

## The relationship between match-play characteristics of elite rugby league and indirect markers of muscle damage

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1 **Title:** THE RELATIONSHIP BETWEEN MATCH-PLAY CHARACTERISTICS OF  
2 ELITE RUGBY LEAGUE AND INDIRECT MARKERS OF MUSCLE DAMAGE

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13

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16

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21 **Abstract**

22 *Purpose:* Whilst exercise-induced muscle damage (EIMD) after a rugby league match has been  
23 well documented, the specific match actions that contribute to EIMD are unclear. Accordingly,  
24 the purpose of this study was to examine the relationship between the physical demands of elite  
25 rugby league matches and subsequent EIMD. *Methods:* Twenty-eight performances were  
26 captured using 10 Hz global positioning systems. Upper and lower body neuromuscular  
27 fatigue, creatine kinase (CK) and perceived muscle soreness were assessed 24 h before and at  
28 12, 36 and 60 h after a competitive match. *Results:* High-intensity running was *moderately*  
29 higher in backs ( $6.6 \pm 2.6 \text{ m}\cdot\text{min}^{-1}$ ) compared to forwards ( $5.1 \pm 1.6 \text{ m}\cdot\text{min}^{-1}$ ), whereas total  
30 collisions were *moderately* lower ( $31.1 \pm 13.1$  cf.  $54.1 \pm 37.0$ ). Duration ( $r = 0.9$ , CI: 0.77 to  
31 0.96), total distance covered ( $r = 0.86$ , CI: 0.7 to 0.95) and distance covered over 18 km·h<sup>-1</sup> ( $r$   
32  $= 0.76$ , CI: 0.51 to 0.91) were associated with increased CK concentration post-match. Total  
33 collisions and repeated high-intensity efforts (RHIE) were associated with *large* decrements in  
34 upper body neuromuscular performance ( $r = -0.48$ , CI: -0.74 to 0.02 and  $r = -0.49$ , CI: -0.77  
35 to 0.05, respectively), muscle soreness ( $r = -0.68$ , CI: -0.87 to -0.1 and  $r = -0.66$ , CI: -0.89 to  
36 0.21, respectively), and CK concentration ( $r = 0.67$ , CI: 0.42 to 0.85 and  $r = 0.73$ , CI: 0.51 to  
37 0.87, respectively). *Conclusion:* Match duration, high-intensity running and collisions were  
38 associated with variations in EIMD markers, suggesting recovery is dependent on individual  
39 match demands.

40

41 **Key words:** Time-motion analysis, recovery, neuromuscular fatigue, physical demands

## 42 **Introduction**

43 Exercise-induced muscle damage (EIMD) after rugby league match-play is well documented.  
44 This EIMD is characterised by elevations in myofibrillar proteins in plasma,<sup>1-3</sup> decrements in  
45 neuromuscular function<sup>3-5</sup> and increases in perceived muscle soreness<sup>6</sup> that last several days  
46 after competition. Symptoms of EIMD might therefore compromise the quality of a player's  
47 performance in the days after the original insult,<sup>3</sup> particularly where congested training and  
48 competitive schedules occur.<sup>1</sup>

49

50 The precise match actions that cause EIMD are poorly understood. Team sports, including  
51 rugby league, involve frequent bouts of high-intensity or maximal activity intermittently  
52 separated by prolonged bouts of low-intensity work. All players are subject to collisions at a  
53 rate of ~0.6 – 1.0 per minute<sup>6,7</sup> and perform approximately ~0.4 – 0.8 rapid accelerations per  
54 minute<sup>8</sup> and high-intensity sprinting movements<sup>9</sup> during match-play. Such actions are likely to  
55 result in EIMD associated with physical trauma to the muscle<sup>6</sup> and repeated eccentric  
56 contractions.<sup>10</sup> However, the type and frequency of these high-intensity bouts are largely  
57 dependent on position<sup>11</sup> meaning considerable match-to-match variability of these movements  
58 exist.<sup>12</sup> As such, there is potential for the magnitude of EIMD to vary between individual  
59 players,<sup>6</sup> although the extent to which these match actions are associated with post-match  
60 recovery has received limited attention. Indeed, previous studies in rugby have either assessed  
61 the relationship between EIMD and the frequency and nature of contact<sup>4,6,13</sup> or examined  
62 changes in creatine kinase concentration alone to quantify muscle damage.<sup>14</sup> Thus, the purpose  
63 of this study was to determine the potential relationship between the physical demands of elite  
64 rugby league match-play and post-match neuromuscular, perceptual and biochemical fatigue.

65

## 66 **Method**

### 67 *Subjects*

68 After institutional ethical approval, seventeen elite rugby league players (age:  $24.5 \pm 4.4$  y,  
69 stature:  $1.84 \pm 0.06$  m, body mass:  $98.5 \pm 10.3$  kg) from an English Super League team  
70 volunteered to participate in the study. Data were collected over four competitive matches  
71 during the 2014 Super League season, with a total of 28 individual performances recorded for  
72 forwards ( $n = 17$ ) and backs ( $n = 11$ ). The matches analysed comprised 1 win and 3 losses with  
73 an aggregated score of  $19 \pm 5$  points. Only players who were deemed free of injury and fit to  
74 play in a match during the time of testing participated in the study. Players were familiarised  
75 with all experimental procedures before testing.

