BMJ Open Sport & Exercise Medicine

Movement and physical demands of school and university rugby union match-play in England

Dale Read,[1,2] Daniel Weaving,[1,3] Padraic Phibbs,[1,2] Joshua Darrall-Jones,[1,2] Gregory Roe,[1,2] Jonathon Weakley,[1,2] Sharief Hendricks,[1,4] Kevin Till,[1,2] Ben Jones[1,2,5]

To cite: Read D, Weaving D, Phibbs P, *et al*. Movement and physical demands of school and university rugby union match-play in England. *BMJ Open Sport Exerc Med* 2017;**2**:e000147. doi:10.1136/bmjsem-2016-000147

▸ Prepublication history and additional material is available. To view please visit the journal (http://dx.doi.org/10.1136/bmjsem-2016-000147).

Accepted 9 January 2017

[1]Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, UK
[2]Yorkshire Carnegie Rugby Union Football Club, Kirkstall Training Ground, Leeds Rugby Academy, Leeds, UK
[3]Department of Sport, Health and Exercise Science, University of Hull, Kingston upon Hull, UK
[4]Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa
[5]The Rugby Football League, Red Hall Lane, Leeds, UK

Correspondence to
Dr Ben Jones; b.jones@leedsbeckett.ac.uk

ABSTRACT

Background: In England, rugby union is a popular sport and is widely played within schools. Despite the large participation numbers, the movement and physical demands of the sport and how they progress by age have not been explored.

Method: Ninety-six male rugby union players wore microtechnology devices during six rugby union matches within the education pathway to investigate the movement and physical demands of match-play. To quantify the positional differences and progression by age, data were obtained for participants at the under 16 (U16) (n=31 participants), under 18 (U18) (n=34 participants) and university (n=31 participants) levels. Players were further divided in forwards and backs. Data were analysed using magnitude-based inferences.

Results: For the movement demands, U16 total distance and 'striding' was likely higher for forwards than backs, whereas at U18, unclear differences were observed and from university players the inverse was observed (very likely). In all age groups sprint distance was likely to very likely greater for backs than forwards. Forwards had greater physical demands than backs at all age groups. For consecutive age groups, U16 had a likely higher relative distance than U18, and U18 had a likely lower relative distance than university players. Physical demands were similar across age groups for forwards, and greater for backs at older age groups.

Conclusion: The movement and physical demands of rugby union players participating in schools (U16 and U18), may not be as expected, however, the findings from university players show a similar pattern to the senior game.

Key messages

What are the new findings?

- Younger rugby union players (under 16 and under 18) appear to have different movement demands by playing position than known in senior players; forwards undertake more running than backs.
- The progression by age group suggests backs should focus on preparing for the increase in sprinting (under 16 to under 18) and also striding and physical load (under 18 to university).
- The progression trajectory of movement and physical demands for forwards is less clear, while large differences in body mass were observed.

How might it impact on clinical practice in the near future?

- Awareness on the movement and physical demands of young rugby union players competing within the education system in England.
- Position and age-specific movement and physical data which can be used when developing preparation strategies for rugby union players.

INTRODUCTION

England has the most rugby union players in the world.[1] Recently, collision exposures during schoolboy rugby, in particular tackling, has been questioned.[2] However, limited empirical evidence exists on the physical demands young rugby union players are exposed to in a bid to support or refute these apparent concerns. Data from the senior game has been used to determine the characteristics of rugby union match-play. It shows the game to be an intermittent contact sport exposing players to short-duration, high-intensity activities including high-speed running, sprinting, collisions and tackling interspersed with longer periods of activity at lower intensities.[3 4] The injury incidence during match-play in young rugby union players participating within a regional (professional) academy is 47 per 1000 player-hours, which is greater than school rugby (35 per 1000 player-hours).[5] The injury incidence in both groups is less than previously reported in senior men's professional rugby union matches (81 per 1000 player hours).[6] Despite the available injury epidemiology data in youth rugby union, little is known about the demands of the sport at this level.[7]

