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### Article

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1 Daily Changes of Resting Metabolic Rate in Elite Rugby Union Players.

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21 **Abstract**

22 **INTRODUCTION:** Preparation for competitive contact sport has been extensively  
23 researched. There are, however, limited data to guide players as to how the demands of their  
24 sport affect the energy requirements of recovery. We aimed to provide novel data on changes  
25 in resting metabolic rate (RMR) in contact sport athletes and relate these to the physical  
26 demands of training and competition.

27 **METHODS:** 22 Elite professional Premiership Rugby Union players were recruited to the  
28 study. Indirect calorimetry (Vyntus CPX canopy, CareFusion) was used to measure RMR  
29 each morning of the competitive game week, in a fasted, rested state. External loads for  
30 training and game play were monitored and recorded using global positioning systems  
31 (Catapult Innovations, Australia), whilst internal loads were tracked using rate of perceived  
32 exertion scales. Collisions were reviewed and recorded by expert video analysts for contacts  
33 in general play (breakdown and tackle area) or the set piece (scrum or maul).

34 **RESULTS:** There were significant ( $p=0.005$ ) mean increases in RMR of  $\approx 231$  kcal the  
35 morning after (GD+1) and 3 days after the game (GD+3), compared with the day before the  
36 game (GD-1). The players were exposed to internal and external loads during the training  
37 week comparable to that of a match day, however, despite the equivocal loads between  
38 training and game play, there were no significant increases in RMR following training.

39 **CONCLUSION:** The collisions experienced in rugby match play are likely to be responsible  
40 for the significant increases in RMR at GD+1 and GD+3. Consequently, the measurement of  
41 RMR via indirect calorimetry may provide a novel non-invasive measure of the effects of  
42 collisions. This study provides a novel insight to the energy requirements of recovering from  
43 contact sport.

44 **Keywords:** Damage, Team Sport, Contact, Injury, DOMS, Soreness

45

46 **Introduction.**

47 Rugby Union is a dynamic and combative team sport participated in globally (1). Two teams  
48 of 15 players, broadly categorised as forwards (n=8) and backs (n=7) contest a match for 80  
49 minutes (1). The sport is comprised of intermittent, high intensity activities incorporating high  
50 speed running, sprinting, accelerations and decelerations (2-4). Rugby Union also involves  
51 collision-based activities at the tackle area (tackle and breakdown contest) and the set piece  
52 (scrum and maul). Time motion analysis and global positioning systems (GPS) studies report  
53 that forwards experience ~60% more high level impacts during contact situations than backs  
54 (4). However, there are significant limitations of using GPS technology to determine contact  
55 occurrence and quantitative measurement of force, rendering it unreliable to determine the  
56 physical strain placed on the players (5).

57 Whilst the technology to accurately quantify physical collisions in rugby is currently lacking,  
58 the recognition of their impact made upon the athlete is not (6). The forces and mechanical  
59 stress in rugby can cause exercise induced muscle damage (EIMD) and impact induced muscle  
60 damage (IIMD) which may be distinct in their symptomology and recovery time course (7).  
61 These physical collisions have been shown to increase indirect markers of muscle damage (8,  
62 9), reduce neuromuscular function (10, 11), and increase perception of muscle soreness (11).  
63 Sport scientists have examined a wide array of modalities to enhance recovery from the  
64 damaging collisions of rugby match play, some of which may mildly alleviate symptoms (12).  
65 However, despite multiple interventions being implemented, we have reported that elite rugby  
66 players are in pain every day throughout a competitive rugby season (13). It is therefore crucial  
67 that accurate and quantitative markers are developed to assess the extent of the IIMD to allow  
68 more targeted interventions to be developed. One potential candidate is assessing the energy  
69 expenditure of players given that the total energy expenditure (TEE) of young rugby league  
70 players was 5% higher when training weeks involved collisions (14).

71 Resting metabolic rate (RMR) is the primary component of TEE and is the energy expended to  
72 maintain homeostasis at rest. Indirect calorimetry (IC) requiring both oxygen ( $\dot{V}O_2$ ) and carbon  
73 dioxide ( $\dot{V}CO_2$ ) to be measured is the most accurate method of assessing RMR (15). Large  
74 variations in the estimation of RMR using prediction equations have been noted in a variety of  
75 sports (16), especially athletes with a high fat free mass (17) such as rugby (18-20). It is  
76 therefore imperative that RMR is accurately measured rather than predicted using equations.  
77 Importantly, much of the existing understanding around effectively calculating an athlete's  
78 energy requirements are based upon studies which primarily utilise recreational or youth  
79 athletes and are thus limited by lower training ages and exposures to lower absolute intensities  
80 of work. To our knowledge there are no data on the daily variations in RMR across an entire  
81 competitive match week in any sport, including positional differences. It is therefore crucial  
82 that potential changes in RMR are explored in highly trained professional athletes with indirect  
83 calorimetry performed prior to and the days following a competitive fixture.

84 To facilitate recovery, it is essential that rugby players are provided with the correct nutrition  
85 in terms of both the total energy intake and the provision of recovery promoting foods. The  
86 majority of nutrition research in rugby has focussed upon preparation for match play, ensuring  
87 muscle glycogen concentrations are optimal for performance (21). It appears elite players now  
88 have a good understanding of this (22), however, the nutritional intakes in the days following  
89 a match are much more variable (22) with many players decreasing total energy intake the day  
90 after a game. If muscle damage arising from match play causes an increase in energy  
91 requirements in recovery, current guidelines could be underestimating player's needs post  
92 competition.