76

### 77 *Design*

78 After a rest day, players reported to the training ground at approximately 09:00 on the day  
79 before the match. During this time, baseline measurements for creatine kinase (CK) activity,  
80 repeated plyometric push-up (RPP), counter-movement jump (CMJ) flight time and perceived  
81 muscle soreness were taken. The next day players competed in a rugby league match, during  
82 which the physical demands of selected players were measured using a global positioning  
83 system (GPS) device. Measurements of biochemical (CK) responses, followed by  
84 neuromuscular and perceptual measures (RPP, CMJ, muscle soreness) were then repeated at

85 12, 36 and 60 h after the match. An example of the training schedule and recovery strategies  
86 used around a match are outlined in Table 1.

87 \*\*\*Table 1 near here\*\*\*

## 88 *Procedures*

### 89 *Movement demands of match play*

90 Movement demands of the matches were recorded using 10 Hz MinimaxX GPS units (Team  
91 2.5, Catapult Innovations, Melbourne, Australia) that were simultaneously activated at pitch  
92 side before the warm-up. Distance covered was calculated according to four movement  
93 categories: walking or jogging (0-12 km·h<sup>-1</sup>), cruising (12-14 km·h<sup>-1</sup>), striding (14-18 km·h<sup>-1</sup>)  
94 and high-intensity running (>18 km·h<sup>-1</sup>).<sup>11</sup>

95

96 Collisions experienced were determined via accelerometer and gyroscope data provided in ‘G’  
97 force. For a collision to be registered, the athlete maintained a non-vertical position classified  
98 as either; leaning forward by more than 60 degrees, leaning backwards by more than 30 degrees  
99 or leaning left or right by more than 45 degrees for one second. Combined G-force was  
100 calculated as the average acceleration on each directional axis. Each collision was coded into  
101 one of five classification zones according to their severity, these being: light (2-3 G), moderate  
102 (3-4.5 G), heavy (4.5-6 G), very heavy (6-8 G) and severe (>8 G). Maximal accelerations and  
103 decelerations, classified as greater than 2.79 m·s<sup>-2</sup>, and RHIE bouts, defined as three or more  
104 maximal accelerations, high velocity sprints (>5 m·s<sup>-2</sup>) or contact efforts with less than 21 s  
105 recovery between efforts,<sup>15</sup> were also recorded.

106

### 107 *Creatine Kinase (CK) activity*

108 CK concentration was determined from 30 µL of capillarized, whole blood. Samples were  
109 obtained from a fingertip using a spring-loaded disposable lancet. Blood was then analysed  
110 using a colorimetric assay procedure (Reflotron, Type 4, Boehringer, Mannheim, Germany).  
111 All samples were taken at the same time (09:00 – 11:00) to reduce the effects of diurnal  
112 variation.

113

### 114 *Repeated plyometric push-up (RPP)*

115 Participants started in a press up position, with their hands placed on the floor 70 cm apart.  
116 Participants then rapidly flexed their elbows to approximately 90 degrees before maximally  
117 exploding off the floor, clapping their hands together, and landing with their arms fully  
118 extended. This was repeated three times within quick succession using an Optojump timing  
119 system (Optojump, Microgate, Microgate S.r.l., Bolzano, Italy). Flight time for each push up  
120 was recorded, and the total flight time was used for comparison. After completing one sub-  
121 maximal plyometric push up as a warm up, participants performed two maximal RPP efforts,  
122 with one minute recovery after the warm up, and in-between each effort. Flight time for each  
123 push up was recorded, and the total flight time was used for comparison. The coefficient of  
124 variation (CV%) for this measurement with the same group of players was 5.5%.

125

### 126 *Counter-movement jump (CMJ)*

127 Participants began standing upright in a shoulder width stance, with their hands placed on their  
128 hips. They rapidly flexed their knees to approximately 90 degrees, before jumping to maximal  
129 height. Flight time was recorded based on the recommendations of Cormack and colleagues.<sup>16</sup>  
130 Similar to the RPP protocol, participants completed one sub-maximal practice jump as a warm  
131 up, then after one minute, performed two maximal CMJ, with one minute of rest between each  
132 jump. The longest flight time was used for analysis. All CMJs were recorded using a timing  
133 mat system (Just Jump System, Probotics, Inc., Huntsville, AL). Reliability for this  
134 measurement demonstrated a CV% of 2.7%.

