SPRINT) Research Centre, Australian Catholic University, Australia^k Rugby Football Union, United Kingdom^l UK Collaborating Centre on Injury and Illness Prevention in Sport (UKCCIIS), University of Bath, United Kingdom^m Leeds Rhinos Rugby League Club, United Kingdomⁿ Premiership Rugby, United Kingdom

ARTICLE INFO

Article history:

Received 12 April 2023

Received in revised form 9 August 2023

Accepted 1 September 2023

Available online xxxxx

Keywords:

Brain injury

Injury

Epidemiology

Contact sport

ABSTRACT

Objectives: To quantify the incidence of concussion and compare between playing levels in male rugby league.**Design:** Retrospective cohort.**Methods:** Between 2016 and 2022, medically diagnosed concussions in Super League, Championship, and Academy competitions were reported to the Rugby Football League via club medical staff. Anonymised data were analysed using generalised linear mixed-effects models by season, month, and between competitions.**Results:** Overall, 1403 concussions were identified from 104,209 player-match hours. Concussion incidence for Super League, Championship, and Academy was 15.5, 10.5, and 14.3 per 1000 player-match hours, respectively. Championship concussion incidence was significantly lower than the Super League ($p < 0.001$) and Academy ($p < 0.001$). No significant differences were identified between years for Super League (range: 13.3 to 18.8 per 1000 player-match hours) and Championship (range: 8.4 to 12.1 per 1000 player-match hours). In Academy (range: 9.6 to 20.5 per 1000 player-match hours), concussion incidence was significantly greater in 2021 compared to earlier years (2016, $p = 0.01$ and 2017, $p = 0.03$). No significant differences were identified between months for any competition.**Conclusions:** The incidence of concussion is greater in Super League and Academy compared to the Championship. Academy concussion incidence has increased over time. Different factors between and within competitions, such as changes to medical standards and knowledge, could have influenced the identification and diagnosis of concussion.© 2023 The Authors. Published by Elsevier Ltd on behalf of Sports Medicine Australia. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Practical implications

- The overall incidence of concussion between 2016 and 2022 was 15.5, 14.3 and 10.5 per 1000 player-match hours in Super League, Academy

and Championship rugby league players, which is higher than previously reported in similar cohorts.

- Championship rugby league has lower resources than Super League for medical provision, therefore it is important to delineate if the lower rates of reported concussion are due to less concussions and not undiagnosed concussions, due to challenges in identification and diagnosis at sub-elite levels.

* Corresponding author.

E-mail address: b.jones@leedsbeckett.ac.uk (B. Jones).<https://doi.org/10.1016/j.jsams.2023.09.001>1440-2440/© 2023 The Authors. Published by Elsevier Ltd on behalf of Sports Medicine Australia. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).Please cite this article as: D. Eastwood, C. Owen, G. Phillips, et al., Incidence of concussion in men's Super League, Championship, and Academy rugby league matches between 2016 and 2022, Journal of Science and Medicine in Sport, <https://doi.org/10.1016/j.jsams.2023.09.001>

- Academy rugby league players had the highest incidence of concussion in 2021, which may be due to the enforced COVID-19 break, which reinforces the need for rugby league players to be exposed to appropriate training, specifically related to the tackle.

1. Introduction

Recognising, managing, and reducing concussion are priorities for sports,¹ given the potential immediate health risks, and potential risk to later-in-life mental and cognitive health which can include neurodegenerative diseases.^{2,3} National sports governing bodies should ensure the incidence of concussions is quantified. Given the contact demands of rugby league,^{4,5} the sport has a relatively high risk of injury, including concussion.^{6,7} The incidence of concussion is currently under-researched in rugby league in England, compared to Australasian rugby league,^{8–10} and rugby union.¹¹

A systematic review of concussion in rugby league, reported an incidence of 0.0 to 40.0 per 1000 player-match hours.⁶ In the National Rugby League (NRL [the highest level of senior male professional competition in Australasia]), the incidence of concussion was 14.9 per 1000 player-match hours.¹² Amateur rugby league players had a higher concussion rate (19.1 per 1000 player-match hours) than professional and semi-professional players (7.1 and 5.9 per 1000 player-match hours).¹³ In youth male rugby league players, varied concussion rates have been observed across competitions in Under-19 (U19) academy players in England (13.0 per 1000 player-match hours),¹⁴ U16 and U18 players in New Zealand (14.7 per 1000 player-match hours),¹⁵ and 17–18 year old players in Australia (4.6 per 1000 player-match hours).¹⁶ In the Super League (the highest level of senior male professional competition in England and France), concussions were reported as 5.0 per 1000 player-match hours between 2013 and 2015.¹⁷ Since 2015, the concussion incidence has not been reported, and there has been no research comparing whether concussion incidence differs between playing levels in England.