93 To this end, the objectives of the present study were twofold. 1) To assess, for the first-time,  
94 changes in RMR in an elite group of professional rugby union players measured throughout a  
95 competitive week, including the days before and after a professional game using indirect

96 calorimetry. 2) To explore the relationship between game day factors, (e.g. the number of  
97 physical collisions), and changes in RMR. These data would provide more accurate  
98 information into the energy requirements of players in the days after a game, which could help  
99 recovery strategy, as well as providing a novel non-invasive assessment of the effects of the  
100 physical collisions upon the players.

## 101 **Methods**

### 102 *Participants*

103 A convenience sample of twenty-two healthy elite rugby union players, all members of an  
104 English Premiership squad, were recruited for this study. The participants included six  
105 internationals, and many established Premiership or Super 15 players (mean  $\pm$ SD, age; 25.7  
106  $\pm$ 4.1 years, body mass; 104.6  $\pm$ 12.6 kg). Five participants were excluded from the analysis  
107 having sustained an injury during games which prevented them from completing all aspects of  
108 the study. All playing positions were covered in the remaining 17 players who were eligible  
109 for the full study analysis. All participants gave written informed consent prior to commencing  
110 the study. Ethical approval (18/SPS/004) was granted by the university research ethics  
111 committee at Liverpool John Moores University, UK.

### 112 *Research Design*

113 The study was designed to allow RMR to be measured within the training schedules of elite  
114 rugby players during a complete microcycle. Timepoints throughout the study are described  
115 relative to game day (GD) using +/- symbols for days before (-) and days after (+) GD. Due to  
116 the timing of team selection defining when recruitment could occur, the first measurement was  
117 taken at GD-2. Measurements were then repeated every day, apart from the game day itself, as  
118 this was deemed too disruptive to the players' habitual routine. Table 1 details the training  
119 schedule for the match week. Seven microcycles were used to attain the total data set, with all

120 games played on the Saturday afternoon (Game Day). This ensured that the training schedules  
121 throughout the microcycle were the same and there were no conflicting kick-off times, which  
122 would alter the time relative to match play of the subsequent measures. Internal and external  
123 loads for training and match play were recorded throughout the week. The weeks chosen were  
124 throughout the middle of the season (weeks 13-30) so the players were accustomed to the  
125 training load and rigours of match play.

### 126 *Resting Metabolic Rate*

127 The RMR of participants was assessed 6 times in total. All measures were completed at the  
128 same time between 7-9am and players arrived after an overnight fast, with their last meal at  
129 least 8 hours prior to measurement. Players awoke and came straight to the training ground as  
130 per reliable outpatient protocol (23). To ensure best practice, a private room was established  
131 at the training facility away from the main building where temperature was maintained at 21-  
132 23 °C, the room was dimly lit, and quiet (15). Players lay in a comfortable supine position and  
133 were reminded to stay awake. A twenty minute resting period was prescribed, as the minimum  
134 sufficient time to achieve rest (24). A ventilated hood was employed rather than mouth piece  
135 and nose clip to reduce day-to-day variance (25). The coefficient of variance for our protocol  
136 was measured at 1.13% for RMR and 1.62% for RER. The ventilated hood was placed over  
137 the head of the athlete and expired gas was analysed using the dilution canopy method (Vyntus  
138 CPX canopy, CareFusion, Hoechberg, Germany). The gas analyser was calibrated every day  
139 using the manufacturer's automated flow and digital volume transducer calibration (15.92%  
140 O<sub>2</sub> and 5.03% CO<sub>2</sub>). The first 5 minutes of measurements were discarded following best  
141 practice guidelines (15). Measurements were subsequently recorded for 15 minutes  
142 continuously at 10 second intervals for  $\dot{V}O_2$  and  $\dot{V}CO_2$ . Data were exported into Microsoft  
143 Excel (2018, Seattle, USA), and mean respiratory exchange ratio (RER) across the



144 measurement period generated, with the calorific value, carbohydrate and fat oxidation rates  
145 determined according to the table of Zuntz (26).

#### 146 ***Measurement of lean body mass***

147 Lean body mass was measured using a dual-energy-X-ray absorptiometry (DXA) fan beam  
148 scanner (Hologic Horizon W, Hologic, Bedford, MA), with scanning and analysis performed  
149 by the same trained individual using Apex software version 13.5.3.1(Hologic, Bedford, MA).  
150 Players were scanned twice during the period of data collection for this study and the scan  
151 corresponding closest to their week of participation used, which was no longer than 4 weeks.  
152 Measurements were taken first thing in the morning prior to eating, drinking, or exercise and  
153 protocols implemented to maximise reliability of positioning (27).

#### 154 ***Training and Match loads***

155 Internal loads for each training day and the game day were assessed by the session rating of  
156 perceived exertion (sRPE) using a modified Borg scale (28). This RPE of the training session  
157 was multiplied by the training duration to calculate a player load in arbitrary units (sRPE; AU)  
158 (28). External demands of all rugby training sessions and match play were recorded using  
159 micro-technological units worn by players containing GPS (10Hz) and accelerometer (100Hz)  
160 (Catapult Innovations, Melbourne, Australia). Data were downloaded and analysed using  
161 Catapult Sprint software (Catapult Innovations, Melbourne, Australia). The total distance  
162 covered, number of high-speed efforts (>60% positional average) and the number of very high-  
163 speed efforts (>80% individual average) were recorded (29, 30). The GPS sampling frequency  
164 of 10Hz is the most reliable in team sports measuring high speed running activities (31).