135

### 136 *Perceived muscle soreness*

137 Players provided a rating of perceived muscle soreness using a seven point Likert scale ranging  
138 from 0 (extreme soreness) to 6 (no soreness). All players completed this measurement on their  
139 own to ensure no influence from other players or members of staff. Despite being subjective,  
140 this measurement allows for complex psycho-physiological stresses to be monitored, all of  
141 which are associated with poor recovery.<sup>17</sup> Research employing similar scales has  
142 demonstrated a good level of reliability (Cronbach's alpha coefficient = 0.9).<sup>18</sup>

143

### 144 *Statistical Analysis*

145 Differences in match demands between positions were determined using multiple one-way  
146 analyses of variance (ANOVAs). Sphericity was assessed via Mauchly's test, with any  
147 violations accounted for via the Greenhouse-Geisser statistic. Independent *t*-tests were used to  
148 follow up any significant effects. Changes in muscle damage markers were analysed using  
149 repeated measures ANOVAs and paired sample *t*-tests were used to follow up any significant  
150 effects. Effect sizes and magnitude based inferences, as previously suggested by Twist and  
151 Highton,<sup>17</sup> were calculated for GPS variables and fatigue markers at 12 and 36 h post-match.  
152 Threshold probabilities for a considerable effect based on the 90% confidence intervals were:  
153 >0.5% most unlikely, 0.5-5% very unlikely, 5-25% unlikely, 25-75% possibly, 75-95% likely,  
154 95-99.5% very likely, > 99.5% most likely. The magnitude of the observed change was  
155 determined as the within-participant standard deviation multiplied by 0.2, 0.5 and 0.8 for a  
156 small, moderate and large effect, respectively.<sup>19</sup> Effects with confidence limits across a likely  
157 small positive or negative change were classified as unclear.<sup>20</sup> Pearson's product-moment  
158 correlation (*r*), the coefficient of determination ( $R^2$ ) and the 95% confidence interval (95% CI)  
159 was used to assess the relationship between match demands and recovery post-match. Where  
160 appropriate the alpha level was set at  $p < 0.05$ .

161

## 162 **Results**

### 163 *Match-demands*

164 Positional comparisons for match-demands are presented in Tables 2 and 3. ANOVA revealed  
165 no significant interaction between position and relative distance covered in each speed zone ( $F$   
166 = 0.840,  $p > 0.05$ ). Forwards experienced significantly more light collisions ( $t = 2.75$ ,  $p < 0.05$ )  
167 and total collisions ( $t = 2.19$ ,  $p < 0.05$ ) than backs. Magnitude-based inferences indicated *likely*  
168 positional effects for cruising and high-intensity running distance relative to duration of match-  
169 play, high-intensity accelerations, total efforts performed over  $18 \text{ km} \cdot \text{h}^{-1}$ , light, moderate and  
170 total collisions experienced and total RHIE bouts.

171

172 \*\*\*Table 2 and 3 near here\*\*\*

173

#### 174 *Recovery*

175 Changes in CK concentration over time are presented in Figure 1. ANOVA revealed significant  
176 differences in CK concentration over each time point ( $F = 13.2, p < 0.05$ ). CK concentration  
177 was significantly increased at 12 h ( $t = -9.451, p < 0.05$ ), and 36 h ( $t = -8.207, p < 0.05$ ),  
178 returning to baseline at 60 h post-match. These increases were *most likely large* at 12 and 36 h  
179 post-match (Table 4).

180 \*\*\*Figure 1 and Table 4 near here\*\*\*

181

182 CMJ flight time significantly decreased ( $F = 5.781, p < 0.05$ ) at 12 h ( $t = 4.108, p < 0.05$ ) and  
183 36 h post-match ( $t = 2.872, p < 0.05$ ) in comparison to baseline (Figure 2). The magnitude of  
184 change at these time points was *very likely large* (Table 4). Total flight time during RPP is  
185 displayed in Figure 3. ANOVA failed to show significant differences in flight time during the  
186 RPP at 12 and 36 h post-match compared to baseline ( $F = 2.684, p > 0.05$ ). However, effect  
187 sizes demonstrated *possibly small* and *likely moderate* decrements in RPP at 12 and 36 h,  
188 respectively. Significant increases in perceived muscle soreness were observed at 12 h ( $t =$   
189  $4.974, p < 0.05$ ) and 36 h ( $t = 3.286, p < 0.05$ ) post-match (Table 4).

190 \*\*\*Figure 2 and Figure 3 near here\*\*\*

191

#### 192 *Relationship between match demands and recovery*

193 Correlations between selected match demands and markers of fatigue at 12 h are presented in  
194 Table 5 and 6. All correlations for CMJ flight time were  $r < 0.3$  and therefore have not been  
195 reported within the study.

196 \*\*\*Table 5 and Table 6 near here\*\*\*

197

#### 198 **Discussion**

199 To our knowledge, this is the first study to examine the relationship between the movement  
200 demands of elite rugby league match-play and post-match neuromuscular, perceptual and  
201 biochemical markers of EIMD. The key findings of this study were reductions in upper body  
202 neuromuscular function and elevations in CK concentration and muscle soreness were  
203 associated with duration of match-play, distance covered during high-intensity running ( $>18$   
204  $\text{km}\cdot\text{h}^{-1}$ ), total collisions and RHIE bouts performed during the matches analysed.

