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Workload, fatigue and muscle damage in an U20 rugby union team over an intensified international tournament

Lacome, M., Carling, C., Hager, J.P., Dine, G., and Piscione, J.

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

3

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5

6 **Authors:** M. Lacomme^{1,4}, C. Carling^{1,2}, JP. Hager¹, G. Dine³, J. Piscione¹.

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8 1. Research Department, French Rugby Union, Marcoussis, France.

9 2. Institute of Coaching and Performance, University of Central Lancashire, Preston, UK.

10 3. Biotechnological Institute of Troyes, Troyes, France

11 4. Performance Department, Paris Saint-Germain FC, Saint-Germain-en-Laye, France.

12

13

14 **Corresponding author:**

15 M. Lacomme.

16 Research Department, French Rugby Union, Marcoussis, France

17 Phone: +33 (0) 609427833

18 Email: mathlacomme@gmail.com

19

20 **Running head:** Performance in international junior rugby union

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22

23

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25 **intensified international tournament.**

26

27 1. Abstract

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

48

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

50

51 Introduction

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

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

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

88 2. Methods

89 Participants

90 A cohort of twenty-four elite junior rugby union players (19.8 ± 0.5 yrs, 99.1 ± 9.1 kg,
91 185.4 ± 7.0 cm) belonging to a single national European team participated. Prior to participation,
92 all players received comprehensive verbal and written explanations of the study and provided
93 voluntarily signed informed consent. These data arose as a condition of selection for their
94 national team in which player performance was routinely measured over the course of the
95 competitive season. Local Institutional Board approval for the study was nevertheless obtained.
96 This study conformed to the recommendations of the Declaration of Helsinki. To ensure
97 confidentiality, all performance data were anonymized.

98 Design

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

102 Methodology

103 During the tournament, the team participated in 5 matches and 10 training sessions over a 19-
104 day period. A total of 4 days (94-98h) separated matches 1 (M1) and 2 and matches 2 (M2) and
105 3 (M3) and 5 days (118-120h) separated matches 3 and 4 (M4) and matches 4 and 5 (M5).

106 Players were subdivided into two groups, respective to their match-play time: high exposure
107 group (HEG, $n=13$; playing time: 276 ± 44 min; $69\pm 11\%$ of total playing time; 4.5 ± 0.7 matches;
108 2.7 ± 1.2 matches >60 -min play) vs. low exposure group (LEG, $n=11$; playing time; 132 ± 52 min;
109 $33\pm 13\%$ of total playing time; 3.4 ± 1.2 matches; 0.7 ± 0.9 matches >60 -min play) groups. The
110 HEG and LEG were comprised of 6 backs & 7 forwards and 6 backs & 5 forwards respectively.

111 External workload (running activity) was monitored in training and competition over the entire
112 duration of the competition using a global positioning system (GPS). Each player wore a 16Hz
113 unit (Sensoreverywhere V2, Digital Simulation, Paris, France) in a lycra vest or in a bespoke
114 pocket fitted in their playing jersey which positioned the unit on the upper thoracic spine
115 between the scapulae. Preliminary work (unpublished data) conducted by the authors assessed
116 the quality and reliability of the GPS data in comparison to timing gate measures (SmartSpeed,
117 Fusion Sport, Sumner park, Australia). High-levels of validity, intra-class correlation (ICC):
118 0.98 ± 0.02 to 1.00 ± 0.00 , typical error of measurement (TEM): 1.2 ± 0.2 to 1.8 ± 0.4 %) and
119 reliability (TEM: 0.5 ± 0.2 to $0.6\pm 0.4\%$) were demonstrated in activities ranging from walking
120 to high speed running while a low coefficient of variation ([CV], $0.5\pm 0.1\%$) and trivial TEM
121 (0.09 ± 0.01 m.s⁻¹) values were observed for maximal sprinting speed.

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

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

131 Perceived training and match load was estimated using session rating of perceived exertion
132 (sRPE) multiplied by the duration of the training sessions/matches¹⁵. Data were collected 30-
133 min after every training session and match.

134
135 The players' perception of fatigue was assessed using a wellbeing questionnaire on the same
136 morning as the matches (MD, between 7:30 and 8:30 AM) and in the morning two days
137 following the matches (D+2, between 7:30 and 8:30 AM). No measures on the same morning
138 as or following M5 were collected. The questionnaire assessed fatigue, sleep quality, general
139 upper-body and lower-body muscle soreness, stress levels and mood on a five-point scale
140 (scores of 1-5, 0.5 point increments).¹⁷ Overall wellbeing was determined by summing the six
141 individual scores.