165 Contacts were analysed in match play by a professional rugby union analyst with over five  
166 years' experience working in English domestic and European rugby using NacSport (Analysis  
167 Pro, UK). The potential collisions were then further reviewed by an expert ex-professional  
168 player with 15 years and over 250 matches played in English domestic, European and

169 International Rugby Union. The games were reviewed to ensure contacts recorded involved an  
170 actual collision. For example, a scrum may be analysed as a single contact but there may have  
171 been more than one engagement process involving a full collision before the match restarted.  
172 Some players may also be analysed as having been involved at a breakdown to keep possession,  
173 but they may not necessarily have endured a collision as part of this. The nature of these were  
174 then also accounted for as either set piece based (scrum or maul), or general phase play  
175 (breakdown and tackle area).

### 176 *Data analysis*

177 All data are presented as mean ( $\pm$  SD). All statistical analyses were completed using SPSS  
178 (Version 24 for Windows, SPSS Inc., Chicago, IL). A one-way repeated measures ANOVA  
179 was used to compare all gas exchange measures and the work completed by players throughout  
180 training days and during the competitive game day. The tests of within subjects' effects  
181 provided values for Mauchly's test for sphericity. If this was violated, then a Greenhouse-  
182 Geisser correction was used. The difference between means were tested at a significance level  
183 of  $p < 0.05$ . The least significant difference (LSD) was used post hoc to compare specific time  
184 points when the ANOVA revealed a significant difference between measures over the week.  
185 This was examined in the whole group ( $n=17$ ), sub-groups forwards ( $n=11$ ) and backs ( $n=6$ ).  
186 A Spearman's correlation was run to assess any associations between changes in RMR  
187 throughout the microcycle, with the metrics of physical load and collision data gathered from  
188 the competitive match play ( $n=17$ ). A Spearman's rank-order correlation coefficient value ( $r_s$ )  
189 was generated and this was tested at  $p < 0.05$  to test the significance of any relationships found  
190 (32).

191

192

\*\*TABLE 1 ABOUT HERE\*\*

193 **Results**

194 *Training and match demands*

195 The training schedule and structure of sessions can be seen in Table 1 with the internal and  
196 external demands of the week in Table 2. It should be noted that data are presented as n=14 for  
197 these analyses due to faults with GPS data collection, resulting in lost running metrics for some  
198 training sessions in three of the participants.

199

\*\*TABLE 2 ABOUT HERE\*\*

200 *Player Load*

201 There was no significant difference in player load on GD+3 compared with GD. This was also  
202 true for the sub-groups of forwards and backs. The player load on all other days of the training  
203 week were significantly lower than the game day in the whole group and when subdivided into  
204 forwards, and backs.

205 *High Speed Running Distance*

206 In the whole group, there was no significant difference in high speed running distance covered  
207 on GD+3 compared with GD. In the forwards sub-group, there was only significantly less HSR  
208 distance covered on GD-1(p=0.001) and GD+2(p=0.013) compared with GD. In the backs sub-  
209 group, there was significantly less HSR distance covered on GD-2 (p=0.005), GD-1  
210 (p<0.0005), GD+2 (p<0.0005), and GD+3(p=0.019) compared with GD.

211 *Number of High Speed Running Efforts*

212 In the whole group, there were significantly fewer HSR efforts on GD-2 (p=0.002), GD-1  
213 (p<0.0005), GD+2 (p<0.0005), and GD+3 (0.031) compared with GD. In the forwards sub-  
214 group, significantly fewer HSR efforts were completed on GD-1 (p=0.001) and GD+2

215 (p=0.014) compared with GD. In the backs sub-group, significantly fewer HSR efforts were  
216 completed on GD-2 (p=0.003), GD-1 (p=<0.0005), GD+2 (p=0.001), and GD+3 (p=0.001)  
217 compared with GD.

### 218 *Very High Speed Running Distance*

219 In the whole group, VHSR distance was only significantly lower on GD-1 (p=0.002) and GD+2  
220 (p=0.002) compared with GD. Within the forwards sub-group, there was no significant  
221 difference in VHSR distances covered on any day compared with GD. The backs covered  
222 significantly fewer VHSR metres on GD-1 (p=0.005) and GD+2 (p=0.006).

### 223 *Very High Speed Running Efforts*

224 In the whole group, the number of VHSR efforts completed was only significantly lower on  
225 GD-1 (p=0.003), and GD+2 (p=0.013) compared with GD. In the forwards sub-group, there  
226 was no significant difference in VHSR efforts on all training days compared with GD. In the  
227 backs sub-group, there were only significantly less VHSR efforts on GD-1 (p=0.001), and  
228 GD+2 (p=0.013) compared with GD.