205

206 The absolute distances covered at high-intensity during matches was greater for backs ( $481.4$   
207  $\pm 262.1$  m) compared to forwards ( $306.5 \pm 194.3$  m), a difference that also remained when high  
208 intensity running was expressed relative to playing time ( $6.6 \pm 2.6$  cf.  $5.1 \pm 1.6$   $\text{m}\cdot\text{min}^{-1}$ ). Such  
209 findings reaffirm those reported previously.<sup>21,22</sup> The observed differences in the number of  
210 maximal accelerations performed by backs in comparison to forwards ( $9.1$  cf.  $4.7$ ) might be  
211 explained by the shorter sprint distances (6 – 10 m) typical of hit-up forwards.<sup>23</sup> However, no

212 such differences were found for the number of maximal decelerations performed during match-  
213 play between positions ( $8.4 \pm 4.6$  cf.  $9.6 \pm 5.7$ ) and could be due to rapid changes of direction  
214 to return to the defensive-line particularly when the opposing team gains possession of the ball.

215

216 Similar to previous reports,<sup>6,21,23</sup> forwards experienced a greater number of total collisions than  
217 backs ( $54.1 \pm 37.0$  cf.  $31.1 \pm 13.1$ ). Whilst McLellan et al.<sup>13</sup> reported noticeably higher  
218 collisions (795 to 858) during rugby league match-play, the use of an alternative GPS device  
219 incorporating different algorithms for a collision to be registered, reaffirms that comparisons  
220 of match characteristics between GPS models should not be made.<sup>24</sup> RHIE bouts occurred  
221 regularly throughout the game between both positions, indicating repeated sprints  
222 incorporating physical collisions are essential to fully prepare players for competition,  
223 particularly given their association with higher standard rugby league teams.<sup>25</sup> Collectively, the  
224 data provides evidence to confirm the movement patterns observed within the current study are  
225 typical of rugby league match-play.

226

227 In accordance with previous research<sup>2,13</sup> the largest increases in CK concentration were  
228 observed at 12 h post-match, with values remaining elevated for at least 36 h. Increases in  
229 circulating CK suggest match-play resulted in disruption to the structural integrity of skeletal  
230 tissue, causing an increase in cell permeability.<sup>26</sup> Combined with contemporaneously large  
231 decrements in CMJ flight time, small to moderate decrements in RPP and large increases in  
232 muscle soreness (as indicated by a lower score) at 12 and 36 h post-match, these data reaffirm  
233 muscle damage occurred in the 36 h period after a rugby league match.<sup>1,4,6</sup> Coaches of elite  
234 rugby league players should be cognisant that both upper and lower body muscular function  
235 are reduced for at least 36 h after a competitive match. Furthermore, increases in perceived  
236 muscle soreness are also likely to alter an athlete's sense of effort, causing them to down-  
237 regulate their exercise capacity.<sup>27</sup> These findings have clear implications for the programming  
238 of training and recovery strategies in the days after a match.

239

240 The novel aspect of the study assessed the relationship between match demands and markers  
241 of muscle damage after elite rugby league match-play. Significant correlations were observed  
242 between total distance ( $r = 0.86$ ), match duration ( $r = 0.9$ ) and CK concentration. A longer  
243 period of time on the field would explain the greater total distance covered, both of which lead  
244 to an increase in circulating CK that is indicative of tissue damage. Strong associations were  
245 also observed between absolute ( $r = 0.76$ ) and relative distance ( $r = 0.49$ ) covered over 18  
246  $\text{km}\cdot\text{h}^{-1}$  and increases in CK concentration. These data support previous research demonstrating  
247 small to moderate correlations between high-intensity distance covered and CK activity after  
248 rugby union matches.<sup>14</sup> Given that high intensity running incorporates high-force, high-  
249 velocity eccentric contractions, which can induce muscle damage,<sup>10</sup> it is proposed that players  
250 who engage in more of these actions will experience a greater magnitude of tissue damage. The  
251 total number of high intensity accelerations and decelerations performed were moderately  
252 correlated ( $r = 0.44$  and  $r = 0.48$ , respectively) with CK concentration. Whilst little research  
253 exists on the relationship between the number of accelerations performed during match-play  
254 and markers of muscle damage Nedelec et al.<sup>28</sup> reported a significant relationship between  
255 decrements in CMJ and the number of hard changes in direction performed during a soccer  
256 match. The mechanical loading, caused by rapid accelerations and decelerations could have  
257 caused a lengthening and 'popping' of the sarcomeres ultimately leading to a loss of calcium  
258 ion homeostasis and a decrease in force production.<sup>29</sup>

259

260 Total collisions experienced were significantly correlated with decrements in RPP ( $r = -0.48$ ),  
261 increases in CK concentration ( $r = 0.67$ ) and muscle soreness ( $r = -0.68$ ). These results are  
262 consistent with others who have observed associations between CK concentration and  
263 collisions experienced in rugby league.<sup>6,14</sup> Typically, heavier collisions were associated with  
264 greater decrements in RPP and increases in CK concentration and muscle soreness,  
265 highlighting the importance of quantifying the severity of collisions to implement appropriate  
266 recovery strategies after a match. A novel finding of the study was that decrements in upper  
267 body neuromuscular function were associated with total collisions experienced. Whilst no other  
268 study has assessed this relationship, McLellan & Lovell<sup>4</sup> found heavy impacts were  
269 significantly correlated to decrements in CMJ performance at 24 h after a match. Similarly,  
270 Twist et al.<sup>6</sup> found correlations between total contacts during match-play and tissue damage  
271 after a match in forwards. Collectively, these data support the notion that players who  
272 experience a higher number of collisions during match-play experience a greater magnitude of  
273 muscle damage, and the associated loss of muscle strength post-match.