It is important to understand the incidence of concussion across varying levels of rugby league in order to fully understand the risk posed to players. Therefore, the aim of this study is to describe the incidence of concussion by season and month between 2016 and 2022, across the Super League, Championship, and Academy levels in men's rugby league in England and France. This research will also act as a baseline to evaluate initiatives aimed at reducing concussion in rugby league.

2. Methods

2.1. Study design

This was a retrospective study using data extracted from the Rugby Football League (RFL) that was recorded prospectively by club medical team personnel over seven seasons (2016–2022). As part of recognised medical standards, rugby league medical teams at elite senior and academy levels must complete a concussion report by a medical doctor or equivalent. The report was filled out electronically and submitted to the RFL via email within 24 h of an incident that resulted in a player being removed from the field of play with concussion, or suspected concussion. Anonymised concussion numbers were provided by the RFL. Exposure for each level (i.e., Super League, Championship, Academy) was calculated by multiplying the number of games in a season for each level by the number of players on the field (26) and the duration of the game (80 min).¹⁸ Ethics approval was granted by Leeds Beckett University, Local Ethics Committee (87571) for secondary data analysis.

All incidents of concussion were reported by either top tier Super League ($n = 12$ teams), second tier Championship ($n = 14$ teams following the expansion from 12 teams in 2019), and RFL Academy (U19 and below; $n = 12$) teams. The total team seasons for Super League, Championship and Academy were 84, 90 (2020 COVID-19 shortened season) and 168 (2020 COVID-19 shortened season). The RFL Academy structure during the study period consisted of 12 clubs competing at

two levels, “Academy” and “Scholarship”. The scholarship competition was for players in the U16 age grade, with the academy initially for players competing at U19 with a change to U18 in 2020. During 2021, due to COVID-19 the Scholarship included four matches at the U17 age grade. This study also includes data from the 2020 COVID-19 season, where matches were suspended between March 16th and August 2nd 2020 for Super League to form a shorter season and cancelled for both the Championship and Academy until the start of the 2021 season.

2.2. Data sources and definitions

Concussion was operationalised according to the consensus-based definitions set out in the RFL medical standards following the principles agreed at the 2016 Berlin conference and the concussion in sport consensus statement.¹⁹ The RFL HIA procedure recognises ten category 1 signs and symptoms including: abnormal neurological signs, loss of consciousness, no protective action on falling, traumatic convulsion, impact seizures, loss of tone, ataxia, memory impairment, confusion, and behavioural changes. These features indicate a prompt and permanent removal from play. Category 2 signs and symptoms include: possible loss of consciousness, loss of responsiveness, possible impact seizures, possible balance disturbance and suspected facial injury or fracture. The presence of these descriptors should prompt the team doctor to initiate a temporary 15-minute interchange for an off-field assessment. Symptoms (e.g., headache), physical signs (e.g., loss of consciousness), balance impairment, behavioural changes, and cognitive impairment are used to suspect concussion. The RFL medical standards direct that the Sport Concussion Assessment Tool—Fifth Edition (SCAT5) be administered as part of the multimodal, standardised concussion assessment, used to aid the clinical diagnosis.²⁰

2.3. Statistical analysis

Concussion incidence rates were calculated as the count of concussions per 1000 player-match hours of exposure: (concussion count / exposure hours) \times 1000. All estimations were performed using R (version 4.1.0, R Foundation for Statistical Computing, Vienna, Austria). Generalised linear mixed-effects models (*glmer*) were fitted using the *lme4* package,²¹ using a Poisson distribution, log-link function, and offset for match exposure hours. The count of concussion injuries incurred was the dependent variable. Predictor variables (i.e., season, month, and competition) were included as fixed effects to evaluate their association with concussion incidence rates. A random intercept term for ‘playing level’ (Academy, Championship, or Super League) was used to account for clustering and repeated observations. Data were reported as the mean and 95 % confidence interval. The *emmeans* package²² was used to make pairwise comparisons, with a ‘false discovery rate’ post-hoc correction used to account for making multiple comparisons.²³

3. Results

A total of 1403 (Super League = 538; Championship = 358; Academy = 507) concussions were reported from a total of 104,209 (Super League = 34,701; Championship = 34,078; Academy = 35,429) exposure hours. The overall incidence of concussion between 2016 and 2022 was found to be significantly greater for Super League (15.5 per 1000 player-match hours; 95 % CI 14.2–16.9; $p < 0.001$) and Academy (14.3 per 1000 player-match hours; 95 % CI 13.1–15.6; $p < 0.001$) when compared to the Championship (10.5 per 1000 player-match hours; 95 % CI 9.5–11.7).