229 \*\*FIGURE 1. a-f ABOUT HERE\*\*

230 \*\*TABLE 3 ABOUT HERE\*\*

### 231 *Changes in resting metabolic rate*

232 Changes in RMR adjusted for lean body mass across the microcycle can be seen in Figure 1a  
233 whilst the absolute ( $\text{kcal}\cdot\text{day}^{-1}$ ) and relative ( $\text{kcal}\cdot\text{kg}\cdot\text{day}^{-1}$ ) RMR measures are displayed in  
234 Table 3. Lean body mass (measured by DXA) was  $74.8\pm 7.4\text{kg}$  for the whole group,  $78.2\pm 5.6\text{kg}$   
235 for the forwards, and  $68.6\pm 6.0\text{kg}$  for the backs. In the whole group, there was a significant  
236 increase in RMR from GD-1 to GD+1 (p=0.005) and GD-1 to GD+3 (p=0.04). In the forwards  
237 sub-group, there was a significant increase in RMR between GD-1 to GD+1 (p=0.017) and

238 GD-1 to GD+3 ( $p=0.045$ ). However, in the backs sub-group, there was no significant difference  
239 in RMR at any time point across the week.

#### 240 ***Changes in respiratory exchange ratio***

241 Changes in RER across the microcycle can be seen in Figure 1b. In the whole group, there were  
242 significant increases at GD+2 ( $p=0.030$ ) and GD+3 ( $p=0.006$ ) compared with GD-1. In the  
243 positional subgroups there were no significant differences across the microcycle  $p=0.065$  and  
244  $p=0.177$  for forwards and backs respectively.

#### 245 ***Changes in $VO_2$ and $VCO_2$***

246 Figures 1c and 1d show the measures of  $VO_2$  and  $VCO_2$ . There were significant increases in  
247  $VO_2$  in the whole group at GD+1 ( $p=0.008$ ) and GD+3 ( $p=0.041$ ) compared with GD-1. These  
248 significant increases were also observed in the forwards at GD+1 ( $p=0.025$ ) and GD+3  
249 ( $p=0.027$ ) compared with GD-1. There were no significant differences for  $VO_2$  in the backs  
250 subgroup across the week. There were significant increases in  $VCO_2$  in the whole group at  
251 GD+1 ( $p=0.008$ ), GD+2 ( $p=0.01$ ), and GD+3 ( $p=0.001$ ) compared to GD-1. These significant  
252 increases were also observed in the forwards at GD+1 ( $p=0.037$ ) and GD+3 ( $p<0.001$ )  
253 compared to GD-1. There were no significant differences across the week in measures of  $VCO_2$   
254 in the backs.

#### 255 ***Changes in carbohydrate and fat oxidation***

256 Measures of carbohydrate and fat oxidation are displayed in Figures 1e and 1f. Carbohydrate  
257 oxidation significantly increased at GD+2 ( $p=0.044$ ) and GD+3 ( $p=0.003$ ) compared with GD-  
258 1 in the whole group. In the forwards a significant increase was measured at GD+3 ( $p=0.003$ )  
259 compared with GD-1, whilst there were no significant differences across the microcycle in the  
260 backs for carbohydrate oxidation. Fat oxidation decreased significantly at GD+3 ( $p=0.029$ ) in  
261 the whole group and at the same time point in the forwards ( $p=0.028$ ) compared with GD-1.

262 There were no significant differences measured for fat oxidation across the microcycle in the  
263 backs.

264 \*\*TABLE 4 ABOUT HERE\*\*

265 *Associations of match demands with changes in metabolic measurements*

266 Table 3 displays the Spearman's coefficient associations between the physical match demands,  
267 and changes in RMR. In the whole group, there were no significant associations found between  
268 phase contacts, total contacts, player load, HSR meters, HSR efforts, VHSR meters, VHSR  
269 efforts and the change in RMR observed between GD-1 to GD+1. This was also true when the  
270 positional sub-groups of forwards and backs were analysed.

271 **Discussion**

272 The aim of the present study was to assess changes in RMR in an elite group of professional  
273 RU players measured throughout a competitive week and explore the impact of game day  
274 factors on changes in RMR. To this end, we monitored RMR using indirect calorimetry  
275 alongside game day and training demands in 22 Premiership RU players throughout a game  
276 week. We report, for the first-time, that RMR increased significantly following elite rugby  
277 union match play, a change that was not observed following intense training with the same  
278 training loads. These data therefore illustrate that changes in RMR following match days exist,  
279 reflecting a yet unreported increased energy demand in the days after a game of elite rugby and  
280 allows the development of individualised nutritional strategies to help facilitate recovery.  
281 Furthermore, increased RMR may also represent the physical collisions of match play and  
282 indeed could suggest that RMR may be used as a non-invasive marker of muscle damage.

283 We have reported a mean increase in RMR following match play of ~231kcal per day at GD+1,  
284 a 10% increase from GD-1. We are confident this represents a truly significant increase given  
285 that it is greater than the suggested 6% required as meaningful change using the canopy method  
286 (25). The rigour in our protocol also resulted in a lower coefficient of variance than reported  
287 previously (25). Importantly, these increases in RMR were due to significant increases in VO<sub>2</sub>  
288 and VCO<sub>2</sub> and are not merely EPOC being measured as increased VO<sub>2</sub>. The range of increased  
289 RMR was large, with individual responses between 240-1000kcal. The greatest increases in  
290 RMR were seen in the forwards, who underwent more physical collisions during a game at the  
291 scrum, maul and tackle area vs. backs (4). The whole group, and forwards positional group,  
292 also experienced increased RMR which remained elevated 3 days post-game. This sustained  
293 increase at GD+3 may be a result of the lower limb resistance training session on GD+2 given  
294 that resistance training, especially with an eccentric component, has been shown to increase  
295 RMR (33). It is possible that this sustained increase in RMR, as a result of the resistance

296 training session, negatively affected the recovery from match play, therefore extending the  
297 period during which RMR remained elevated, although this suggestion remains speculative  
298 and requires further investigation.

