Title: Workload, fatigue and muscle damage in an u20 rugby union team over an intensified international tournament.

Submission type: Original investigation.

Authors: M. Lacome[1,4], C. Carling[1,2], JP. Hager [1], G. Dine[3], J. Piscione[1].

1. Research Department, French Rugby Union, Marcoussis, France.
2. Institute of Coaching and Performance, University of Central Lancashire, Preston, UK.
3. Biotechnological Institute of Troyes, Troyes, France
4. Performance Department, Paris Saint-Germain FC, Saint-Germain-en-Laye, France.

Corresponding author:

M. Lacome.

Research Department, French Rugby Union, Marcoussis, France

Phone: +33 (0) 609427833

Email: mathlacome@gmail.com

Running head: Performance in international junior rugby union

Title: Workload, fatigue and muscle damage in an u20 rugby union team over an intensified international tournament.

1. Abstract

Purpose: This study examined the effects of an intensified tournament on workload, perceptual and neuromuscular fatigue and muscle damage responses in an international under-20 rugby union team. Methods: Players were subdivided into two groups according to match-play exposure time: high (HEG, n=13) and low (LEG, n=11). Measures monitored over the 19-day period included training session (n=10) and match (n=5) workload determined via global positioning systems and session ratings of perceived exertion (sRPE). Wellbeing scores, countermovement jump height performance (CMJ) and blood creatine kinase [CK]b concentrations were collected at various time points. Results: Analysis of workload cumulated across the tournament entirety for training and match-play combined showed that high-speed running distance was similar between groups while a very likely larger sRPE load was reported in HEG vs. LEG. In HEG high-speed activity fluctuated across the 5 successive matches albeit with no clear trend for a progressive decrease. No clear tendency for a progressive decrease in wellbeing scores prior to or following matches was observed in either group. In HEG trivial to possibly small reductions in post-match CMJ performance were observed while unclear to most likely moderate increases in pre-match [CK]b concentrations occurred until prior to match 4. Conclusion: The magnitude of match-to-match changes in external workload, perceptual and neuromuscular fatigue and muscle damage was generally unclear or small. These results suggest that irrespective of exposure time to match-play players generally maintained performance and readiness to play across the intensified tournament. These findings support the need for holistic systematic player monitoring programmes.

Keywords: high-speed running, wellbeing, creatine kinase, neuromuscular performance, rugby

Introduction

Rugby Union is considered one of the most intense and physically demanding field sport games. In elite senior rugby union, a large body of literature exists describing the locomotor demands of match-play.[1-6] Results in these studies demonstrate that the game is intermittent in nature frequently requiring players to perform bouts of high-speed running activities interspersed with sub-maximal low-speed activities over an 80-minute period.[7] In addition, physical collisions such as tackling and being tackled and intense static actions such as scrums, rucks and mauls are performed regularly. The combative and high-speed intermittent nature of the sport results in considerable muscle damage.[8] Research has demonstrated elevated blood creatine kinase concentrations for 48-hours before returning to baseline levels at 70-hours post-match.[9] These elevated concentrations are principally associated with the frequency of player involvements in tackles and game contact events.[10] Concomitant alterations in neuromuscular performance via measures of jump height and peak power output also occur following match-play. West et al.[11] reported that peak power output was reduced by ~7 % at 36-hours before returning to baseline levels at 60-hours post-match in elite senior players. The authors also reported disturbances in player mood at 12-hours post-match with these dissipating by 36-hours. Thus, if recovery time is insufficient before next exercise, whether a training session or competition, muscle damage and residual physical and mental fatigue could affect ensuing performance.

In comparison to elite-standard senior rugby union, little information[12,13] exists on the general match-play demands in the elite junior game and especially those during intensified tournaments. At international junior standards, the International Rugby Board (IRB) under-20 (u20) World Cup tournament is held on an annual basis. The tournament's schedule requires national teams to participate in 5 matches over a 19-day period. The teams that recover the quickest or limit the accumulation of fatigue are considered to have a better chance of being successful.[14] Yet, no information on players' ability to cope physically, physiologically and psychologically over the course of such an intensified schedule is available. There is a need to determine the magnitude of player fatigue via measures of workload, muscle damage, neuromuscular performance and wellbeing to assess recovery and readiness for play.[15] The ability to manage training and match load over such an intensive tournament is dependent upon achieving a fine balance between exercise stress and recovery particularly in players highly exposed to match-play. Equally, ensuring that non-starter players are not 'underloaded' especially in terms of high-speed running activity and potentially underprepared physically is a key issue.[16]

This study examined the effects of an intensified competition (2016 IRB u20 World Rugby Championship) on external and internal workload, perceptual fatigue, neuromuscular performance and muscle damage in international standard u20 rugby union players with specific emphasis on exposure time to match-play.