Fig. 1 shows the concussion incidence for Super League, Championship, and Academy by year. Whilst there was some variation in concussion incidence, no significant differences were observed between years in Super League or Championship. A larger range of incidences were reported for Academy, with the lowest identified in 2018 (9.6 per 1000 player-match hours; 95 % CI 7.5–12.1) and the highest in 2021 (20.5 per 1000 player-

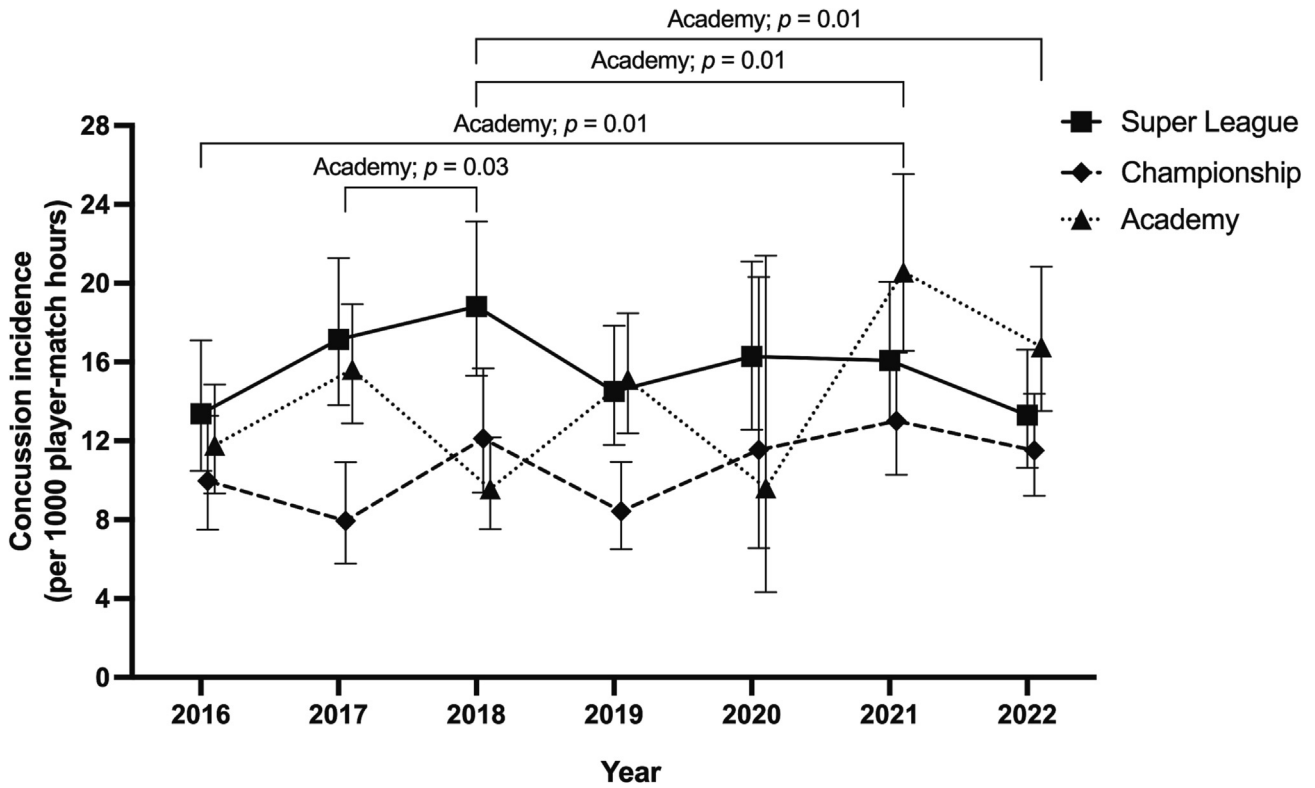


Fig. 1. Incidence of concussion (95 % confidence intervals) per 1000 player-match hours for Super League, Championship, and Academy by year.

match hours; 95 % CI 16.6–25.5). Within the Academy, the 2018 season (i.e., lowest year) had a significantly lower concussion incidence than 2017 ($p = 0.03$), 2021 ($p < 0.001$) and 2022 ($p = 0.01$). 2016 was also significantly lower than 2021 for Academy players ($p = 0.01$).