299 Along with changes in RMR in the days after the game we also report significant changes in  
300 RER. The increased RER at GD+2 and GD+3 corresponds with significant increases in resting  
301 carbohydrate oxidation coupled with a significant reduction in fat oxidation at GD+3. These  
302 significant changes in carbohydrate oxidation are occurring at a time where markers of muscle  
303 damage and soreness typically peak following match play (8, 9, 11). Muscle damage induced  
304 reductions in glucose transport may result in a decreased whole-body glucose tolerance which  
305 has been reported after a laboratory based muscle damage protocol (34). It should also be  
306 recognised that the inflammatory cytokine activity associated with muscle damaging exercise,  
307 together with the presence of various cell types such as neutrophils and macrophages (35), may  
308 alter substrate oxidation in the recovery period (36). Taken together, we have demonstrated  
309 increased RMR and altered carbohydrate oxidation, following match play, which suggests that  
310 post-exercise nutrition should be specifically tailored to the unique metabolic demands of this  
311 time period. Moreover, we have shown highly individual responses with some players  
312 increasing their RMR by 1000kcal. It is crucial to identify such players and tailor their dietary  
313 plans and recovery strategies accordingly.

314 Given that the participants in the present study were full-time professional players, in the  
315 middle of a competitive playing season, it was not possible to either control or record dietary  
316 intake. It is possible that some of the differences in RMR and RER seen between the forwards  
317 and backs could have been a result of differing diets of the 2 sub-groups. However, whilst there  
318 is evidence that the thermic effect of food and the total energy content of a meal may alter  
319 resting metabolic rate measures (15) we do not believe that the player to player variations in  
320 diet would have any meaningful effects on RMR or RER in the present study. Previous research



321 has reported that a large meal containing 1300kcal had negligible effects upon measuring RMR  
322 and RER when measured 7 hours later, and in lean male subjects both measures had returned  
323 to baseline at 8 hours following this meal (37). Given that both the forwards and backs in the  
324 present study had undergone a minimum of an 8 hour fast prior to having their RMR and RER  
325 assessed, it is unlikely that differences in diet would be a primary contributor to the observed  
326 changes. Moreover, we believe that this group of players consumed a more than adequate  
327 energy availability as indicated by no major changes in body mass over the testing periods.  
328 This group are unlikely to be in low energy availability, however, future studies should attempt  
329 to measure or control dietary intake to fully explore this hypothesis.

330 We propose that the muscle damage as a result of elite rugby union match play could be a key  
331 factor in accounting for the changes in metabolism we have witnessed. By carefully monitoring  
332 the internal and external demands of the competitive week we have shown that when contact  
333 sport athletes are exposed to comparable player load (including HSR and VHSR metrics) to  
334 that of a match day but without the physical collisions, there is no change in RMR in the  
335 following days. We therefore speculate that the collisions encountered on a game day could be  
336 responsible for the significant changes in RMR reported at GD+1. This may account for the  
337 increases in TEE previously observed in youth players when a training session contained  
338 collisions similar to that of match play (14).

339 When we investigated the positional groups of forwards and backs there were differences in  
340 how they reacted to match play. The backs sub-group did not show any significant changes in  
341 RMR or RER post-match, albeit they did show a similar pattern across the week as seen in the  
342 forwards sub-group. The backs did not experience as many contact incidents as the forwards  
343 as has previously been shown (4), and they were not involved in the static exertions of the  
344 scrum and maul which are potentially damaging. These positional differences may further

345 substantiate our hypothesis that the contact-based activities are responsible for the metabolic  
346 changes reported here.

347 The total number of contacts were rigorously evaluated; however, the Spearman's correlations  
348 did not show any significant correlations of changes in RMR with the match demands or  
349 collisions experienced. There was one back who exhibited a large increase of  $\approx 796$  kcal in  
350 RMR. Although the actual number of contacts performed by this player were not significantly  
351 different to the mean of the backs group, subjective analysis of these collisions (by experienced  
352 rugby staff) classified the magnitude and intensity of these as being much greater than typical.  
353 Examples like this, coupled with the current inability to accurately quantify collision activities,  
354 emphasises the need for a practical measure of the impact contact sports have upon these  
355 athletes to be developed.

### 356 *Practical implications.*

357 From an applied perspective the periodisation of nutrition throughout microcycles to optimise  
358 adaptation and ultimately performance is well established under the 'Fuel for the work  
359 required' paradigm (38). The novel data presented here could enhance the application of this  
360 in team sports, especially those involving muscle damage due to collision-based activities.  
361 Even using a modest physical activity level (PAL) of 1.3-1.4 for a GD+1 rest day, would  
362 translate these findings into a required increase in energy intake of  $>300$  kcal. This, on a day  
363 where the continued restoration of muscle glycogen is a primary concern, in a population  
364 who habitually appear to consume lower than the recommended carbohydrate intakes, may  
365 require a conscious intervention (22). Carbohydrate intake as part of an in-season week in  
366 elite rugby union players appears to be 3g/kg on GD+1 (22), therefore an extra  $\sim 70$  g  
367 carbohydrate could be an increase of  $\sim 20\%$  required on that day. We speculate the timing of  
368 carbohydrate feeding may also require further investigation though, if indeed substrate  
369 oxidation is altered until the muscle damage due to match play is resolved (34, 39).