Within rugby union, there are distinct game characteristics for different positional groups; forwards and backs. Quantification of the movement demands by positions for senior professional rugby union competition has been extensively documented via both video[8 9] and more recently, microsensor-based technology.[3 4] It is likely that decisions or opinions surrounding the school and university game are derived from senior data. However, while the quantification of the movement demands from competition in young players have been quantified in other team sports such as rugby league[10] and soccer,[11] there is currently limited information available detailing the match demands of rugby union competition below the senior level. The only study investigating the movement demands in English adolescent rugby union players has been reported for under 20 years old (U20) international players.[12] The movement demands of the U20 international players are similar to those of senior players,[3 4] although this sample is representative of an elite group, thus may not be typical of the movement demands of rugby union below the representative level in England. Furthermore, despite this study[12] providing the first insight into the movement demands of young rugby union players, it is still unclear how the movement demands of the sport are influenced during the progression by age group, which has consequences for player preparation, development, injury prevention and performance.

Player safety, performance, development and participation are all key within young players, thus understanding the load that young rugby union players are exposed to during a match is needed to potentially inform policy and practice. Within England, numerous concurrent playing pathways (ie, education (school and university), club and regional academy) exist both within and across different age groups.

The largest playing pathway for young rugby union players in England is within the school or education programme.[13] Following school, adolescents may continue their education at a university, whereby further participation in rugby union can also take place. When considering the safe progression within rugby union for school boys, it should be considered that school boy rugby is classified based on yearly (eg, U16) and bi-yearly (eg, U18) age categories, whereas university rugby is open age. As such any student studying in higher education is eligible to participate. To date, it is unclear how the movement and physical demands of rugby union change during this transitional period, which has consequences for participation numbers (eg, reduce player drop-off), player performance (eg, recruitment into representative teams) and also injury risk.[14] To this end, the aim of the current study was to determine the differences in the movement and physical demands of match-play in the English educational rugby union player pathway by playing position (ie, forwards and backs) and age group (ie, U16, U18, university).

METHODS

Participants

The movement (global positioning system (GPS)) and physical demands (tri-axial accelerometer) of rugby union within the educational pathway were investigated using microsensor technology. Data were collected during six matches from 96 male rugby union players participating across three age categories in England - U16 (n=31 participants), U18 (n=34 participants) and university (n=31 participants). Players were further divided in forwards and backs and participant characteristics are detailed in table 1. The matches were collected from two local independent schools and a university team. The official playing times of matches were 60 (U16), 70 (U18) and 80 (university) min, respectively. Institutional ethics approval was granted and written consent was obtained from the participants or a parent or guardian when a participant was under 18 years of age.

Procedures

During the matches, each participant wore a microsensor device (Optimeye S5, Catapult Innovations, Melbourne, Australia) according to the manufacturer's instructions. The device contained a 10 Hz GPS and a 100 Hz; tri-axial accelerometer, gyroscope and magnetometer. Participants were familiarised with the device during a training session prior to data collection. 10 Hz GPS units have been reported to possess a typical error (coefficient of variation) of 1.9%, 4.7% and 10.5% for total distance, high-speed running (>4.7 ms^{-1}) and very high-speed running (>5.56 ms^{-1}), respectively.[15] The mean±SD number of satellites during data collection was 14.1±0.9 with a horizontal dilution of precision of 0.89±0.17. High within- (0.91%–1.05%) and between- (1.02%–1.10%) unit reliability of the tri-axial accelerometer has previously been reported for the Minimax X model, however, no data are currently available for the Optimeye model.[16] At the end of the match, data were downloaded to the manufacturer's software (Catapult Sprint 5.1.7, Catapult Innovations, Melbourne, Australia) and trimmed to include each participant's actual playing time only. Participants whom were substitutes during the match, were only included in the analyses if their playing time exceeded the average substitute playing time.[4]