274

275 The total amount of RHIE bouts was also significantly correlated with decrements in RPP ( $r =$   
276  $-0.49$ ), increases in CK concentration ( $r = 0.73$ ) and muscle soreness ( $r = -0.66$ ). Thus, tissue  
277 damage caused by blunt force trauma from physical collisions interspersed with high intensity  
278 eccentrically biased actions might affect muscle soreness and muscle damage to a greater extent  
279 than that caused by repeated eccentric actions alone. Indeed, Johnston & Gabbett<sup>30</sup> reported a  
280 higher internal load for repeated sprints performed in conjunction with tackling ( $167 \text{ b} \cdot \text{min}^{-1}$ ),  
281 compared to a repeated sprint performed without ( $154 \text{ b} \cdot \text{min}^{-1}$ ). This high physiological cost  
282 could limit ATP availability, decreasing the action of the calcium adenosine triphosphatase  
283 (ATPase), compromising the removal of calcium.<sup>31</sup> Furthermore, an increase in hydrogen ions,  
284 resulting from high rates of glycolysis has been implicated in the loss of calcium homeostasis,  
285 associated with EIMD.<sup>32</sup> Given the association between RHIE bouts performed and muscle  
286 damage, reporting RHIE bouts might provide a more comprehensive understanding of player  
287 recovery after a match.

288

289 Despite very large reductions in CMJ performance after match-play, these changes were not  
290 strongly correlated with match demands. These data are in contrast to previous studies  
291 reporting relationships between match demands and post-match decreases in CMJ  
292 performance.<sup>4,28</sup> That we observed no relationship between changes in jump performance and  
293 movement demands might be partly explained by a weak association between vertical jumping  
294 and horizontal running performance.<sup>33</sup> Previous studies reporting stronger associations  
295 between running demands and changes in CMJ performance have also used a portable force  
296 platform, to quantify jump performance.<sup>4,28</sup> These apparatus provide a more comprehensive  
297 understanding of neuromuscular fatigue by allowing measures of muscle force and power<sup>17</sup>  
298 that might possess a greater capability to detect a potential relationship between jump  
299 performance and match demands.

300

### 301 **Practical Implications**

302 The decrements observed in both RPP and CMJ confirm that measurements of upper and lower  
303 body neuromuscular fatigue are necessary in the days after a rugby league match. For the first

304 time, we have shown that individual player measurements of duration, distance covered over  
305 18 km·h<sup>-1</sup>, the total number of collisions experienced and RHIE bouts performed during a  
306 match are indicative of the magnitude of muscle damage experienced by an individual player  
307 in the days that follow. Given the routine assessment of movement demands using GPS in both  
308 training and matches, we propose that coaches might want to use these data to forward plan so  
309 that training quality and recovery in the days after is not compromised. The strong association  
310 between increases in perceived muscle soreness and collisions experienced during match-play  
311 also reaffirms the use of this psychometric tool to monitor recovery status in rugby league  
312 players.

313

## 314 **Conclusion**

315 In conclusion, the movement patterns observed within the current study were typical of elite  
316 rugby league match-play and resulted in evidence of muscle damage that lasted for up to 36 h  
317 after a match. Reductions in upper body neuromuscular function and increases in CK  
318 concentration and perceived muscle soreness were associated with playing duration, high-  
319 intensity running and the number of collisions experienced. Accordingly, subsequent recovery  
320 for one player might vary from another based on individual match demands. Although lower  
321 limb neuromuscular function was compromised after a match, no significant correlations  
322 between decrements in CMJ performance and specific match demands were observed. These  
323 findings extend the use of GPS in training sessions and competitive matches to provide an  
324 advanced indication of individual player recovery and preparedness to train.

325

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329

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445 **Tables**

446 **Table 1.** An example of typical training and recovery strategies performed before and after a match  
 447 day.

|                  | <b>Day 1 pre-match</b>                       | <b>Match day</b>                              | <b>Day 1 post-match</b>               | <b>Day 2 post-match</b> | <b>Day 3 post-match</b>                     |
|------------------|--|---|---------------------------------------|-------------------------|---|
| <b>Morning</b>   | Testing<br>Captains run session<br>20-30 min | Rest  | Testing<br>Recovery session<br>30 min | Testing<br>Rest         | Testing<br>Resistance training<br>30–40 min |
| <b>Afternoon</b> | Rest   | Pre-match warm up 20 – 30 min<br>Match 80 min | Rest                                  | Rest                    | Team training (skills)<br>40–60 min         |

448 Testing: comprised blood samples for assessing CK, neuromuscular measurements (CMJ, RPP) and perceptual  
 449 muscle soreness.

450 Captains run session: attack and defence patterns and game structure.

451 Recovery session: 20 minutes of low intensity exercise followed by 10 minutes of massage

452 Resistance training: typical exercises include squat variations, bench press, shoulder press, horizontal pull,  
 453 power clean and push/pull variations.