370 Given that the true definition of resting metabolic rate involves ‘strict and steady resting  
371 conditions’ it could be argued that the present study did not actually measure RMR at any  
372 time point where in fact Morning Metabolic Rate (MMR) was actually measured. Indeed, it  
373 could be argued that rugby players (and indeed many athletes) during a competitive season  
374 are never truly at ‘rest’ bringing about methodological questions over when during a training  
375 period RMR should be measured to accurately predict energy requirements. A protocol  
376 according to best practice and adhering strictly to a minimum rest time, fasted measurement  
377 and proper outpatient protocols *as per* resting metabolic rate are crucial for reliability but this  
378 measure may need to be categorised differently (15, 23). In the applied world, the term  
379 ‘Morning Metabolic Rate’ may be a more accurate description of what is actually being  
380 measured and future studies may choose to adopt this terminology.

### 381 ***Conclusions.***

382 In conclusion, the present study has for the first time assessed the resting metabolic rate of  
383 elite rugby union players across a competitive match week using indirect calorimetry. We  
384 report a significant increase in the RMR of these contact sport athletes in the days after match  
385 play. There were also significant shifts in RER at two and three days after competition. We  
386 propose these changes could be attributed to the collisions experienced in match play rather  
387 than the internal and external loads the athletes are exposed to throughout the microcycle.  
388 The metabolites and markers of these muscle damaging actions need to be researched further  
389 to help guide athletes as how best to feed their recovery after competition. This research is  
390 the first step in working towards a novel non-invasive marker of muscle damage. Further  
391 studies need to control factors of energy availability and exercise modalities responsible for  
392 the forms of muscle damage. Protocols more readily useable in the ‘real world’ of applied  
393 performance science then need to be designed to truly shift the paradigm of athlete  
394 monitoring and optimise recovery from contact sports.

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400 **Conflict of interest.**

401 The authors reported no potential conflict of interest. The results of the current study do not  
402 constitute endorsement by ACSM. All results presented here are done so clearly, honestly, and  
403 without fabrication, falsification, or inappropriate data manipulation.

404 **Word Count 4444.**

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563 **Table 1. The training sessions throughout the competitive micro cycle. Game Day – GD.**

564 **Table 2. Comparison of metrics recorded for training and match play throughout the**  
565 **competitive micro cycle.**

566 \*Denotes values significantly different ( $p < 0.05$ ) when compared with **game day (GD)** shown  
567 in bold.

568 **Figure 1. Gas exchange measurements across the microcycle. a. RMR ( $\text{kcal}\cdot\text{kg}\cdot\text{day}^{-1}$ ). b.**  
569 **RER. c.  $\text{VO}_2$  (L/min). d.  $\text{VCO}_2$  (L/min). e. Carbohydrate (CHO) oxidation (g/min). f.**  
570 **Fat oxidation (g/min).**

571 Measurements displayed as mean  $\pm$  S.D. with individual data points for all participants.

572 Forwards –  $\blacktriangle$  (filled black triangle), Backs-  $\circ$  (empty circle).

573 \*Denotes significant difference ( $p < 0.05$ ) for the whole group when compared to GD-1.

574 +Denotes significant difference ( $p < 0.05$ ) for the forwards group when compared to GD-1.

575 **Table 3. Absolute and adjusted measurements of RMR across the competitive**  
576 **microcycle for all players (n=17).**

577 **Table 4. Spearman's coefficient ( $r_s$ ) associations derived from changes in RMR between**  
578 **GD-1 and GD+1.**

579 \*denotes significant  $p < 0.05$  association

| <b>Time Point</b>                  | <b>GD-3</b>     | <b>GD-2</b>   | <b>GD-1</b>  | <b>GD</b>   | <b>GD+1</b>     | <b>GD+2</b>  | <b>GD+3</b>  | <b>GD+4</b>     |
|------------------------------------|-----------------|---|--|---|-----------------|--|--|-----------------|
| <b>Purpose</b>                     | Rest & Recovery | Intensity   | Team Run   | Match Play  | Rest & Recovery | Installation   | Volume   | Rest & Recovery |
| <b>Resistance Training Content</b> | None            | Upper Limb Strength (30 min)  | None   | None  | None            | Lower Limb Strength (45 mins)  | Upper Limb Strength (45min)  | None            |
| <b>Rugby Content</b>               | None            | Specific Game Prep (35 mins)<br>Unit Split (15-25mins)  | Agility warm-up, Execution of specific game prep at a low-moderate intensity (35min)   | Individual & Team Warm Ups.<br>Rugby Match Play (80 mins).              | None            | Low-moderate intensity attack shapes and defensive systems.<br>Running top-ups for some players. (60 mins) | High Intensity throughout rugby specific drills.<br>Units Split- Forwards - Scrum/Maul<br>Backs - Strike plays. (75 min) | None            |
| <b>Targets</b>                     | Recovery        | Execution of tactical game specifics at a high intensity.<br>Rehearsal of set pieces in a unit split.<br>Forwards – Lineouts<br>Backs – Strike and skill execution. | Execution of specifics at a lower intensity, low intensity unit rehearsal of set pieces.<br>Forwards – Lineouts<br>Backs – Strike plays. | Full competitive rugby match play. Target physical performance and win. | Recovery        | Learning of specifics for the following fixture and recovery.  | High running volume, aiming to overload running volume relative to time.   | Recovery        |