2. Methods

Participants

A cohort of twenty-four elite junior rugby union players (19.8±0.5yrs, 99.1±9.1kg, 185.4±7.0cm) belonging to a single national European team participated. Prior to participation, all players received comprehensive verbal and written explanations of the study and provided voluntarily signed informed consent. These data arose as a condition of selection for their national team in which player performance was routinely measured over the course of the competitive season. Local Institutional Board approval for the study was nevertheless obtained. This study conformed to the recommendations of the Declaration of Helsinki. To ensure confidentiality, all performance data were anonymized.

Design

A prospective, observational, longitudinal design was used to assess the impact of an intensified competition (2016 IRB u20 World Rugby Union Championship) on workload, perceptual and neuromuscular fatigue and muscle damage in international standard under-20 players.

Methodology

During the tournament, the team participated in 5 matches and 10 training sessions over a 19-day period. A total of 4 days (94-98h) separated matches 1 (M1) and 2 and matches 2 (M2) and 3 (M3) and 5 days (118-120h) separated matches 3 and 4 (M4) and matches 4 and 5 (M5).

Players were subdivided into two groups, respective to their match-play time: high exposure group (HEG, n=13; playing time: 276±44min; 69±11% of total playing time; 4.5±0.7 matches; 2.7±1.2 matches >60-min play) vs. low exposure group (LEG, n=11; playing time; 132±52min; 33±13% of total playing time; 3.4±1.2 matches; 0.7±0.9 matches >60-min play) groups. The HEG and LEG were comprised of 6 backs & 7 forwards and 6 backs & 5 forwards respectively.

External workload (running activity) was monitored in training and competition over the entire duration of the competition using a global positioning system (GPS). Each player wore a 16Hz unit (Sensoreverywhere V2, Digital Simulation, Paris, France) in a lycra vest or in a bespoke pocket fitted in their playing jersey which positioned the unit on the upper thoracic spine between the scapulae. Preliminary work (unpublished data) conducted by the authors assessed the quality and reliability of the GPS data in comparison to timing gate measures (SmartSpeed, Fusion Sport, Sumner park, Australia). High-levels of validity, intra-class correlation (ICC): 0.98±0.02 to 1.00±0.00, typical error of measurement (TEM): 1.2±0.2 to 1.8±0.4 %) and reliability (TEM: 0.5±0.2 to 0.6±0.4%) were demonstrated in activities ranging from walking to high speed running while a low coefficient of variation ([CV], 0.5±0.1%) and trivial TEM (0.09±0.01 $m.s^{-1}$) values were observed for maximal sprinting speed.

The GPS units were switched on at least 30 minutes prior to each match or training to facilitate satellite signal connection. Following the sessions, GPS data were downloaded to a laptop and analysed with proprietary software. Each data file was cropped to ensure that only data recorded when the player was on the field was included. Two locomotor variables were analysed: total distance (TD) and that covered at high-speeds (HS) using individualised thresholds according to movement performed above maximal aerobic speed (MAS). MAS was determined using an intermittent progressive running test (adapted from the Leger and Boucher test) involving 3-

min running bouts interspersed with 1-min passive rest on a tartan outdoor track during a training camp that took place two weeks prior to the competition.

Perceived training and match load was estimated using session rating of perceived exertion (sRPE) multiplied by the duration of the training sessions/matches[15]. Data were collected 30-min after every training session and match.

The players' perception of fatigue was assessed using a wellbeing questionnaire on the same morning as the matches (MD, between 7:30 and 8:30 AM) and in the morning two days following the matches (D+2, between 7:30 and 8:30 AM). No measures on the same morning as or following M5 were collected. The questionnaire assessed fatigue, sleep quality, general upper-body and lower-body muscle soreness, stress levels and mood on a five-point scale (scores of 1-5, 0.5 point increments).[17] Overall wellbeing was determined by summing the six individual scores.