454 Team training (skills): attack and defensive patterns and general skills.

455 Rest: No structured training, players encouraged to rest.

456

457 **Table 2.** Positional comparison of distance covered, duration, accelerations and decelerations  
 458 performed during rugby league match-play.

|   | <b>Forwards<br/>(n = 17)</b> | <b>Backs<br/>(n = 11)</b> | <b>Mean diff ±<br/>90%<br/>confidence<br/>interval</b> | <b>Qualitative<br/>interpretation</b> |
|---|------------------------------|---------------------------|--|---------------------------------------|
| Playing duration (min)                      | 55:14 ± 21:26                | 67:10 ± 25:18             | 11:56 ± 16:42  | Unclear                               |
| Total distance (m)                          | 4675 ± 1678                  | 5640 ± 2191               | 964.8 ± 1409.1   | Unclear                               |
| m·min <sup>-1</sup>                         | 81.9 ± 7.3                   | 83.2 ± 10.1               | 1.4 ± 6.4  | Unclear                               |
| Walking/jogging (m)                         | 3584.1 ± 1254.1              | 4322.5 ± 1705.3           | 738.5 ± 1089   | Unclear                               |
| m·min <sup>-1</sup>                         | 65.0 ± 7.1                   | 64.1 ± 6.5                | -0.9 ± 4.7   | Unclear                               |
| Cruising distance (m)                       | 393.1 ± 121.9                | 384.5 ± 181.5             | -8.7 ± 113.9   | Unclear                               |
| m·min <sup>-1</sup>                         | 7.3 ± 1.5                    | 5.9 ± 2.2                 | -1.5 ± 1.4   | Likely, moderate ↓                    |
| Striding distance (m)                       | 376.8 ± 152.1                | 451.5 ± 230.2             | 74.6 ± 144.0   | Unclear                               |
| m·min <sup>-1</sup>                         | 6.9 ± 1.3                    | 6.5 ± 2.0                 | -0.3 ± 1.3   | Unclear                               |
| HI running (m)                              | 306.5 ± 194.3                | 481.4 ± 262.1             | 174.9 ± 167.7  | Likely, moderate ↑                    |
| m·min <sup>-1</sup>                         | 5.1 ± 1.6                    | 6.6 ± 2.6                 | 1.5 ± 1.6  | Likely, moderate ↑                    |
| Total efforts over 18<br>km·h <sup>-1</sup> | 21.4 ± 13.0                  | 31.9 ± 16.6               | 10.6 ± 10.7  | Likely, moderate ↑                    |
| HI accelerations (n)                        | 4.7 ± 3.0                    | 9.1 ± 6.4                 | 4.4 ± 3.8  | Likely, large ↑                       |
| HI decelerations (n)                        | 8.4 ± 4.6                    | 9.6 ± 5.7                 | 1.2 ± 3.7  | Unclear                               |

459

460 **Table 3.** Positional comparison of collisions and repeated high-intensity effort bouts during rugby  
 461 league match-play.

|                        | <b>Forwards<br/>(n = 17)</b> | <b>Backs<br/>(n = 11)</b> | <b>Mean diff ±<br/>90% confidence<br/>interval</b> | <b>Qualitative<br/>interpretation</b> |
|------------------------|------------------------------|---------------------------|--|---------------------------------------|
| <i>Collisions (n):</i> |                              |                           |  |                                       |
| Light (2-3 G)          | 24.2 ± 16.0                  | 11.5 ± 7.1                | -12.6 ± 7.9  | Very likely, large ↓                  |
| Moderate (3-4.5 G)     | 21.3 ± 13.2                  | 13.9 ± 4.5                | -7.4 ± 6.2   | Likely, moderate ↓                    |
| Heavy (4.5-6 G)        | 6.1 ± 6.0                    | 4.1 ± 3.0                 | -2.0 ± 3.0   | Unclear                               |
| Very heavy (6-8 G)     | 1.8 ± 2.7                    | 1.1 ± 1.4                 | -0.7 ± 1.4   | Unclear                               |
| Severe (8-15 G)        | 0.7 ± 1.9                    | 0.5 ± 0.7                 | -0.3 ± 0.9   | Unclear                               |
| Total                  | 54.1 ± 37.0                  | 31.1 ± 13.1               | -23.0 ± 17.4                                       | Likely, moderate ↓                    |
| RHIE bouts (n)         | 14.4 ± 10.4                  | 10.0 ± 4.8                | -4.4 ± 5.1   | Likely, small ↓                       |

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464 **Table 4.** Magnitude based inferences for fatigue markers at 12 h and 36 h post-match in comparison  
 465 to baseline.