Movement demands

Movement demands were determined by total distance and classified in absolute arbitrary velocity zones devised by Hartwig *et al*[17] using adolescent rugby union players of various ages. The zones were defined

Table 1 Descriptive data for adolescent male rugby union players during school-boy and university match-play

	Under 16	Under 18	University	Under 16	Under 18	University
	Forwards			Backs		
n	16	18	17	15	16	14
Age (years)	15.8±0.3	17.7±0.5	21.3±1.6	15.9±0.3	17.5±0.6	21.1±2.1
Stature (cm)	180.4±7.1	182.3±6.6	189.5±6.7	178.8±5.2	179.6±5.6	184.5±4.7
Body mass (kg)	72.0±10.2	88.9±10.8	109.8±8.5	72.0±9.1	78.8±10.1	88.2±7.8
Actual playing time (min)	62.5±2.3	66.2±15.5	70.7±21.4	58.8±7.8	65.7±17.8	82.4±10.7
TD (m)	4364±654	4232±985	4683±1377	3884±700	4489±1299	5889±719
RD (m min^{-1})	69.7±9.2	64.2±5.4	66.6±5.0	66.4±9.4	68.3±5.7	71.1±5.5
V_{max} (ms^{-1})	6.8±0.7	6.9±0.9	6.7±0.8	7.5±0.9	7.9±0.7	8.1±0.4
Walking (m)	2007±218	2099±546	2235±699	2011±304	2307±647	2820±503
Jogging (m)	1278±291	1044±318	1271±400	865±325	854±264	1256±219
Striding (m)	993±295	995±370	1112±442	843±342	1009±444	1460±357
Sprinting (m)	87±86	94±93	64±65	165±101	319±176	353±147
PL (AU)	456±47	437±96	504±157	332±76	395±118	500±80
PL min^{-1} (AU min^{-1})	7.3±0.7	6.7±0.7	7.2±0.8	5.6±0.9	6.0±0.6	6.0±0.9
PL_{slow} (AU)	231±24	224±51	250±76	152±34	172±49	213±31
PL_{slow} min^{-1} (AU min^{-1})	3.7±0.4	3.4±0.4	3.5±0.2	2.6±0.4	2.6±0.3	2.6±0.4

Data are presented as mean±SD.
Walking (0-1.94 ms^{-1}), Jogging (1.94-3.33 ms^{-1}), Striding (3.33-5.83 ms^{-1}), Sprinting (>5.83 ms^{-1}).
AU, arbitrary unit; PL, PlayerLoad; PLslow, PlayerLoad slow; RD, relative distance; TD, total distance; V_{max}, maximum sprint velocity.

as walking (0–1.94 ms^{-1}), jogging (1.95–3.33 ms^{-1}), striding (3.34–5.83 ms^{-1}) and sprinting (>5.84 ms^{-1}).

Physical demands

PlayerLoad(PL; arbitrary units (AU)) was used to quantify the physical demands of rugby union match-play. PL is a vector magnitude measure that was calculated from the root mean square of accelerations recorded in the vertical, anteroposterior and mediolateral vectors measured by the 100 Hz tri-axial accelerometer embedded within the microsensor device.[3] In addition, the accumulated PL at slow velocities (<2 ms^{-1}; PL_{slow}) was used to measure the static exertion demands (ie, rucks, mauls, scrums) that are involved within rugby union competition.[3] This method was used to quantify additional external physical demands such as team-sport specific movements and collisions which are unable to be measured using GPS or video-based methods in isolation.[17] Previous research has identified a very large correlation between PL and PL_{slow} with the number of collisions during a rugby union match, with (r=0.785, r=0.701) and without scrums (r=0.727, r=0.799) in forwards.[18] The correlation for PL and PL_{slow} vs number of collisions was found to be moderate and large for backs (r=0.477, r=0.613).[18] Both absolute and relative PL variables were included in the analysis. All relative measures were calculated as the absolute measure divided by the on-field playing time for each player.