The incidence of concussion for Super League, Championship, and Academy by month can be observed in Fig. 2. Overall, there were no significant differences between months. The months with the highest incidence of concussion were November for Super League (28.8 per 1000 player-

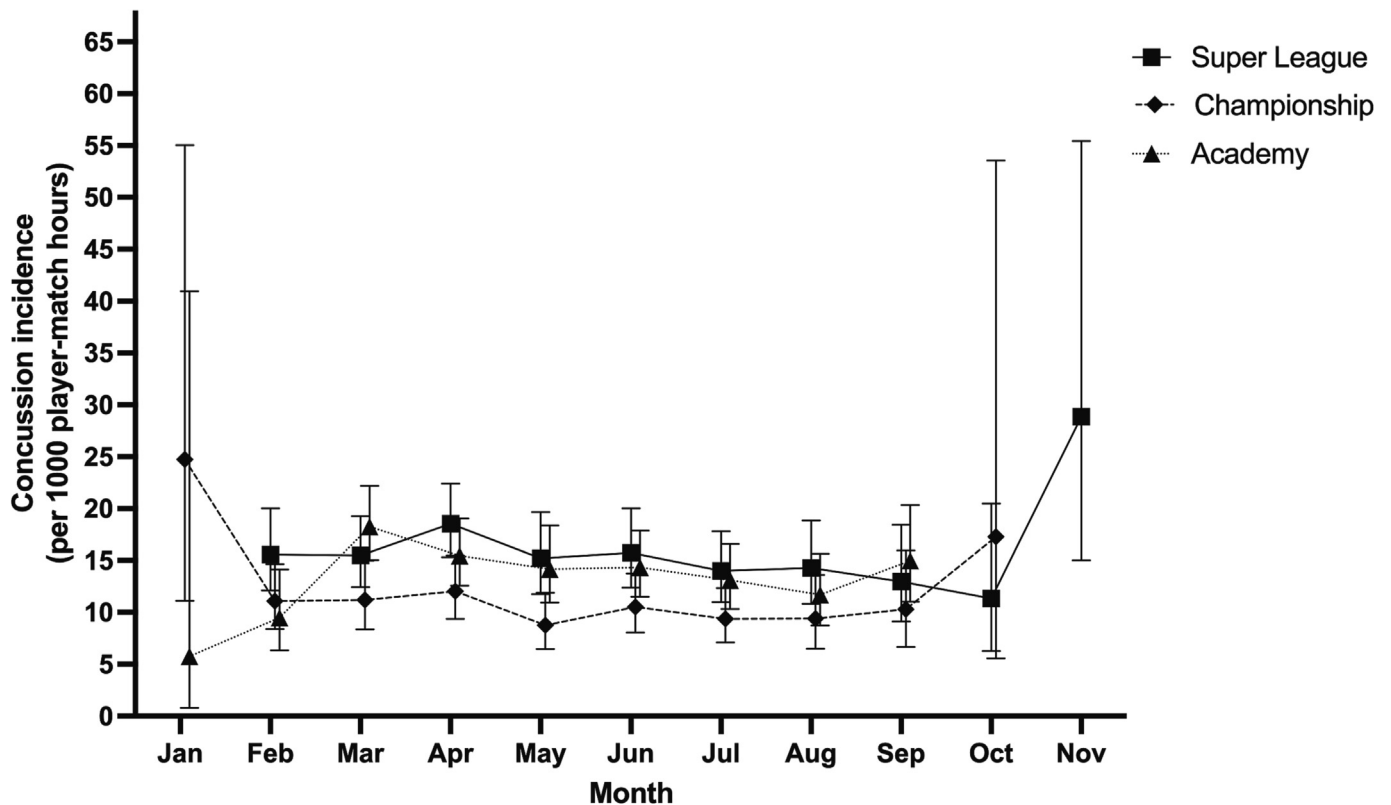


Fig. 2. Incidence of concussion (95 % confidence intervals) per 1000 player-match hours for Super League, Championship, and Academy by month.

match hours; 95 % CI 15.0–55.4), January for the Championship (24.7; 95 % CI 11.1–55.0), and April for Academy (15.5 per 1000 player-match hours; 95 % CI 12.6–19). The months with the lowest incidence of concussion were October for Super League (11.3 per 1000 player-match hours; 95 % CI 6.3–20.5), May for Championship (8.7 per 1000 player-match hours; 95 % CI 6.5–11.9) and January for Academy (5.8 per 1000 player-match hours; 95 % CI 0.8–41.0).