|                        | Baseline to 12 h                        |                                 | Baseline to 36 h                        |                                 |
|------------------------|---|---------------------------------|---|---------------------------------|
|                        | Mean diff $\pm$ 90% confidence interval | Qualitative interpretation      | Mean diff $\pm$ 90% confidence interval | Qualitative interpretation      |
| RPP (s)                | -0.04 $\pm$ 0.1                         | Possibly, small $\downarrow$    | -0.07 $\pm$ 0.1                         | Likely, moderate $\downarrow$   |
| CMJ (s)                | -0.02 $\pm$ 0.0                         | Very likely, large $\downarrow$ | -0.02 $\pm$ 0.0                         | Very likely, large $\downarrow$ |
| CK (U.L <sup>1</sup> ) | 808.0 $\pm$ 169.3                       | Most likely, large $\uparrow$   | 525.0 $\pm$ 136.4                       | Most likely, large $\uparrow$   |
| Muscle soreness        | -1.1 $\pm$ 0.5                          | Most likely, large $\downarrow$ | -0.8 $\pm$ 0.5                          | Very likely, large $\downarrow$ |

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468 **Table 5.** Correlations between running based match demands and fatigue markers at 12 h post-match.

| Match demands                          | Fatigue markers |               |                |       |               |                |
|--|-----------------|---------------|----------------|-------|---------------|----------------|
|  | RPP             |               |                | CK    |               |                |
|  | r               | 95% CI        | R <sup>2</sup> | r     | 95% CI        | R <sup>2</sup> |
| Playing Duration (min)                 | -0.39           | -0.74 to 0.05 | 0.15           | 0.9*  | 0.77 to 0.96  | 0.81           |
| Total distance (m)                     | -0.43           | -0.77 to 0.01 | 0.18           | 0.86* | 0.7 to 0.95   | 0.74           |
| HI running (m)                         | -0.41           | -0.72 to 0.02 | 0.17           | 0.76* | 0.51 to 0.91  | 0.58           |
| HI (m·min <sup>-1</sup> )              | -0.31           | -0.65 to 0.05 | 0.1            | 0.49* | 0.12 to 0.84  | 0.24           |
| Efforts over 18 km·h <sup>-1</sup> (n) | -0.38           | -0.71 to 0.4  | 0.14           | 0.76* | 0.49 to 0.91  | 0.58           |
| HI accels (n)                          | 0.19            | -0.25 to 0.66 | 0.04           | 0.44  | -0.06 to 0.84 | 0.19           |
| HI decels (n)                          | -0.23           | -0.68 to 0.28 | 0.05           | 0.48* | -0.02 to 0.85 | 0.23           |

469 \* Significant correlation (p<0.05).

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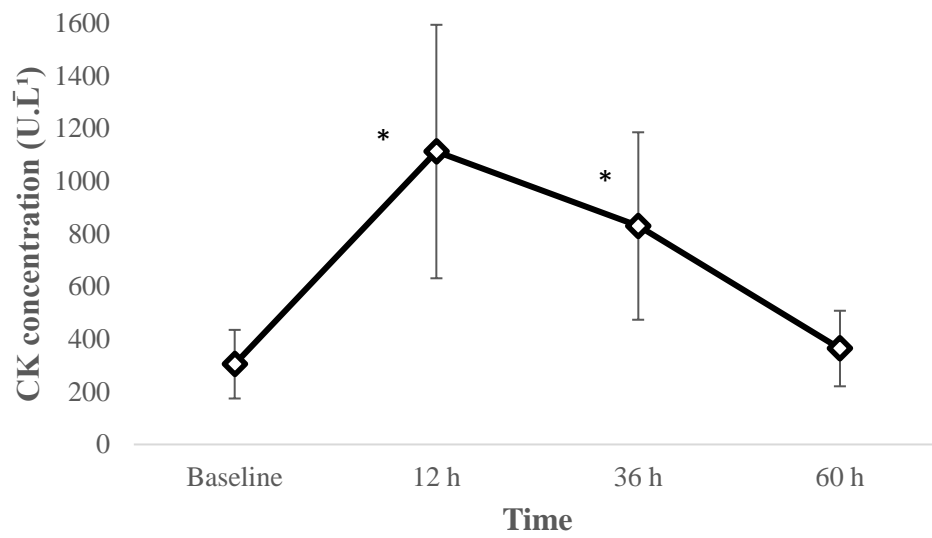
471 **Table 6.** Correlations between collision match demands and fatigue markers at 12 h post-match.

| Match demands        | Fatigue markers |                |                |       |              |                |                 |                |                |
|----------------------|-----------------|----------------|----------------|-------|--------------|----------------|-----------------|----------------|----------------|
|                      | RPP             |                |                | CK    |              |                | Muscle soreness |                |                |
|                      | r               | 95% CI         | R <sup>2</sup> | r     | 95% CI       | R <sup>2</sup> | r               | 95% CI         | R <sup>2</sup> |
| Collisions:          |                 |                |                |       |              |                |                 |                |                |
| Light                | -0.43           | -0.74 to 0.16  | 0.18           | 0.68* | 0.36 to 0.84 | 0.46           | -0.66*          | -0.89 to 0.09  | 0.44           |
| Moderate             | -0.54*          | -0.75 to -0.24 | 0.29           | 0.73* | 0.45 to 0.88 | 0.53           | -0.66*          | -0.86 to -0.01 | 0.44           |
| Heavy                | -0.38           | -0.68 to 0.15  | 0.14           | 0.72* | 0.4 to 0.91  | 0.52           | -0.74*          | -0.89 to -0.46 | 0.55           |
| Very heavy           | -0.4            | -0.69 to 0.37  | 0.16           | 0.58* | 0.47 to 0.83 | 0.34           | -0.56           | -0.82 to -0.03 | 0.31           |
| Severe               | -0.33           | -0.74 to 0.14  | 0.1            | 0.43  | 0.04 to 0.79 | 0.18           | -0.56*          | -0.73 to -0.4  | 0.31           |
| Total collisions (n) | -0.48*          | -0.74 to 0.02  | 0.23           | 0.67* | 0.42 to 0.85 | 0.31           | -0.68*          | -0.87 to -0.1  | 0.76           |
| Total RHIE bouts (n) | -0.49*          | -0.77 to 0.05  | 0.26           | 0.73* | 0.51 to 0.87 | 0.53           | -0.66*          | -0.89 to 0.21  | 0.44           |