Statistical analyses

Descriptive data are presented as the mean±SD. Prior to analysis, all data were log-transformed to reduce bias arising from non-uniformity error and then analysed for practical importance using magnitude-based inferences.[19] Data are presented as Cohen's effect size (ES) statistic with 90% confidence limit (ES; ±CL). The chances of the performance measure being lower, similar or greater than the smallest worthwhile difference (0.2x between-participant SD) were calculated using a spreadsheet.[20] The chances that the difference between groups was lower or greater than the smallest worthwhile difference was assessed qualitatively as follows:<0.5%, most unlikely; 0.5%–5%, very unlikely; 5%–25%, unlikely; 25%–75%, possibly; 75%–95%, likely; 95%–99.5%, very likely; >99.5%, most likely.[21] Where the chances of both lower and greater performance measures were >5% the magnitude of difference was reported as unclear.

RESULTS

The mean±SD of GPS and tri-axial accelerometer variables for forwards and backs across U16, U18 and

Table 2 Standardised effect size (ES) difference in movement and physical demands for adolescent male rugby union players during school-boy and university match-play by position within age groups and between consecutive age groups within positions

	Positional differences			Consecutive age group differences			
	U16	U18	UNI	Fwds		Bcks	
	Fwds vs Bcks	Fwds vs Bcks	Fwds vs Bcks	U16 vs U18	U18 vs UNI	U16 vs U18	U18 vs UNI
TD	0.70; ±0.60	−0.10; ±0.68	−0.91; ±0.57	−0.23; ±0.56	−0.21; ±0.56	−0.33; ±0.59	−1.07; ±0.59
	Fwds likely ↑	Unclear	Fwds very likely ↓	Unclear	Unclear	Unclear	U18 very likely ↓
RD	0.36; ±0.60	−0.72; ±0.57	−2.11; ±0.57	0.69; ±0.58	−0.46; ±0.56	−0.28; ±0.60	−0.48; ±0.60
	Unclear	Fwds likely ↓	Fwds most likely ↓	U16 likely ↑	U18 likely ↓	Unclear	U18 likely ↓
V_{max}	−0.91; ±0.60	−1.16; ±0.56	−2.08; ±0.58	−0.15; ±0.56	0.28; ±0.56	−0.39; ±0.60	−0.38; ±0.60
	Fwds very likely ↓	Fwds most likely ↓	Fwds most likely ↓	Unclear	Unclear	Unclear	Unclear
Walking	0.02; ±0.60	−0.23; ±0.57	−0.84; ±0.58	−0.05; ±0.56	−0.08; ±0.56	−0.32; ±0.59	−0.80; ±0.59
	Unclear	Unclear	Fwds very likely ↓	Unclear	Unclear	Unclear	U18 very likely ↓
Jogging	1.35; ±0.60	0.53; ±0.57	−0.10; ±0.58	0.75; ±0.56	−0.51; ±0.56	0.01; ±0.60	−1.37; ±0.59
	Fwds most likely ↑	Fwds likely ↑	Unclear	U16 likely ↑	U18 likely ↓	Unclear	U18 most likely ↓
Striding	0.46; ±0.60	0.04; ±0.57	−0.82; ±0.58	0.06; ±0.57	−0.18; ±0.56	−0.28; ±0.59	−1.05; ±0.59
	Fwds likely ↑	Unclear	Fwds very likely ↓	Unclear	Unclear	Unclear	U18 very likely ↓
Sprinting	−0.74; ±0.59	−1.41; ±0.56	−1.93; ±0.57	0.09; ±0.57	0.12; ±0.56	−0.97; ±0.60	−0.29; ±0.60
	Fwds likely ↓	Fwds most likely ↓	Fwds most likely ↓	Unclear	Unclear	U16 very likely ↓	Unclear
PL	1.75; ±0.60	0.39; ±0.58	−0.13; ±0.58	0.32; ±0.56	0.31; ±0.56	−0.42; ±0.59	−0.91; ±0.59
	Fwds most likely ↑	Fwds possibly ↑	Unclear	Unclear	Unclear	U16 Possibly ↓	U18 very likely ↓
PL min^{-1}	2.09; ±0.60	0.95; ±0.57	1.36; ±0.61	0.90; ±0.57	−0.66; ±0.56	−0.52; ±0.60	−0.02; ±0.61
	Fwds most likely ↑	Fwds very likely ↑	Fwds most likely ↑	U16 very likely ↑	U18 likely ↓	U16 likely ↓	Unclear
PL_{slow}	2.26; ±0.60	0.84; ±0.57	0.34; ±0.58	0.25; ±0.56	−0.22; ±0.56	−0.27; ±0.59	−0.86; ±0.59
	Fwds most likely ↑	Fwds very likely ↑	Unclear	Unclear	Unclear	Unclear	U18 very likely ↓