4. Discussion

This study describes the concussion incidence in the highest tier of rugby league in England and France and, for the first time, compares concussion incidence between different levels of competition. Overall, the incidence of concussion between 2016 and 2022 across the Super League and Academy was greater than the Championship. When considering between season differences, similar concussion incidence was observed for both Super League and Championship, however concussion incidence was higher in Academy players after the 2020 season (2021 and 2022 seasons). Across all levels, no differences were observed between months suggesting that concussion incidence does not vary across a season regardless of the playing level. This study is the largest of its kind to present concussion incidence in European rugby league and can act as a reference point for the future.

Concussion incidence in the Super League is similar to the NRL¹² (2020; 14.9 concussions per 1000 player-match hours) and lower than recent years in rugby union¹¹ (e.g., 2018/2019; 20.4 concussions per 1000 player-match hours). Compared to the incidence of concussions previously reported in the same competition between 2013 and 2015,¹⁷ an increase from 4.6 per 1000 player-match hours between 2013 and 2015 to 18.8 per 1000 player-match hours in 2018 was observed. Similar changes are noted in rugby union's English Premiership, with concussion rates increasing from 5.0 concussions per 1000 player-match hours from 2011/2012 to 20.4 concussions per 1000 player-match hours in 2018/2019.²⁴ In an effort to improve player welfare with regard to concussion, the SCAT5 was adopted across sport following the Berlin consensus in 2016²⁰ and a number of changes implemented in rugby league by the RFL since the 2013–2015 study by Fitzpatrick et al.¹⁷ This includes an off-field, in-game head injury assessment of 15 min with a free temporary interchange (introduced in 2016); mandatory live pitch-side video replay for medical teams to review injury footage (introduced in 2018); and the introduction of two home-team doctors (introduced in 2019) for Super League. However, since 2016 there were no significant differences between years in Super League with a similar plateau occurring following the 2016/2017 season in rugby union.²⁵ As a consequence, it is likely that rather than a rise in the rates of concussions, the interventions have improved the attention and resources for identifying suspected concussions. This has likely resulted in a more conservative approach to concussion diagnosis and management.

The incidence of concussion in Academy players (14.3 concussions per 1000 player-match hours) was similar to Super League players in the current study and previously reported incidence in New Zealand academy rugby league (14.7 concussions per 1000 player-match hours).¹⁵ Of the previously discussed interventions, only the HIA has been introduced to Academy level rugby league. Therefore, it is surprising that Academy concussion incidence is comparable to Super League, given the lower resources. Anecdotally, it is suggested that extra caution is taken with concussion in youth players in Academy rugby league, due to the negative short- and long-term consequences on neurodevelopment.²⁶ This may therefore result in a more cautious approach to the permanent removal of players from the field of play following a HIA to prioritise player welfare. However, differences could also be a result of less proficient tackle choice and execution²⁷ or exposure to a greater intensity of competition than players are used to (some players will enter the talent development system from the community pathway). To gain further understanding of why the concussion incidence is similar between Super League and Academy given the

differences in policy, further research is required into clinical approaches towards player removal and the mechanisms and confounding factors of concussion (i.e., tackle technique, body mass and player speed) at different standards. In addition, this should be investigated within community and women's rugby league.²⁸

Academy was the only playing level with between season differences in concussion incidence. Higher concussion incidence was observed in 2021 and 2022 compared to the years prior to 2020, the COVID-19 effected season. It is possible that the increase in concussion incidence is influenced by limited training and playing opportunities during the COVID-19 pandemic. The 2020 season was cancelled as a consequence of the UK lockdown on the 23rd March following initial games that season, with academy rugby league returning the following year (2021). Players taking part in the 2021 and 2022 academy competitions, therefore missed out on a year of technical, tactical, and physical development within the talent system, potentially negatively affecting the acquisition of appropriate tackle technique^{29,30} and physical qualities³¹ that have been associated with increased concussion rates. Furthermore, an increased risk of concussion in youth athletes that have contracted COVID-19 has recently been reported.³² Coaches should therefore consider the effects of COVID-19 or prolonged periods away from training (e.g., long-term injury) on player development and implement appropriate interventions to support player safety.^{33,34}