Neuromuscular performance was assessed using height achieved in a countermovement jump (CMJ_{Height}). Monitoring took place 36h before M1 (D-2) and between +30 and +36h (D-2, between 10 and 11:00 AM) before M3, M4, and M5. Assessments could not be performed prior to M2. Prior to testing subjects performed a 10-minute dynamic warm-up consisting of foam rolling, active mobility and progressive lower-body loading with lunges, step-up and squats. Jump assessments required each participant to perform 4 unloaded CMJs with a wood stick placed on their shoulders. Each participant performed four repetitions, pausing for ~3-5s between each jump.[18] The mean of the trials (excluding best and worst measures) was calculated and used as a marker of neuromuscular performance.

Finally, blood creatine kinase $[CK]_b$ concentrations were measured using approximately 500µl of blood collected from fingertip capillary punctures and stored in a microtube containing lithium heparinate (BD Microtainer, BD, New Jersey, US). Within one hour after the blood collection, 32µl were taken from the tube using a specific pipette and placed on a measurement strip. Analyses were performed using a Reflotron Sprint (Roche Diagnostics, Grenzacherstrasse, Switzerland). The Reflotron was calibrated according to the manufacturer recommendations. $[CK]_b$ measures were collected in the evening the day before every match (D-1, between 7 and 8:00 PM; -20 to -24h) and 20 to 24h following the matches (D+1, between 7 and 8:00 PM) except after M5. Previous work examining $[CK]_b$ measures conducted under similar conditions reported a between-day CV of 10.6, ±8.2% and a very large ICC (0.99).[18]

Statistics

Pairwise comparisons between exposure groups were investigated using linear mixed models as these models appropriately handle repeated measures data. Random effects (individual athletes) were specified to allow for different within-subject standard deviations by the use of random intercepts, and fixed effects (exposure groups) were included to describe the relationship with the dependent variables. The Least Squares mean test provided positional comparisons from the final models, that were further assessed using magnitude-based inferences. Within-group (according to match-play exposure) changes in external and internal workload, CMJ, wellbeing scores and $[CK]_b$ were examined using standardised differences (ES), classified as; <0.20 trivial; 0.21–0.60 small; 0.61–1.20 moderate; 1.21–2.0 large and >2.01 very large.[19] The chances that the changes in scores were greater for a measure (i.e., greater than the smallest worthwhile change, SWC [0.2 multiplied by the between-subject standard deviation using Cohen's d principle]), similar or smaller than another one were calculated. Quantitative chances of greater or smaller changes in performance variable were assessed qualitatively. Descriptive statistics are reported as mean±SD, and while all other data are reported as mean±90% confidence limits (CL), unless otherwise stated. Statistical analyses were performed using a customised spreadsheet[20] and R Studio Statistical software (V0.99.446).

3. Results

Cumulated workload

External (running activity)

Figure 1 reports total and HS distance covered in training and match-play both cumulatively and at different time points according to exposure group. There was a very likely moderate difference in the cumulated total distance covered by HEG vs. LEG (39030±8061 vs. 33923±5797 m, +15±14%, 98/2/0) while an unclear difference between groups was reported for HS distance (3427±1865 vs 3260±1416 m, +5±35%, 39/38/24). Analysis of cumulated match-play data reports most likely very large differences in total distance covered (20240±4231 vs. 10040±3662 m, +54±14%, 0/0/100) and a likely moderate difference in HS distance (1886±1110 vs. 1002±1481 m, +44±29%, 93/6/1) in HEG vs. LEG.

Internal (session-RPE)

Figure 1 also reports sRPE load both at different time points and cumulatively for training and match-play according to exposure group. There was a very likely large difference in cumulated sRPE load in HEG vs. LEG (4940±601 vs. 4024±741, +19±10%, % chances: 99/1/0). Regarding cumulated match load, there was a most likely large difference in sRPE for HEG vs. LEG (2327±573 vs 1137±463, +56±16%, 100/0/0).