Continued

Table 2 Continued

	Positional differences			Consecutive age group differences			
	U16	U18	UNI	Fwds		Bcks	
	Fwds vs Bcks	Fwds vs Bcks	Fwds vs Bcks	U16 vs U18	U18 vs UNI	U16 vs U18	U18 vs UNI
PL_{slow} min^{-1}	2.86; ±0.60	2.21; ±0.57	2.80; ±0.62	0.72; ±0.57	−0.44; ±0.56	−0.15; ±0.60	0.06; ±0.61
	Fwds most likely ↑	Fwds most likely ↑	Fwds most likely ↑	U16 likely ↑	U18 likely ↓	Unclear	Unclear

Data are presented as Cohen's ES statistic with 90% confidence limit (ES; ±CL) followed by magnitude-based inference and direction of the difference.
Walking (0–1.94 ms^{-1}), jogging (1.94–3.33 ms^{-1}), striding (3.33–5.83 ms^{-1}), sprinting (>5.83 ms^{-1}).
Bcks, backs; Fwds, forwards; PL, PlayerLoad; PL_{slow}, PlayerLoad slow; RD, relative distance; TD, total distance; U16, under 16; U18, under 18; UNI, university; V_{max}, maximum sprint velocity.

university are presented in table 1. The between position and age-group differences are shown in table 2.

DISCUSSION

The aim of the current study was to investigate the differences in the movement and physical demands of rugby union match-play in young players by age groups within the English educational pathway for forwards and backs. The key findings of this study were that the between-position differences varied for age groups, and the movement demands of rugby union played at younger age groups are not the same as the senior game. The movement demands that progress by age group were striding and sprinting for backs, whereas several movement and PL variables are lower for U18 compared with both U16 and university forwards. As such, coaches, practitioners and scientists can use these data to physically prepare players in an attempt to reduce the risk of injury and improve physical performance within the rugby union education pathway.

Between position differences

Movement demands

Differences between positions were typical of the senior professional game[4] at the university level. For example, backs covered a greater total, striding and sprinting distance than forwards. However, below the university level, while some findings were similar (eg, U16 and U18 backs covered greater sprinting distances than forwards), unclear differences in total distance at U18 were observed. Furthermore, in contrast to the senior game, the U16 forwards covered more total, jogging and striding distances than backs. This may be due to a lower level of skill at the younger age group, as recently proposed.[22] As such, the ball may get to the backs less frequently resulting in forwards undertaking more work, although this is yet to be established. This suggests position specific movement demands may not be as profound at youth age categories as in the senior game.[4]