Overall, the concussion incidence in the Championship was significantly lower than both the Super League and Academy. The lower incidence of concussions at the Championship level could be a result of lower medical standards. The Championship is a league that combines full-time professional and part-time semi-professional clubs (of the 12/14 team league, two or three were full-time per season). During the study period, except for the HIA, the medical standards outlined above for Super League were only compulsory for full-time clubs. Additional scrutiny is also placed on the Super League, with more televised matches, and potential pressure on clinical staff to be scrupulous with their decision-making. Compared to Academy, there may be less caution in the Championship surrounding players and the threshold for a concussion to be identified may be similar to that of Super League, however there is less resource to identify them. Players are also more likely to under-report concussions, especially at part-time clubs where players rely on income from match appearance fees. It is suggested that 20 % of Super League players underreport concussions, with 35 % of those players reporting that they hide their symptoms as they “do not want to miss games”.³⁵ Given the increased pressure of needing to play for appearance fees in part-time clubs, this figure may be even greater in the Championship. The incidence of concussion is therefore likely impacted by a range of factors and not solely due to an increased awareness or risk, and policy to prevent concussion may need to consider a broad range of factors including socio-economic considerations for part-time players.

No differences in concussion incidences across the months of the season were identified for any of the three competitions. This is similar to the findings of West et al.²⁵ in rugby union English Premiership. Whilst the point estimates reported indicate some potential variation at the start (January) and end of the season (November), due to the limited number of matches available to sample from these months as they are outside of the regular season playing window, the confidence intervals display a large degree of uncertainty. Further data collection from games that occur at these periods of the season is required to confirm any differences that may be present.

Whilst this study provides the most comprehensive, multi-year quantification of concussion incidence in elite senior and academy rugby league players in England and France, it is not without limitations. The RFL collects concussion data routinely, so one would expect coding and entry errors to be minimal; however, the authors relied on data being accurately transposed from completed concussion assessments to a computerised format. As data were anonymised by the RFL, player

characteristics, including age, player position, and previous concussion and return date were not available. Therefore, injury severity and burden were not calculable and other influences on concussion incidence could not be included in the analysis. In addition, it was also not possible to evaluate factors which could influence concussion incidence such as tackle mechanisms or physical characteristics.

5. Conclusions

This study provides concussion incidence for rugby league's male Super League, Championship, and Academies in England and France between 2016 and 2022. The overall concussion incidence was lower in the Championship compared to Super League and Academy which were comparable. These differences are likely a result of improved resource for identifying concussion and greater caution for youth players. Concussion incidence at all levels is higher than previously reported in the Super League between 2013 and 2015. However, given several changes in the match day medical standards aimed to improve the identification and diagnosis of concussion, it is not possible to know if the number of concussions is increasing or rather more are being identified. Given the incidence of concussion across all levels of rugby league clinicians, practitioners, and governing bodies should continue to optimise player welfare and mitigate risk in the sport.

Funding information

This project was not funded.

Confirmation of ethical compliance

The Rugby Football League provided consent for the results to be published prior to the study commencement.

CRedit authorship contribution statement

David Eastwood: Investigation, Methodology, Writing – original draft. **Cameron Owen:** Writing – review & editing. **Gemma Phillips:** Conceptualization, Investigation, Data curation, Writing – review & editing. **Sean Williams:** Formal analysis, Supervision. **James Brown:** Writing – review & editing. **Andrew Gardner:** Writing – review & editing. **Sharief Hendricks:** Writing – review & editing. **Rich D. Johnston:** Writing – review & editing. **Keith Stokes:** Conceptualization, Writing – review & editing, Supervision. **Daniel Tadmor:** Writing – review & editing. **Kevin Till:** Writing – review & editing. **Sarah Whitehead:** Data curation, Writing – review & editing. **Ben Jones:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing, Project administration.

Data availability

The datasets (deidentified participant data) generated during and/or analysed are available from the corresponding author on request.

Declaration of interest statement

David Eastwood was employed in a consultancy capacity by Wakefield Trinity at the time of study conceptualisation, investigation and writing of the original draft. His MSc was partly funded by BASEM (British Association of Sport and Exercise Medicine). Cameron Owen's research fellowship is funded by the Rugby Football League. Gemma Phillips is employed in a consultancy capacity by the Rugby Football League and Hull Kingston Rovers. James Brown has received research funding from World Rugby. Andrew Gardner serves as a scientific advisor for HitQ, Ltd. He has a clinical practice in neuropsychology involving individuals who have sustained sport-related concussion (including current and former athletes). He has been a contracted concussion