Changes in workload, perceptual and neuromuscular fatigue and muscle damage responses

External (running activity)

Match-to-match values for total and HS distance covered per minute by the HEG over the course of the tournament are presented in Figure 2. Overall, no progressive trend for a decrease in running performance across the five successive matches was observed (Figure 2). In comparison to M1, TD was moderately higher for M2 (64.0±5.2 vs. 67.3±7.4 $m.min^{-1}$; +6±9%, 81/15/5) as well as most likely largely higher for M3 (73.8±6.0 $m.min^{-1}$; +15±7%; 100/0/0). Relative HS was likely moderately higher for M2 (7.6±3.6 vs. 11.1+/-5.7 $m.min^{-1}$; +50±57%; 90/9/2) and very likely slightly higher for M3 (12.5±5.7 $m.min^{-1}$; +43±18%; 99/1/0) compared to M1.

Wellbeing

Table 1 reports data for the exposure groups' subjective perception of fatigue over the course of the tournament. Standardized differences for changes in comparison to the benchmark measures collected on the same day (MD) as M1 and two days afterwards (D+2) are presented in Figure 3. In comparison to the M1 benchmark value unclear to possibly small increases in MD well-being scores for each match were observed across the tournament in the LEG while in the HEG possibly small increases in well-being scores occurred on MD for M2 and M3 (+4.5±6.1% and +3.4±6.1%). For measures at D+2 there were unclear variations in well-being scores in the LEG following M2 and M3 and a possibly small decrease after M4 (-5.4±9.9%) compared to the M1 benchmark measure. Similarly, unclear changes in wellbeing scores at D+2 were reported in the HEG following M2 while possibly small decreases in wellbeing scores were observed after M3 and M4 (-3.0±5.5% and -5.1±5.8%) compared to the M1 benchmark measure.

CMJ

Table 1 presents data for counter-movement jump performance (CMJ_{Height}). Analysis of standardized changes compared to the benchmark measure obtained at M-2 prior to M1 are provided in Figure 3. In the LEG, possibly small decreases in performance occurred at D-2 prior to M3 and M4 (-4.7±5.1% and -2.8±5.3% respectively) while unclear results were observed before M5. In the HEG, possibly small decreases in performance were observed at D-2 before M3 and M5 (-3.9±4.2% and -5.5±6.0% respectively) whereas a likely trivial effect was observed at D-2 before M4 (-1.8±1.9%).

$[CK]_b$

Table 1 reports $[CK]_b$ data collected before (D-1) and after (D+1) matches. In the LEG, analysis of standardized changes (Figure 3) for D-1 measures prior to M2, M3 and M5 reported unclear changes for $[CK]_b$ in comparison to the benchmark value obtained prior to M1 (+15±46%, 0±37% and -8±48% respectively). A possibly small increase in $[CK]_b$ was observed for M4 compared with M1 (+22±47%, ES=0.24±0.51, % chances: 43/53/4). In the HEG, possibly small increases in $[CK]_b$ at D-1 were observed prior to M2, M3 and M4 compared to M1 (+20±45%, +40±45%, ±44±45%) while unclear changes were reported before M5 (-9.4±45%).

In the LEG, analyses of measures at D+1 showed small increases in $[CK]_b$ following M2 and M3 compared to the benchmark measure after M1 (+32±36% and 25±43%) while unclear variations were reported following M4. In the HEG, unclear variations at D+1 were reported following M2 compared to M1 (13±44%). In contrast, a most likely moderate increase in $[CK]_b$ at D+1 was observed after M3 compared to M1 (+83±44%) while a likely small decrease was reported following M4 (-27±44%).

4. Discussion

To the authors' knowledge, the present study is the first to examine the effects of an intensified tournament on external and internal workload, perceptual and neuromuscular fatigue and muscle damage in international standard u20 rugby union players. Main findings were: 1) cumulated high-speed running load over the entirety of the tournament for training and match-play combined was comparable between groups whereas a very likely larger cumulated sRPE load was observed in HEG compared to LEG; 2) high-speed running activity fluctuated across successive matches in HEG albeit with no clear trend emerging for a progressive change; 3) no clear tendency for a progressive change in wellbeing scores prior to or following matches was observed in either exposure group; 4) trivial to possibly small reductions in countermovement jump performance were observed in HEG following all matches, and; 5) unclear to most likely moderate increases in pre-match $[CK]_b$ concentrations occurred progressively until prior to match 4 in HEG.