**Table 1. The training sessions throughout the competitive micro cycle. Game Day – GD.**

| Time Point                                  |                 | GD -2           | GD -1                | GD                    | GD +1                      | GD +2           | GD +3          | GD +4                      |
|---|-----------------|-----------------|----------------------|-----------------------|----------------------------|-----------------|----------------|----------------------------|
| <b>Player Load (sRPE x Time)</b>            | Whole group     | 404.07± 103.88* | 27.00± 34.52*        | <b>622.36± 98.70</b>  | <b>Rest &amp; Recovery</b> | 238.14± 186.90* | 631.07± 110.67 | <b>Rest &amp; Recovery</b> |
|   | Forwards        | 391.25± 83.93*  | 31.25± 35.65*        | <b>595.13± 106.45</b> |                            | 243.13± 212.10* | 654.37± 100.19 |                            |
| Backs                                       | 421.17± 132.60* | 21.33± 35.39*   | <b>658.67± 81.85</b> | 231.50± 166.58*       |                            | 600.00± 125.57  |                |                            |
| <b>High Speed Running Distance (m)</b>      | Whole group     | 168.00± 60.12*  | 6.21± 10.15*         | <b>285.43± 113.09</b> |                            | 63.29± 95.43*   | 254.64± 214.15 |                            |
|   | Forwards        | 132.88± 45.89   | 9.25± 12.10*         | <b>215.88± 96.82</b>  |                            | 72.00± 102.86*  | 279.63± 268.19 |                            |
| Backs                                       | 214.83± 42.94*  | 2.17± 5.31*     | <b>378.17± 45.46</b> | 51.67± 92.63*         |                            | 221.33± 127.33* |                |                            |
| <b>High Speed Running Efforts (n)</b>       | Whole group     | 11.43± 3.34*    | 0.93± 1.69*          | <b>20.29± 7.23</b>    |                            | 4.93± 6.86*     | 14.79± 8.91*   |                            |
|   | Forwards        | 10.50± 3.55     | 1.38± 2.07*          | <b>16.63± 6.99</b>    |                            | 5.63± 7.05*     | 15.50± 10.90   |                            |
| Backs                                       | 12.67± 2.88*    | 0.33± 0.82*     | <b>25.17± 4.17</b>   | 4.00± 7.13*           |                            | 13.83± 6.18*    |                |                            |
| <b>Very High-Speed Running Distance (m)</b> | Whole group     | 17.86± 16.28    | 0.00*                | <b>16.50± 15.89</b>   |                            | 0.36± 0.93*     | 23.29± 31.10   |                            |
|   | Forwards        | 9.88± 10.64     | 0.00                 | <b>10.75± 16.46</b>   | 0.38± 1.06                 | 23.75± 38.99    |                |                            |
| Backs                                       | 28.50± 17.10    | 0.00*           | <b>24.17± 12.42</b>  | 0.33± 0.82*           | 22.67± 19.66               |                 |                |                            |
| <b>Very High-Speed Running Efforts (n)</b>  | Whole group     | 1.29± 0.91      | 0.00*                | <b>1.14± 1.17</b>     | 0.14± 0.36*                | 1.29± 1.14      |                |                            |
|   | Forwards        | 1.13± 0.99      | 0.00                 | <b>1.00± 1.51</b>     | 0.13± 0.35                 | 1.25± 1.28      |                |                            |
| Backs                                       | 1.50± 0.84      | 0.00*           | <b>1.33± 0.52</b>    | 0.17± 0.41*           | 1.33± 1.03                 |                 |                |                            |

**Table 2. Comparison of metrics recorded for training and match play throughout the competitive micro cycle.**

\*Denotes values significantly different ( $p < 0.05$ ) when compared with **game day (GD)** shown in bold.