consultant to Rugby Australia. He has received travel funding or been reimbursed by professional sporting bodies, and commercial organisations for discussing or presenting sport-related concussion research at meetings, scientific conferences, workshops, and symposiums. Previous grant funding includes the NSW Sporting Injuries Committee, the Brain Foundation (Australia), an Australian–American Fulbright Commission Postdoctoral Award, a Hunter New England Local Health District, Research, Innovation and Partnerships Health Research & Translation Centre and Clinical Research Fellowship Scheme, and the Hunter Medical Research Institute (HMRI), supported by Jennie Thomas, and the HMRI, supported by Anne Greaves. He has current philanthropic support from the Nick Tooth Foundation. He acknowledges unrestricted philanthropic support from the National Rugby League (NRL). Keith Stokes is employed by the Rugby Football Union. Daniel Tadmor's PhD is funded by Leeds Rhinos. Kevin Till is employed in a consultancy capacity by Leeds Rhinos. Ben Jones is employed in a consultancy capacity by Premiership Rugby, and the @23benjones Rugby Football League.

Acknowledgements

The authors would like to thank club medical staff and members of the Rugby Football League, specifically Laura Fairbank and Julie Turton for their involvement in this study.

References

1. Patricios JS, Schneider KJ, Dvorak J et al. Consensus statement on concussion in sport: the 6th International Conference on Concussion in Sport–Amsterdam, October 2022. *Br J Sports Med* 2023;57(11):695–711. doi:10.1136/bjsports-2023-106898.
2. Iverson GL, Castellani RJ, Cassidy JD et al. Examining later-in-life health risks associated with sport-related concussion and repetitive head impacts: a systematic review of case-control and cohort studies. *Br J Sports Med* 2023;57(12):810–824. doi:10.1136/bjsports-2023-106890.
3. Manley G, Gardner AJ, Schneider KJ et al. A systematic review of potential long-term effects of sport-related concussion. *Br J Sports Med* 2017;51(12):969–977. doi:10.1136/bjsports-2017-097791.
4. Naughton M, Jones B, Hendricks S et al. Quantifying the collision dose in rugby league: a systematic review, meta-analysis, and critical analysis. *Sports Med - Open* 2020;6:6. doi:10.1186/s40798-019-0233-9.
5. Rennie G, Weaving D, Hart B et al. Tackle and ball carrier demands of rugby league: a seven-year league-wide study including over 1,000,000 tackle events. *J Sci Med Sport* 2022;25(10):850–854. doi:10.1016/j.jsams.2022.07.002.
6. Gardner A, Iverson GL, Levi CR et al. A systematic review of concussion in rugby league. *Br J Sports Med* 2015;49(8):495–498. doi:10.1136/bjsports-2013-093102.
7. King D, Clark T, Hume P et al. Match and training injury incidence in rugby league: a systematic review, pooled analysis, and update on published studies. *Sports Med Health Sci* 2022;4(2):75–84. doi:10.1016/j.smhs.2022.03.002.
8. Gardner AJ, Howell DR, Levi CR et al. Evidence of concussion signs in national rugby league match play: a video review and validation study. *Sports Med - Open* 2017;3:29. doi:10.1186/s40798-017-0097-9.
9. Gardner AJ, Iverson GL, Stanwell P et al. A video analysis of use of the new “concussion interchange rule” in the national rugby league. *Int J Sports Med* 2016;37(4):267–273. doi:10.1055/s-0035-1565203.
10. Iverson GL, Gardner AJ. Incidence of concussion and time to return-to-play in the national rugby league. *Clin J Sport Med* 2022;32(6):595–599. doi:10.1097/JSM.0000000000000965.
11. Williams S, Robertson C, Starling L et al. Injuries in elite men's rugby union: an updated (2012–2020) meta-analysis of 11,620 match and training injuries. *Sports Med* 2022;52(5):1127–1140. doi:10.1007/s40279-021-01603-w.
12. O'Connor D. *NRL Injury Surveillance Report 2020 Season*, Rugby League Research Committee, 2020.
13. King D, Hume P, Gissane C et al. Semi-professional rugby league players have higher concussion risk than professional or amateur participants: a pooled analysis. *Sports Med* 2017;47(2):197–205. doi:10.1007/s40279-016-0576-z.
14. Tee JC, Till K, Jones B. Incidence and characteristics of injury in under-19 academy level rugby league match play: a single season prospective cohort study. *J Sports Sci* 2019;37(10):1181–1188. doi:10.1080/02640414.2018.1547100.
15. King D. Incidence of injuries in the 2006 New Zealand national junior rugby league competition. *N Z J Sports Med* 2006;34(1):2.
16. Gabbett TJ. Incidence of injury in junior rugby league players over four competitive seasons. *J Sci Med Sport* 2008;11(3). doi:10.1016/j.jsams.2007.06.003.
17. Fitzpatrick AC, Naylor AS, Myler P et al. A three-year epidemiological prospective cohort study of rugby league match injuries from the European Super League. *J Sci Med Sport* 2018;21(12):160–165. doi:10.1016/j.jsams.2017.08.012.
18. Fuller CW, Molloy MG, Bagate C et al. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *Br J Sports Med* 2007;41(5):328–331. doi:10.1136/bjism.2006.033282.