Over the course of the present tournament, external load represented by the cumulated total distance covered in training and match-play combined was likely moderately greater in players with high-exposure to match-play. This difference in overall external load was associated with a higher cumulated internal sRPE load. In contrast, cumulated training and match high-speed activity was comparable between exposure groups despite the HEG evidently covering a substantially greater distance at high-speeds in match-play. These results can be explained by compensatory adjustments in high-speed running workload prescribed by practitioners to the LEG. Out of competition 'top-up' sessions are conducted to make up for the loss in match stress and aid physical 'readiness' for competition.[16] Indeed, coaches and practitioners should be aware of the potential effects of 'under loading' non-starter and fringe team sports players on forthcoming match performance especially when those unaccustomed to match loads are suddenly required to complete the habitual physical loads performed by regular starting players.[21] Players not selected in the team's match-day squad performed 4 vs. 4 touch rugby matches (4 x 10-min duration with 90-s work intervals interspersed with 30-s recovery on a 35m width x 40m length grass pitch) the day before the match. These results demonstrate the importance of systematic monitoring of training and match workload to enable manipulation of training particularly in non-starter players in an attempt to recreate the high-intensity running loads required in match-play.

The impact of fixture congestion on match running performance in junior elite rugby union players has up to now received no coverage. Related research in junior Rugby League tournament reported a progressive accumulation of fatigue represented by a reduced capacity to perform high-speed activity when multiple matches were played over five days.[23] An investigation more representative of the present study design (4 matches in 22 days vs. 5 matches in 19 days here) albeit in senior professional rugby league players, reported fluctuations in running activity with reductions in high-speed and increases in low-speed distance in the latter matches.[24] Here, players in the HEG demonstrated fluctuations in high-speed running performance across games although no clear trend emerged for a progressive decrease. Indeed, given the large degree of between-match variation observed in high-speed running performance in elite rugby competition[25] interpretation of the present results is challenging. Analyses of similar match-to-match running data on the present team's direct opponents and additional teams in the tournament while accounting for potential contextual influences are necessary. External workload measures could also be extended to include metabolic power analyses and repeated high-speed exercise bouts while monitoring processes could include a measure of cardiovascular load to complement external assessments. Although the real impact of post-exercise recovery strategies cannot be determined here, it is important to mention that all squad members followed standardized nutrition, hydration, cold bath, massages and compression interventions which might have contributed to them maintaining performance. In elite rugby union, limited data exist on the well-being of players and their ability to recover psychologically from matches and training.[15] While research suggests that mood is potentially a more sensitive post-match indicator of fatigue compared to physiological measures or hormonal markers,[11] no data are available on chronic match loading and in combination with training activities over an extended period of time such the present tournament. Here, a systematic match-to-match decrease in wellbeing scores following each match was reported in the HEG although the magnitude of changes was unclear or small. This trend might suggest an accumulation in post-match perceptual fatigue over the course of the tournament. Research conducted by Twist et al[24] during intensified periods of professional rugby league competition observed similar trends in post-match perceptual wellbeing scores. However, additional larger-scale investigations of a similar nature are warranted as Twist's and the present paper report data for a single professional team. In contrast to post-match measures, no trend for a decrease in wellbeing scores prior to matches were observed irrespective of the players' amount of exposure to match-play. A reasonable explanation for this positive result may be player management strategies based on adapted training workloads and rotation for match-play and the aforementioned recovery protocols performed post-match to aid readiness to play. Another potential explanation is linked to changes in subjective responses due to social desirability bias with athletes "faking-good" to appear to be coping in an attempt to aid their selection for forthcoming competition.[26]

Research in elite rugby union and league players has shown post-match disruptions in neuromuscular performance at various time intervals with full recovery generally attained in 72 hours.[10] Here, in contrast to the LEG, reductions in CMJ performance represented by trivial to small changes were observed in the HEG following all matches compared to the baseline measure performed prior to match 1; the largest decline following match 4 (-5.5%). Despite data being unavailable prior to match 2 and following match 5, these results suggest to a certain degree the accumulation of fatigue resulting in compromised neuromuscular performance in players with higher exposure during an intensified competitive schedule. While the 4-5 day interval between the present matches is in theory sufficient to enable NMF status to return to baseline levels enabling readiness for forthcoming games,[27] a risk of diminished capacity to train optimally following games might have been evident especially toward the end of the tournament. Another suggestion for the aforementioned reduced neuromuscular responses could be explained by a reduction in strength and power exercises in the HEG's training programme. In comparison, the LEG systematically performed powerlifting, explosive and strength lower and upper body movement exercises every 4 days. Indeed, it is notable that the LEG reported its highest values for the CMJ test towards the end of the tournament.