472 \* Significant correlation (p<0.05).

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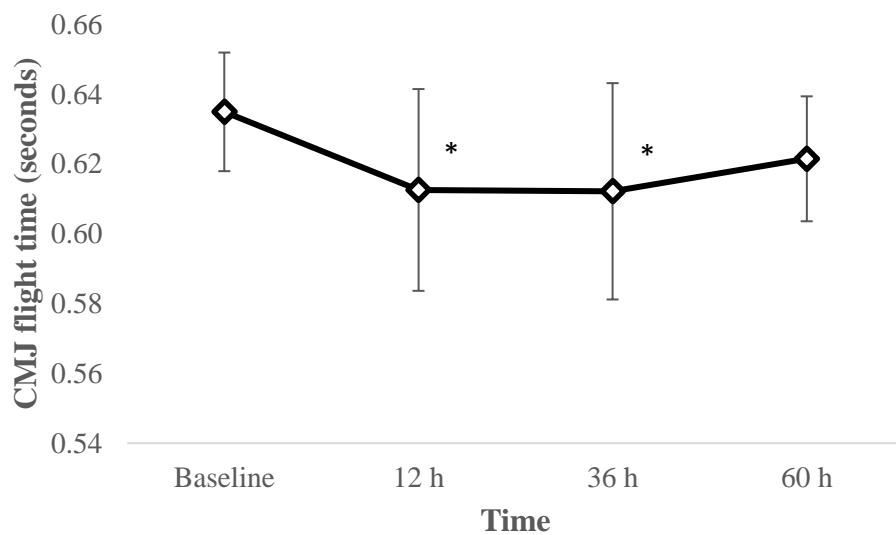


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476 **Figure 1.** Changes in CK concentration after elite rugby league match-play.

477 \* Significantly different from baseline values.

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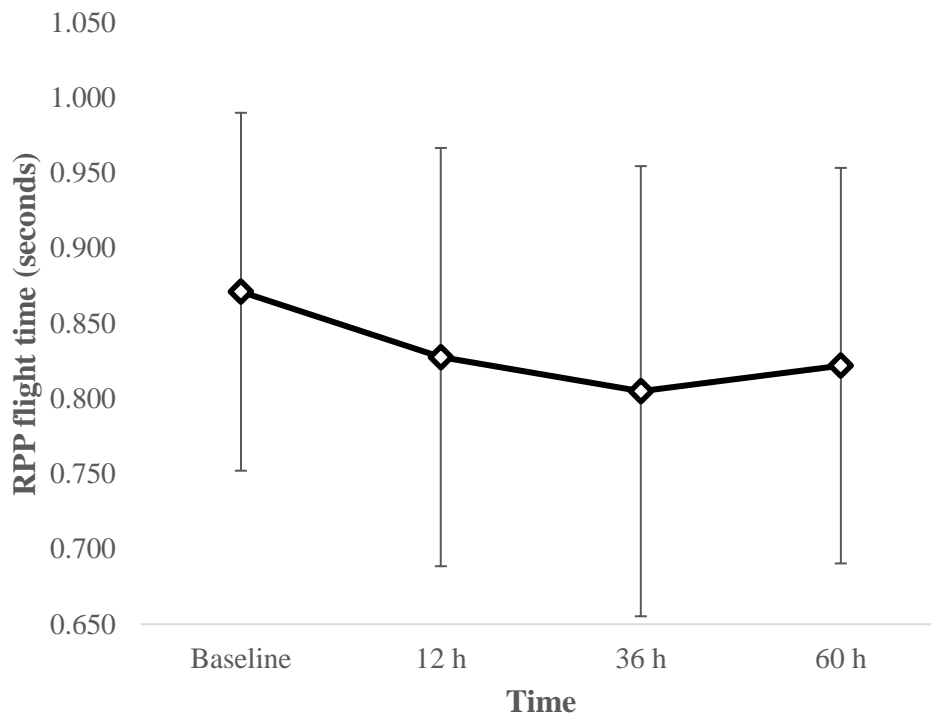


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480 **Figure 2.** Changes in CMJ flight time following elite rugby league match-play.

481 \* Significantly different from baseline values.

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485 **Figure 3.** Changes in total flight time and contact time during a RPP following elite rugby league  
486 match-play.