19. McCrory P, Meeuwisse W, Dvořák J et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med* 2017;51(11):838–847. doi:10.1136/bjsports-2017-097699.
20. Echemendia RJ, Meeuwisse W, McCrory P et al. The Sport Concussion Assessment Tool 5th Edition (SCAT5): background and rationale. *Br J Sports Med* 2017;51(11):848–850. doi:10.1136/bjsports-2017-097506.
21. Bates D, Mächler M, Bolker B et al. Fitting linear mixed-effects models using lme4. *J Stat Softw* 2015;67:1–48. doi:10.18637/jss.v067.i01.
22. Length R. *emmeans: Estimated Marginal Means, aka Least-squares Means*, 2020.
23. Benjamini Y. Discovering the false discovery rate. *J R Stat Soc Series B Stat Methodology* 2010;72(4):405–416. doi:10.1111/j.1467-9868.2010.00746.x.
24. West SW, Starling L, Kemp S et al. Trends in match injury risk in professional male rugby union: a 16-season review of 10 851 match injuries in the English Premiership (2002–2019): the Professional Rugby Injury Surveillance Project. *Br J Sports Med* 2021;55(12):676–682. doi:10.1136/bjsports-2020-102529.
25. West SW, Cross M, Trewartha G et al. Trends in match concussion incidence and return-to-play time in male professional Rugby Union: a 16-season prospective cohort study. *Brain Inj* 2021;35(10):1235–1244. doi:10.1080/02699052.2021.1972142.
26. Karlin AM. Concussion in the pediatric and adolescent population: “different population, different concerns”. *PM R* 2011;3(10 Suppl 2):S369–S379. doi:10.1016/j.pmrj.2011.07.015.
27. Pearce LA, Sinclair WH, Leicht AS et al. Passing and tackling qualities discriminate developmental level in a rugby league talent pathway. *Int J Perform Anal Sport* 2019;19(6):985–998. doi:10.1080/24748668.2019.1689750.
28. Heyward O, Emmonds S, Roe G et al. Applied sport science and medicine of women's rugby codes: a systematic-scoping review and consensus on future research priorities protocol. *BMJ Open Sport Exerc Med* 2021;7(3):e001108. doi:10.1136/bmjsem-2021-001108.
29. Hendricks S, Emery C, Jones B et al. “Tackling” rugby safety through a collective approach. *Br J Sports Med* 2023;57(10):562–563. doi:10.1136/bjsports-2023-107020.
30. Hendricks S, O'Connor S, Lambert M et al. Video analysis of concussion injury mechanism in under-18 rugby. *BMJ Open Sport Exerc Med* 2016;2(1):e000053. doi:10.1136/bmjsem-2015-000053.
31. Nutt S, McKay MJ, Gillies L et al. Neck strength and concussion prevalence in football and rugby athletes. *J Sci Med Sport* 2022;25(8):632–638. doi:10.1016/j.jsams.2022.04.001.
32. Bullock GS, Emery CA, Nelson VR et al. Higher rates of concussion following COVID-19 infection in high school athletes. *Br J Sports Med* 2023;57(10):590–594. doi:10.1136/bjsports-2022-106436.
33. Starling LT, McKay C, Cross M et al. Prolonged restricted training, fixture congestion and player rotation: what the COVID-19 pandemic taught us about injury risk in professional collision sport. *J Sci Med Sport* 2022;25(6):480–485. doi:10.1016/j.jsams.2022.03.012.
34. Stokes KA, Jones B, Bennett M et al. Returning to play after prolonged training restrictions in professional collision sports. *Int J Sports Med* 2020;41(13):895–911. doi:10.1055/a-1180-3692.
35. Tadmor D, Till K, Phillips G et al. I won't let you down; why 20% of Men's and Women's Super League players underreported suspected concussions. *J Sci Med Sport* 2023.