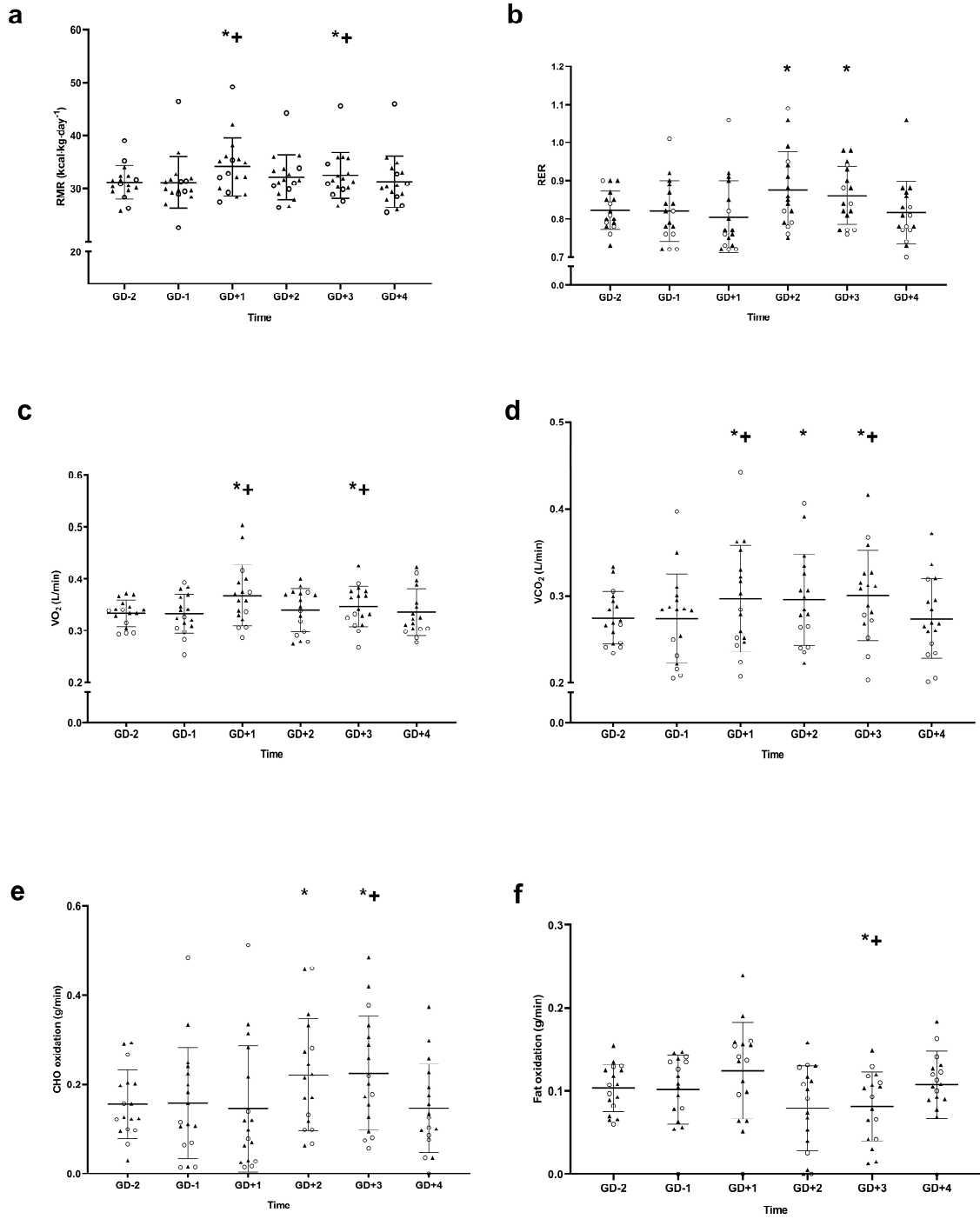
| <b>Time Point</b>                                  | <b>GD-2</b> | <b>GD-1</b> | <b>GD+1</b> | <b>GD+2</b> | <b>GD+3</b> | <b>GD+4</b> |
|--|-------------|-------------|-------------|-------------|-------------|-------------|
| <b>Absolute RMR<br/>(kcal)</b>                     | 2318± 182.1 | 2313± 283.0 | 2544± 396.9 | 2391± 274.2 | 2424± 312.0 | 2327± 305.3 |
| <b>Adjusted RMR<br/>(kcal·kg·day<sup>-1</sup>)</b> | 31.2± 3.0   | 31.1± 4.7   | 34.1± 5.3   | 32.1± 4.1   | 32.5± 4.2   | 31.3± 4.7   |

**Table 3. Absolute and adjusted measurements of RMR across the competitive microcycle for all players (n=17).**

| Timepoints for comparison         | Group       | Phase Contacts       |          | Total Contacts (Phase+set piece) |          | Player Load (sRPE <sub>ExTime</sub> ) |          | HSR (m)              |          | HSR (efforts)        |          | VHSR (m)             |          | VHSR (efforts)       |          |
|-----------------------------------|-------------|----------------------|----------|----------------------------------|----------|---------------------------------------|----------|----------------------|----------|----------------------|----------|----------------------|----------|----------------------|----------|
|                                   |             | <i>r<sub>s</sub></i> | <i>p</i> | <i>r<sub>s</sub></i>             | <i>p</i> | <i>r<sub>s</sub></i>                  | <i>p</i> | <i>r<sub>s</sub></i> | <i>p</i> | <i>r<sub>s</sub></i> | <i>p</i> | <i>r<sub>s</sub></i> | <i>p</i> | <i>r<sub>s</sub></i> | <i>p</i> |
| <b>Change in RMR GD-1 to GD+1</b> | Whole Group | 0.05                 | 0.84     | 0.23                             | 0.38     | -0.17                                 | 0.95     | -0.13                | 0.62     | -0.26                | 0.31     | -0.11                | 0.97     | 0.19                 | 0.48     |
|                                   | Forwards    | -0.10                | 0.77     | 0.16                             | 0.63     | -0.19                                 | 0.58     | -0.28                | 0.40     | -0.24                | 0.47     | 0.19                 | 0.57     | 0.32                 | 0.34     |
|                                   | Backs       | 0.09                 | 0.87     | 0.09                             | 0.87     | 0.34                                  | 0.51     | 0.37                 | 0.47     | -0.44                | 0.39     | -0.09                | 0.87     | 0.00                 | 1.00     |

**Table 4. Spearman's coefficient (*r<sub>s</sub>*) associations derived from changes in RMR between GD-1 and GD+1.**

\*denotes significant  $p < 0.05$  association.



**Figure 1. Gas exchange measurements across the microcycle. a. RMR (kcal·kg·day<sup>-1</sup>). b. RER. c. VO<sub>2</sub> (L/min). d. VCO<sub>2</sub> (L/min). e. Carbohydrate (CHO) oxidation (g/min). f. Fat oxidation (g/min).**



Measurements displayed as mean $\pm$  S.D. with individual data points for all participants.

Forwards – ▲ (filled black triangle), Backs- ○ (empty circle).

\*Denotes significant difference ( $p < 0.05$ ) for the whole group when compared to GD-1.

+Denotes significant difference ( $p < 0.05$ ) for the forwards group when compared to GD-1.