Following competition, rugby union players report muscle soreness and damage which are linked to intense exercise, notably physical collisions and eccentric muscle contractions during high-speed movements.[5] Muscle force generating capacity may subsequently be compromised[28] thereby affecting preparation and readiness for forthcoming games especially if the time interval between games is short. Here unclear or possibly small changes in pre-match $[CK]_b$ concentration, an indirect indicator of muscle damage, were generally observed in the

LEG. In the HEG, possibly small incremental increases in pre-match $[CK]_b$ occurred until match 4 compared to the baseline measure obtained prior to match 1 suggesting players endured progressively higher levels of muscle damage as the tournament advanced. However, a drop albeit unclear in $[CK]_b$ below the baseline measures occurred prior to the 5^{th} (final) match in the series. A possible explanation for this discrepancy might be the benefits on physiological recovery of an additional day off from training/competition between matches 4 and 5. Fatigue and readiness for competition are also influenced by training session content[22] thus future work should examine this potential association over the present intensified competition. A reduction in physical demands linked to opposition standard or playing style might also explain the aforementioned finding. It is notable that post-match $[CK]_b$ was lowest following match 4 (versus the team ranked lowest at end of the competition) and highest following match 3 (versus the team ranked 4th highest at end of the competition and known for its 'physicality') respectively. Information on the frequency and magnitude of player-to-player collisions would be beneficial in future investigations.

Limitations

The study is not without limitations related to the inclusion of a single team and collecting data in real-world elite athletic environments.[24] A multiple-team study would provide a larger sample size to better depict the demands of the competition. In reality however, collaboration and sharing of data between elite teams is difficult to achieve. The present researchers were limited in their ability to perform monitoring at additional time points over the course of the tournament which could have provided a more detailed assessment of time-related changes in performance, recovery and readiness to play. In addition, assessments of neuromuscular performance, $[CK]_b$ and wellbeing were not conducted following the final match as players were immediately required to return to their respective clubs. Finally, research has cast doubt on the reliability and sensitivity of $[CK]_b$ data collected in rugby players thereby caution is necessary when interpreting current findings.[29] In future studies, inclusion of additional biomarkers of biochemical and immunological status (e.g., testosterone to cortisol ratio, cytokines)[10] would complement the present measures.

5. Practical applications

The monitoring of external workload in training and competition showed that players with the highest exposure to match-play during an intensified tournament, were able to sustain match-to-match running performance while adjustments were made in high-speed running load in training in peers with reduced game time to ensure readiness for competition. Similarly, the monitoring of subjective, physical and physiological responses showed that the magnitude of changes in perceptual fatigue, neuromuscular performance and muscle damage in players with high exposure to competition were generally unclear or small. The present findings support the need for holistic systematic player monitoring and management programmes to track and inform practitioners on player recovery and readiness for forthcoming matches. Indeed, throughout the tournament, the present data were shown and explained to the coaching staff in an attempt to help them make evidence-based decisions on player preparation, readiness and selection over the course of an intensified tournament.

6. Conclusion

In conclusion, no clear trend for a progressive decrease in running performance and in perceptual and neuromuscular fatigue responses and muscle damage occurred during an intensified competition in international standard u20 rugby union players, irrespective of exposure time to match-play.