142
143 Neuromuscular performance was assessed using height achieved in a countermovement jump
144 (CMJ_{Height}). Monitoring took place 36h before M1 (D-2) and between +30 and +36h (D-2,
145 between 10 and 11:00 AM) before M3, M4, and M5. Assessments could not be performed prior
146 to M2. Prior to testing subjects performed a 10-minute dynamic warm-up consisting of foam
147 rolling, active mobility and progressive lower-body loading with lunges, step-up and squats.
148 Jump assessments required each participant to perform 4 unloaded CMJs with a wood stick
149 placed on their shoulders. Each participant performed four repetitions, pausing for ~3-5s
150 between each jump.¹⁸ The mean of the trials (excluding best and worst measures) was calculated
151 and used as a marker of neuromuscular performance.

152 Finally, blood creatine kinase [CK]_b concentrations were measured using approximately 500µl
153 of blood collected from fingertip capillary punctures and stored in a microtube containing
154 lithium heparinate (BD Microtainer, BD, New Jersey, US). Within one hour after the blood
155 collection, 32µl were taken from the tube using a specific pipette and placed on a measurement
156 strip. Analyses were performed using a Reflotron Sprint (Roche Diagnostics,
157 Grenzacherstrasse, Switzerland). The Reflotron was calibrated according to the manufacturer
158 recommendations. [CK]_b measures were collected in the evening the day before every match
159 (D-1, between 7 and 8:00 PM; -20 to -24h) and 20 to 24h following the matches (D+1, between
160 7 and 8:00 PM) except after M5. Previous work examining [CK]_b measures conducted under
161 similar conditions reported a between-day CV of 10.6, ±8.2% and a very large ICC (0.99).¹⁸

162 Statistics

163 Pairwise comparisons between exposure groups were investigated using linear mixed models
164 as these models appropriately handle repeated measures data. Random effects (individual
165 athletes) were specified to allow for different within-subject standard deviations by the use of
166 random intercepts, and fixed effects (exposure groups) were included to describe the
167 relationship with the dependent variables. The Least Squares mean test provided positional
168 comparisons from the final models, that were further assessed using magnitude-based
169 inferences. Within-group (according to match-play exposure) changes in external and internal
170 workload, CMJ, wellbeing scores and [CK]_b were examined using standardised differences
171 (ES), classified as: <0.20 trivial; 0.21–0.60 small; 0.61–1.20 moderate; 1.21–2.0 large and
172 >2.01 very large.¹⁹ The chances that the changes in scores were greater for a measure (i.e.,
173 greater than the smallest worthwhile change, SWC [0.2 multiplied by the between-subject

174 standard deviation using Cohen's d principle]), similar or smaller than another one were
175 calculated. Quantitative chances of greater or smaller changes in performance variable were
176 assessed qualitatively. Descriptive statistics are reported as mean±SD, and while all other data
177 are reported as mean±90% confidence limits (CL), unless otherwise stated. Statistical analyses
178 were performed using a customised spreadsheet²⁰ and R Studio Statistical software
179 (V0.99.446).

180 3. Results

181 Cumulated workload

182 *External (running activity)*

183 Figure 1 reports total and HS distance covered in training and match-play both cumulatively
184 and at different time points according to exposure group. There was a very likely moderate
185 difference in the cumulated total distance covered by HEG vs. LEG (39030±8061 vs.
186 33923±5797 m, +15±14%, 98/2/0) while an unclear difference between groups was reported
187 for HS distance (3427±1865 vs 3260±1416 m, +5±35%, 39/38/24). Analysis of cumulated
188 match-play data reports most likely very large differences in total distance covered
189 (20240±4231 vs. 10040±3662 m, +54±14%, 0/0/100) and a likely moderate difference in HS
190 distance (1886±1110 vs. 1002±1481 m, +44±29%, 93/6/1) in HEG vs. LEG.

191 *Internal (session-RPE)*

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

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

198 *External (running activity)*

199 Match-to-match values for total and HS distance covered per minute by the HEG over the
200 course of the tournament are presented in Figure 2. Overall, no progressive trend for a decrease
201 in running performance across the five successive matches was observed (Figure 2). In
202 comparison to M1, TD was moderately higher for M2 (64.0±5.2 vs. 67.3±7.4 m.min⁻¹; +6±9%,
203 81/15/5) as well as most likely largely higher for M3 (73.8±6.0 m.min⁻¹; +15±7%; 100/0/0).
204 Relative HS was likely moderately higher for M2 (7.6±3.6 vs. 11.1±5.7 m.min⁻¹; +50±57%;
205 90/9/2) and very likely slightly higher for M3 (12.5±5.7 m.min⁻¹; +43±18%; 99/1/0) compared
206 to M1.