Physical demands

Regarding the physical demands, forwards typically accumulated greater PL and PL_{slow} measures across all three age categories in comparison to backs. This is in line with senior elite rugby union, reporting that forwards experience greater physical demands than backs (PL; 590±80 vs 520±90 AU and PL_{slow}; 290±30 vs 230±40 AU).[3] Despite these similarities, players participating in the English education pathway appear to be subjected to lower physical demands than professional players[3] which could explain in part, the reduced injury rates in school[5] compared with the professional level.[6] The specific positional demands for forwards are attributed to their prominent role in competing for possession at set pieces and breakdowns, and engage more frequently in tackle contests.[23] The tackle contest, whether a ball-carrier or tackler, has previously been reported to account for 57% of 121 recorded school rugby union injuries during competition,[5] thus understanding potential tackle exposures between positions are of interest to all involved in the game. Given the greater physical demands observed in the current study for the forwards, practitioners should appropriately prescribe training interventions for this positional group, focusing on contact skills[24] alongside the development of both upper and lower body strength and power qualities.[25] The development of those qualities may allow players to better tolerate collision events and concurrently contribute to an improvement in contact ability.[26]

Progression by age group

Movement demands

Understanding the progression of position-specific movement and physical demands across age-groups is also useful for coaches, practitioners and scientists to determine whether players are adequately prepared for the next progression within the playing pathway. Across the three age-categories, unclear differences in total, striding and sprinting distances were observed for the forwards, suggesting the movement patterns may remain similar through the education pathway. For the backs, there were unclear differences in total and relative distance between U16 and U18 age categories while those demands *very* likely increased between U18 and university. Despite this, we found very likely (165±101 vs 319±176 m) increases in sprinting distance between U16 and U18 while unclear differences were observed between U18 and university. This may be an influence of the game context (eg, score, line breaks), given research has shown no differences in sprinting ability between younger and older academy aged rugby union players.[27] As such, the movement demands may warrant further investigation, alongside the game characteristics, to identify potential reasons for any differences in sprinting, or other running activity. This is in addition to understanding the differing trends for forwards and backs. To help prepare backs for the increase in sprinting as they progress from U16 to U18, through appropriate training prescription, U16 players should be exposed to increased sprinting activity for this aspect of competition.[28 29]

When considering the progression or change in the movement demands of young rugby union players between age groups, especially when classifying movement by absolute thresholds,[17] a change in player characteristics should also be considered. Previous research[27] has recently highlighted that sprint test performance (5, 10, 20, 40 m) throughout a professional rugby union club (U16, U18, U21) remains stable across academy ages despite increases in body mass. In the current study, maximum sprinting velocity was *unclear* between ages in both forwards and backs, however, there was a trend for it to increase with age in the backs. In addition, the mean body mass was identical at U16 between forwards and backs (72.0±10.2 vs 72.0±9.1 kg) but increased more at U18 (88.9±10.8 vs 78.8±10.1 kg) and university (109.8±8.5 vs 88.2±7.8 kg) in the forwards compared with the backs. Therefore, the combination of both body mass and sprinting velocity (ie, sprint momentum), may be an important attribute to consider in rugby.[30] Greater player momentum into collision will increase the physical demands[31] of competition as players progress through the pathway.

Physical demands

For forwards there were unclear differences in absolute PL and PL_{slow} across all three age categories, although, when expressed relative to playing time, $PL \cdot min^{-1}$ and $PL_{slow} \cdot min^{-1}$ were found to be very likely and likely lower at U18 compared with both U16 and university competition. Unfortunately, PL is unable to differentiate between the frequency or magnitude of a physical event. As such, U16 may be engaged in more physical collisions of a lower magnitude compared with U18, which would still result in a greater PL accumulation. Similar to the movement demands, the physical demands should now be investigated alongside game characteristics, to further the understanding of rugby union below the senior level. What these data do show is that despite increases in body mass, the absolute physical demands of the English education pathway may not progress in a linear trajectory for forwards.