7. References

1. Cahill N, Lamb K, Worsfold P, Headey R, and Murray S. The movement characteristics of English Premiership rugby union players. J Sports Sci 2013;31:229-237.
2. Cunniffe, B., Proctor, W., Baker, J. S., and Davies, B. (2009). An evaluation of the physiological demands of elite rugby union using Global Positioning System tracking software. J Strength Cond Res 23:1195-1203.
3. Duthie G, Pyne, D, and Hooper S. Time motion analysis of 2001 and 2002 super 12 rugby. J Sports Sci 2005;23:523-530.
4. Jones MR, West D J, Crewther, B. T., Cook, C. J., and Kilduff, L. P. Quantifying positional and temporal movement patterns in professional rugby union using global positioning system. Eur J Sports Sci 2015;15:488-496.
5. Jones MR, West DJ, Harrington BJ, Cook CJ, Bracken RM, Shearer DA, and Kilduff LP. Match play performance characteristics that predict post-match creatine kinase responses in professional rugby union players. BMC Sports Sci Med Rehab 2014;6:38.
6. Lacome, M., Piscione, J., Hager, J.-P., and Bourdin, M. A new approach to quantifying physical demand in rugby union. J Sports Sci 2014;32:290-300.
7. Roberts SP, Trewartha G, Higgitt, RJ, El-Abd J, and Stokes KA. The physical demands of elite English rugby union. J Sports Sci 2008;26:825-833.
8. Tavares F, Smith TB, and Driller M. Fatigue and Recovery in Rugby: A Review. Sports Med 2017;in press.
9. Takarada Y. Evaluation of muscle damage after a rugby match with special reference to tackle plays. Br J Sports Med 2003;37:416–419.
10. Cunniffe B, Hore AJ, Whitcombe DM, Jones KP, Baker JS, and Davies B. Time course of changes in immuneoendocrine markers following an international rugby game. Eur J Appl Physiol. 2010;108:113-122.
11. West DJ, Finn CV, Cunningham DJ, Shearer DA, Jones MR, Harrington BJ, Crewther BT, Cook CJ, and Kilduff LP. Neuromuscular function, hormonal, and mood responses to a professional rugby union match. J Strength Cond Res 2014;28:194-200.
12. Cunningham DJ, Shearer DA, Drawer S, Pollard B, Eager R, Taylor N, et al. Movement Demands of Elite Under-20s and Senior International Rugby Union Players. PLoS One 2016;11:e0164990.
13. Cunningham D, Shearer DA, Drawer S, Eager R, Taylor N, Cook C, and Kilduff LP. Movement Demands of Elite U20 International Rugby Union Players. PLoS One. 2016;11:e0153275
14. Hanson C. (2013) Implentation of Recovery Strategies for international rugby union tournaments. In: Recovery for performance in sport. Hausswirth C & Mujika, I. eds Human Kinetics, Champaign, Il, pp. 109-110.
15. Quarrie KL, Raftery M, Blackie J, Cook CJ, Fuller CW, Gabbett TJ, Gray AJ, Gill N, Hennessy L, Kemp S, Lambert M, Nichol R, Mellalieu SD, Piscione J, Stadelmann J, and Tucker R. Managing player load in professional rugby union: a review of current knowledge and practices. Br J Sports Med 2017;51:421-427.
16. McGuigan, M. Monitoring Training and Performance in Athletes. Champaign: Human Kinetics; 2017.
17. Hooper SL, Mackinnon LT. Monitoring overtraining in athletes. Recommendations. Sports Med. 1995;20:321-327.
18. Mathieu, B., Peeters, A., Piscione, J., and Lacome, M. Reliability of counter-movement jump performance, cycle ergometer sprint performance and creatine kinase concentration in team sport athletes: interest for fatigue monitoring. In Baca A., Wessner B., Diketmüller R., Tschan H., Hofmann M., Kornfeind P.Tsolakidis E. eds. Book of abstracts. 21st Annual Congress of the European College of Sports Science. 6th - 9th July 2016, Vienna, Austria. p 227.
19. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41:3–13.