207 *Wellbeing*

208 Table 1 reports data for the exposure groups' subjective perception of fatigue over the course
209 of the tournament. Standardized differences for changes in comparison to the benchmark
210 measures collected on the same day (MD) as M1 and two days afterwards (D+2) are presented
211 in Figure 3. In comparison to the M1 benchmark value unclear to possibly small increases in
212 MD well-being scores for each match were observed across the tournament in the LEG while
213 in the HEG possibly small increases in well-being scores occurred on MD for M2 and M3
214 (+4.5±6.1% and +3.4±6.1%). For measures at D+2 there were unclear variations in well-being

215 scores in the LEG following M2 and M3 and a possibly small decrease after M4 ($-5.4\pm 9.9\%$)
216 compared to the M1 benchmark measure. Similarly, unclear changes in wellbeing scores at D+2
217 were reported in the HEG following M2 while possibly small decreases in wellbeing scores
218 were observed after M3 and M4 ($-3.0\pm 5.5\%$ and $-5.1\pm 5.8\%$) compared to the M1 benchmark
219 measure.

220 *CMJ*

221 Table 1 presents data for counter-movement jump performance (CMJ_{Height}). Analysis of
222 standardized changes compared to the benchmark measure obtained at M-2 prior to M1 are
223 provided in Figure 3. In the LEG, possibly small decreases in performance occurred at D-2
224 prior to M3 and M4 ($-4.7\pm 5.1\%$ and $-2.8\pm 5.3\%$ respectively) while unclear results were
225 observed before M5. In the HEG, possibly small decreases in performance were observed at D-
226 2 before M3 and M5 ($-3.9\pm 4.2\%$ and $-5.5\pm 6.0\%$ respectively) whereas a likely trivial effect was
227 observed at D-2 before M4 ($-1.8\pm 1.9\%$).

228 $[CK]_b$

229 Table 1 reports $[CK]_b$ data collected before (D-1) and after (D+1) matches. In the LEG, analysis
230 of standardized changes (Figure 3) for D-1 measures prior to M2, M3 and M5 reported unclear
231 changes for $[CK]_b$ in comparison to the benchmark value obtained prior to M1 ($+15\pm 46\%$,
232 $0\pm 37\%$ and $-8\pm 48\%$ respectively). A possibly small increase in $[CK]_b$ was observed for M4
233 compared with M1 ($+22\pm 47\%$, $ES=0.24\pm 0.51$, % chances: 43/53/4). In the HEG, possibly small
234 increases in $[CK]_b$ at D-1 were observed prior to M2, M3 and M4 compared to M1 ($+20\pm 45\%$,
235 $+40\pm 45\%$, $\pm 44\pm 45\%$) while unclear changes were reported before M5 ($-9.4\pm 45\%$).

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

242 4. Discussion

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

255 Over the course of the present tournament, external load represented by the cumulated total
256 distance covered in training and match-play combined was likely moderately greater in players
257 with high-exposure to match-play. This difference in overall external load was associated with
258 a higher cumulated internal sRPE load. In contrast, cumulated training and match high-speed
259 activity was comparable between exposure groups despite the HEG evidently covering a
260 substantially greater distance at high-speeds in match-play. These results can be explained by
261 compensatory adjustments in high-speed running workload prescribed by practitioners to the
262 LEG. Out of competition 'top-up' sessions are conducted to make up for the loss in match stress
263 and aid physical 'readiness' for competition.¹⁶ Indeed, coaches and practitioners should be
264 aware of the potential effects of 'under loading' non-starter and fringe team sports players on
265 forthcoming match performance especially when those unaccustomed to match loads are
266 suddenly required to complete the habitual physical loads performed by regular starting
267 players.²¹ Players not selected in the team's match-day squad performed 4 vs. 4 touch rugby
268 matches (4 x 10-min duration with 90-s work intervals interspersed with 30-s recovery on a
269 35m width x 40m length grass pitch) the day before the match. These results demonstrate the
270 importance of systematic monitoring of training and match workload to enable manipulation of
271 training particularly in non-starter players in an attempt to recreate the high-intensity running
272 loads required in match-play.