For the backs, PL was possibly lower at U16 than U18 and was very likely lower at U18 than university. PL_{slow} was found to be unclear between U16 and U18 yet a very likely increase between U18 and university was found. These findings highlight that low-velocity collision based (PL_{slow}) activities may only increase at the open-age level of competition for the backs, while the overall physical demands (PL) appear to progress across the three age categories. The reader should also be aware of the complexity when quantifying the physical demands. This study failed to quantity the frequency or magnitude of the physical demands, in addition to determining the type of collision (eg, active vs passive shoulder contact).[14] These data suggest backs may be appropriately prepared for the physical demands as they progress from U16 to U18 but may need to improve their capabilities to tolerate the increases in collisions as they progress to open-age (university) competition. The detail of what the collision activity may be, is yet to be established.

Limitations

Despite this study providing the first empirical data to be used by stakeholders when making decisions around rugby union playing and participation pathways within the education system, a small sample size and subsequent lack of further positional breakdowns limits the study. In addition, factors such as match result, standard of opposition and tactics should also be considered in future studies. Furthermore, maturation[32] and developmental (eg, playing experience) differences may influence both the within- and between-game consistency in skill and tactical performance and in turn, impact on the movement demands of education match-play. It should also be acknowledged that PL is a proxy measure of the physical demands and will accumulate during running activity, however, PL_{slow} will only accumulate during low-velocity activities such as collisions (scrums, tackles, rucks and mauls). Finally, the injury risk of age group progression in addition to the psycho-social factors associated with rugby union also warrant consideration.

CONCLUSIONS

This study demonstrates that the movement demands of rugby union played at younger age groups are not the same as the senior game. Both positional groups appear to have different increasing demands through the age groups, suggesting practitioners should consider including more striding and sprinting for backs and physical exposures (eg, collisions and tackling) for forwards during training. Overall, the movement and physical demands experienced by young players are lower in comparison to professional players. Future research is required to further understand the game of rugby union in relation to young players, and provide data on the demands of the sport in relation to potential injury risk.

Acknowledgements The authors would like to acknowledge all teachers, coaches and players who were involved in this research study.

Contributors DR, BJ and KT are responsible for conceptualisation. DR, PP, JDJ, GR and JW are responsible for data collection and analysis. DR prepared the first draft of the manuscript. DW, SH, BJ and KT assisted with the write-up.

Funding The project was part-funded by Yorkshire Carnegie Rugby Union club, as part of the Carnegie Adolescent Rugby Research (CARR) project. Leeds Beckett University provided the remaining funding for research and also open access fees.

Competing interests None declared.

Ethics approval Leeds Beckett University.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement All available data are presented within the manuscript.