20. Hopkins WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. Sportscience. 2007;11:16-20.
21. Anderson L, Orme P, Di Michele R, Close GL, Milsom J, Morgans R, Drust B, and Morton JP Quantification of Seasonal-Long Physical Load in Soccer Players With Different Starting Status From the English Premier League: Implications for Maintaining Squad Physical Fitness. Int J Sports Physiol Perform 2016;11:1038-1046.
22. Roe, G, Joshua Darrall-Jones, Kevin Till, Padraic Phibbs, Dale Read, Jonathon Weakley, Andrew Rock and Ben Jones. The effect of physical contact on changes in fatigue markers following rugby union field-based training. Eur J Sports Sci 2017;17:647-655.
23. Johnston RD, Gabbett TJ, and Jenkins DG. Influence of an intensified competition on fatigue and match performance in junior rugby league players. J Sci Med Sport. 2013;16:460-465.
24. Twist C, Highton J, Daniels M, Mill N, and Close G. Player Responses to Match and Training Demands During an Intensified Fixture Schedule in Professional Rugby League: A Case Study. Int J Sports Physiol Perform 2017;17:1-22.
25. McLaren SJ, Weston M, Smith A, Cram R, and Portas MD. Variability of physical performance and player match loads in professional rugby union. J Sci Med Sport. 2016; 493-7.
26. Saw AE, Main LC, and Gastin PB. Monitoring Athletes Through Self-Report: Factors Influencing Implementation. J Sports Sci & Med. 2015;14:137-146.
27. Bourdon PC, Cardinale M, Murray A, Gastin P, Kellmann M, Varley MC, Gabbett TJ, Coutts AJ, Burgess DJ, Gregson W, and Cable NT. Monitoring Athlete Training Loads: Consensus Statement. Int J Sports Physiol Perform 2017;12(Suppl 2):S2161-S2170.
28. Smart DJ, Gill ND, Beaven CM, Cook CJ, and Blazevich AJ. The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. Br J Sports Med 2018; 42: 198-201
29. Roe G, Darrall-Jones J, Till K, Phibbs P, Read D, Weakley J, and Jones B. Between-Days Reliability and Sensitivity of Common Fatigue Measures in Rugby Players. Int J Sports Physiol Perform 2016;11:581-586.

Figure 1 – Total distance and high-speed distance covered and session-RPE values in training and match-play in players with high (black) and low (white) exposure to match-play over an intensified international u20 rugby union tournament.

*: possible and **: likely difference between high exposure and low exposure players.

Figure 2 – Match-to-match individual and collective values for total distance and high-speed distance in players with high exposure to match-play during over an intensified international u20 rugby union tournament.

: likely and *: very likely change between M1 and the other matches.

Figure 3: Changes in perceptual (Wellbeing) and neuromuscular performance (CMJ) and muscle damage ($[CK]_b$ following matches between match 1 and matches 2 to 5 in players with high and low exposure to match-play over an intensified international u20 rugby union tournament.

*: possible, **: likely, ***: very likely and ****: almost certain change between M1 and the other matches. Black circle: High exposure players. White circle: Low exposure players. MD: Match day. D+1 and D+2 represent values recorded 1 and 2 days following the match while D-1 and D-2 represent values recorded 1 and 2 days preceding the match respectively.

Table 1: Measures of muscle damage ($[CK]_b$, perceptual (Wellbeing) and neuromuscular fatigue (CMJ) in relation to matches played in players with high and low exposure to match-play during an intensified international u20 rugby union tournament.

	Match	**Low exposure group (n=11)**	**High exposure group (n=13)**
$[CK]_b$ (a.u): D-1	M1	376±377	297±336
	M2	440±325	376±327
	M3	464±335	453±327
	M4	369±360	466±327
	M5	348±346	261±336
$[CK]_b$ (a.u): D+1	M1	643±551	787±508
	M2	849±491	872±494
	M3	799±616	1318±494
	M4	589±580	613±494
Wellbeing(a.u): MD	M1	21.8±3.2	21.8±2.3
	M2	22.2±3.5	22.8±2.8
	M3	21.8±2.4	22.6±3.0
	M4	22.6±2.0	22.1±2.4
Wellbeing(a.u): D+2	M1	22.1±4.1	21.5±3.0
	M2	22.1±3.1	21.2±3.6
	M3	21.4±2.1	20.9±2.9
	M4	20.9±3.6	20.4±3.5
CMJ (cm): D-2	M1	47.5±6.9	48.2±6.6
	M3	45.3±6.9	46.4±6.8
	M4	46.2±7.0	47.4±6.8
	M5	48.6±7.0	45.6±6.9

M=Match
MD=measurement performed on same day as match
D-1/D-2= measurement performed 1 or two days prior to match
D+1/D+2= measurement performed 1 or 2 days following match