273 The impact of fixture congestion on match running performance in junior elite rugby union
274 players has up to now received no coverage. Related research in junior Rugby League
275 tournament reported a progressive accumulation of fatigue represented by a reduced capacity
276 to perform high-speed activity when multiple matches were played over five days.²³ An
277 investigation more representative of the present study design (4 matches in 22 days vs. 5
278 matches in 19 days here) albeit in senior professional rugby league players, reported
279 fluctuations in running activity with reductions in high-speed and increases in low-speed
280 distance in the latter matches.²⁴ Here, players in the HEG demonstrated fluctuations in high-
281 speed running performance across games although no clear trend emerged for a progressive
282 decrease. Indeed, given the large degree of between-match variation observed in high-speed
283 running performance in elite rugby competition²⁵ interpretation of the present results is
284 challenging. Analyses of similar match-to-match running data on the present team's direct
285 opponents and additional teams in the tournament while accounting for potential contextual
286 influences are necessary. External workload measures could also be extended to include

287 metabolic power analyses and repeated high-speed exercise bouts while monitoring processes
288 could include a measure of cardiovascular load to complement external assessments. Although
289 the real impact of post-exercise recovery strategies cannot be determined here, it is important
290 to mention that all squad members followed standardized nutrition, hydration, cold bath,
291 massages and compression interventions which might have contributed to them maintaining
292 performance. In elite rugby union, limited data exist on the well-being of players and their
293 ability to recover psychologically from matches and training.¹⁵ While research suggests that
294 mood is potentially a more sensitive post-match indicator of fatigue compared to physiological
295 measures or hormonal markers,¹¹ no data are available on chronic match loading and in
296 combination with training activities over an extended period of time such the present
297 tournament. Here, a systematic match-to-match decrease in wellbeing scores following each
298 match was reported in the HEG although the magnitude of changes was unclear or small. This
299 trend might suggest an accumulation in post-match perceptual fatigue over the course of the
300 tournament. Research conducted by Twist et al²⁴ during intensified periods of professional
301 rugby league competition observed similar trends in post-match perceptual wellbeing scores.
302 However, additional larger-scale investigations of a similar nature are warranted as Twist's and
303 the present paper report data for a single professional team. In contrast to post-match measures,
304 no trend for a decrease in wellbeing scores prior to matches were observed irrespective of the
305 players' amount of exposure to match-play. A reasonable explanation for this positive result
306 may be player management strategies based on adapted training workloads and rotation for
307 match-play and the aforementioned recovery protocols performed post-match to aid readiness
308 to play. Another potential explanation is linked to changes in subjective responses due to social
309 desirability bias with athletes "faking-good" to appear to be coping in an attempt to aid their
310 selection for forthcoming competition.²⁶

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

327 Following competition, rugby union players report muscle soreness and damage which are
328 linked to intense exercise, notably physical collisions and eccentric muscle contractions during
329 high-speed movements.⁵ Muscle force generating capacity may subsequently be
330 compromised²⁸ thereby affecting preparation and readiness for forthcoming games especially
331 if the time interval between games is short. Here unclear or possibly small changes in pre-match
332 [CK]_b concentration, an indirect indicator of muscle damage, were generally observed in the

333 LEG. In the HEG, possibly small incremental increases in pre-match [CK]_b occurred until
334 match 4 compared to the baseline measure obtained prior to match 1 suggesting players endured
335 progressively higher levels of muscle damage as the tournament advanced. However, a drop
336 albeit unclear in [CK]_b below the baseline measures occurred prior to the 5th (final) match in
337 the series. A possible explanation for this discrepancy might be the benefits on physiological
338 recovery of an additional day off from training/competition between matches 4 and 5. Fatigue
339 and readiness for competition are also influenced by training session content²² thus future work
340 should examine this potential association over the present intensified competition. A reduction
341 in physical demands linked to opposition standard or playing style might also explain the
342 aforementioned finding. It is notable that post-match [CK]_b was lowest following match 4
343 (versus the team ranked lowest at end of the competition) and highest following match 3 (versus
344 the team ranked 4th highest at end of the competition and known for its ‘physicality’)
345 respectively. Information on the frequency and magnitude of player-to-player collisions would
346 be beneficial in future investigations.

347 Limitations

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

361 5. Practical applications

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

374 6. Conclusion

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

379

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

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

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

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

466

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

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

474

475 Table 1: Measures of muscle damage ([CK]_b, perceptual (Wellbeing) and neuromuscular fatigue (CMJ)
 476 in relation to matches played in players with high and low exposure to match-play during an intensified
 477 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

478

479 M=Match

480 MD=measurement performed on same day as match

481 D-1/D-2= measurement performed 1 or two days prior to match

482 D+1/D+2= measurement performed 1 or 2 days following match