REFERENCES

1. Freitag A, Kirkwood G, Pollock AM. Rugby injury surveillance and prevention programmes: are they effective? *BMJ* 2015;350:h1587.
2. Sellgren K. Doctors urge schools to ban tackling in rugby. 2016. Retrieved April 2016, from. http://www.bbc.co.uk/news/education-35696238
3. McLaren SJ, Weston M, Smith A, *et al*. Variability of physical performance and player match loads in professional rugby union. *J Sci Med Sport* 2016;19:493–7.
4. Cahill N, Lamb K, Worsfold P, *et al*. The movement characteristics of English Premiership rugby union players. *J Sports Sci* 2013;31:229–37.
5. Palmer-Green DS, Stokes KA, Fuller CW, *et al*. Match injuries in english youth academy and schools rugby union: an epidemiological study. *Am J Sports Med* 2013;41:749–55.
6. Williams S, Trewartha G, Kemp S, *et al*. A meta-analysis of injuries in senior men's professional rugby union. *Sports Med* 2013;43:1043–55.
7. Tucker R, Raftery M, Verhagen E. Injury risk and a tackle ban in youth rugby union: reviewing the evidence and searching for targeted, effective interventions. A critical review. *Br J Sports Med* 2016;50:921–5.
8. Roberts SP, Trewartha G, Higgitt RJ, *et al*. The physical demands of elite english rugby union. *J Sports Sci* 2008;26:825–33.
9. Deutsch MU, Kearney GA, Rehrer NJ. Time - motion analysis of professional rugby union players during match-play. *J Sports Sci* 2007;25:461–72.
10. Waldron M, Worsfold PR, Twist C, *et al*. A three-season comparison of match performances among selected and unselected elite youth rugby league players. *J Sports Sci* 2014;32:1110–9.
11. Goto H, Morris JG, Nevill ME. Motion analysis of U11 to U16 elite english Premier League Academy players. *J Sports Sci* 2015;33:1248–58.
12. Cunningham D, Shearer DA, Drawer S, *et al*. Movement demands of elite U20 international rugby union players. *PLoS One* 2016;11:e0153275.
13. Rugby E. Under 16s pathway strategic review. Retrieved May 2016, from http://www.englandrugby.com/mm/Document/MyRugby/Players/01/30/98/95/AGCR-Under16StrategicReview_Neutral.pdf
14. McIntosh AS, Savage TN, McCrory P, *et al*. Tackle characteristics and injury in a cross section of rugby union football. *Med Sci Sports Exerc* 2010;42:977–84.
15. Rampinini E, Alberti G, Fiorenza M, *et al*. Accuracy of GPS devices for measuring high-intensity running in field-based team sports. *Int J Sports Med* 2015;36:49–53.
16. Boyd LJ, Ball K, Aughey RJ. The reliability of MinimaxX accelerometers for measuring physical activity in australian football. *Int J Sports Physiol Perform* 2011;6:311–21.
17. Hartwig TB, Naughton G, Searl J. Motion analyses of adolescent rugby union players: a comparison of training and game demands. *J Strength Cond Res* 2011;25:966–72.
18. Roe G, Halkier M, Beggs C, *et al*. The use of accelerometers to quantify collisions and running demands of rugby union match-play. *Int J Perf Anal Spor* 2016;16:590–561.
19. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform* 2006;1:50–7.
20. Hopkins WG. A spreadsheet to compare means of two groups. *Sportscience* 2007;11:22–4.
21. Hopkins WG, Marshall SW, Batterham AM, *et al*. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009;41:3–13.
22. Read DB, Jones B, Phibbs PJ, *et al*. Physical demands of representative match play in adolescent rugby union. *J Strength Cond Res* 2016:1.
23. Duthie G, Pyne D, Hooper S. Applied physiology and game analysis of rugby union. *Sports Med* 2003;33:973–91.
24. Hendricks S, Lambert M. Tackling in rugby: Coaching strategies for effective technique and injury prevention. *Int J Sports Sci and Coach* 2010;5:117–36.
25. Darrall-Jones JD, Jones B, Till K. Anthropometric and physical profiles of english academy rugby union players. *J Strength Cond Res* 2015;29:2086–96.
26. Johnston RD, Gabbett TJ, Jenkins DG, *et al*. Influence of physical qualities on post-match fatigue in rugby league players. *J Sci Med Sport* 2015;18:209–13.
27. Darrall-Jones JD, Jones B, Till K. Anthropometric, Sprint, and High-Intensity Running Profiles of English Academy Rugby Union Players by Position. *J Strength Cond Res* 2016;30:1348–58.
28. Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med* 2016;50:273–280.
29. Gabbett TJ, Hulin BT, Blanch P, *et al*. High training workloads alone do not cause sports injuries: how you get there is the real issue. *Br J Sports Med* 2016;50:444–5.
30. Darrall-Jones J, Roe G, Carney S, *et al*. The effect of body mass on the 30-15 intermittent fitness test in rugby union players. *Int J Sports Physiol Perform* 2016;11:400–3.
31. Hendricks S, Karpul D, Lambert M. Momentum and kinetic energy before the tackle in rugby union. *J Sports Sci Med* 2014;13:557–63.
32. Till K, Cobley S, O' Hara J, *et al*. Considering maturation status and relative age in the longitudinal evaluation of junior rugby league players. *Scand J Med Sci Sports* 2014;24:569–76.