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

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Abstract

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

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

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

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

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

Introduction.

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

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

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

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

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

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

Methods

Participants

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

Research Design

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

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

Resting Metabolic Rate

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

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

Data analysis

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

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

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

Very High Speed Running Distance

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

Very High Speed Running Efforts

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

FIGURE 1. a-f ABOUT HERE

TABLE 3 ABOUT HERE

Changes in resting metabolic rate

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

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

Changes in respiratory exchange ratio

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

Changes in VO_2 and VCO_2

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

Changes in carbohydrate and fat oxidation

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

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

TABLE 4 ABOUT HERE

Associations of match demands with changes in metabolic measurements

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

Discussion

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

We have reported a mean increase in RMR following match play of ~231kcal per day at GD+1, a 10% increase from GD-1. We are confident this represents a truly significant increase given that it is greater than the suggested 6% required as meaningful change using the canopy method (25). The rigour in our protocol also resulted in a lower coefficient of variance than reported previously (25). Importantly, these increases in RMR were due to significant increases in VO2 and VCO2 and are not merely EPOC being measured as increased VO2. The range of increased RMR was large, with individual responses between 240-1000kcal. The greatest increases in RMR were seen in the forwards, who underwent more physical collisions during a game at the scrum, maul and tackle area vs. backs (4). The whole group, and forwards positional group, also experienced increased RMR which remained elevated 3 days post-game. This sustained increase at GD+3 may be a result of the lower limb resistance training session on GD+2 given that resistance training, especially with an eccentric component, has been shown to increase 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

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

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

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

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

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

Practical implications.

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

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

Conclusions.

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

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Conflict of interest.

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

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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 (kcal·kg·day^{-1}). b.**
569 **RER. c. VO2 (L/min). d. VCO2 (L/min). e. Carbohydrate (CHO) oxidation (g/min). f.**
570 **Fat oxidation (g/min).**

571 Measurements displayed as mean± S.D. with individual data points for all participants.

572 Forwards – ▲ (filled black triangle), Backs- ○ (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

Time Point	GD-3	GD-2	GD-1	GD	GD+1	GD+2	GD+3	GD+4
Purpose	Rest & Recovery	Intensity	Team Run	Match Play	Rest & Recovery	Installation	Volume	Rest & Recovery
Resistance Training Content	None	Upper Limb Strength (30 min)	None	None	None	Lower Limb Strength (45 mins)	Upper Limb Strength (45min)	None
Rugby Content	None	Specific Game Prep (35 mins) Unit Split (15-25mins)	Agility warm-up, Execution of specific game prep at a low-moderate intensity (35min)	Individual & Team Warm Ups. Rugby Match Play (80 mins).	None	Low-moderate intensity attack shapes and defensive systems. Running top-ups for some players. (60 mins)	High Intensity throughout rugby specific drills. Units Split- Forwards - Scrum/Maul Backs - Strike plays. (75 min)	None
Targets	Recovery	Execution of tactical game specifics at a high intensity. Rehearsal of set pieces in a unit split. Forwards – Lineouts Backs – Strike and skill execution.	Execution of specifics at a lower intensity, low intensity unit rehearsal of set pieces. Forwards – Lineouts 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
Player Load (sRPE x Time)	Whole group	404.07± 103.88*	27.00± 34.52*	**622.36± 98.70**	Rest & Recovery	238.14± 186.90*	631.07± 110.67	Rest & Recovery
	Forwards	391.25± 83.93*	31.25± 35.65*	**595.13± 106.45**		243.13± 212.10*	654.37± 100.19	
	Backs	421.17± 132.60*	21.33± 35.39*	**658.67± 81.85**		231.50± 166.58*	600.00± 125.57	
High Speed Running Distance (m)	Whole group	168.00± 60.12*	6.21± 10.15*	**285.43± 113.09**		63.29± 95.43*	254.64± 214.15	
	Forwards	132.88± 45.89	9.25± 12.10*	**215.88± 96.82**		72.00± 102.86*	279.63± 268.19	
	Backs	214.83± 42.94*	2.17± 5.31*	**378.17± 45.46**		51.67±92.63*	221.33± 127.33*	
High Speed Running Efforts (n)	Whole group	11.43± 3.34*	0.93± 1.69*	**20.29± 7.23**		4.93± 6.86*	14.79± 8.91*	
	Forwards	10.50± 3.55	1.38± 2.07*	**16.63± 6.99**		5.63± 7.05*	15.50± 10.90	
	Backs	12.67± 2.88*	0.33± 0.82*	**25.17± 4.17**		4.00± 7.13*	13.83± 6.18*	
Very High-Speed Running Distance (m)	Whole group	17.86± 16.28	0.00*	**16.50± 15.89**		0.36± 0.93*	23.29± 31.10	
	Forwards	9.88± 10.64	0.00	**10.75± 16.46**		0.38± 1.06	23.75± 38.99	
	Backs	28.50± 17.10	0.00*	**24.17± 12.42**		0.33± 0.82*	22.67± 19.66	
Very High-Speed Running Efforts (n)	Whole group	1.29± 0.91	0.00*	**1.14± 1.17**		0.14± 0.36*	1.29± 1.14	
	Forwards	1.13± 0.99	0.00	**1.00± 1.51**		0.13± 0.35	1.25± 1.28	
	Backs	1.50± 0.84	0.00*	**1.33± 0.52**		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.

Time Point	GD-2	GD-1	GD+1	GD+2	GD+3	GD+4
Absolute RMR (kcal)	2318± 182.1	2313± 283.0	2544± 396.9	2391± 274.2	2424± 312.0	2327± 305.3
Adjusted RMR ($kcal \cdot kg \cdot day^{-1}$)	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 (sRPExTime)		HSR (m)		HSR (efforts)		VHSR (m)		VHSR (efforts)	
		r_s	*p*	r_s	*p*	r_s	*p*	r_s	*p*	r_s	*p*	r_s	*p*	r_s	*p*
Change in RMR GD-1 to GD+1	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_s) associations derived from changes in RMR between GD-1 and GD+1.

*denotes significant $p<0.05$ association.

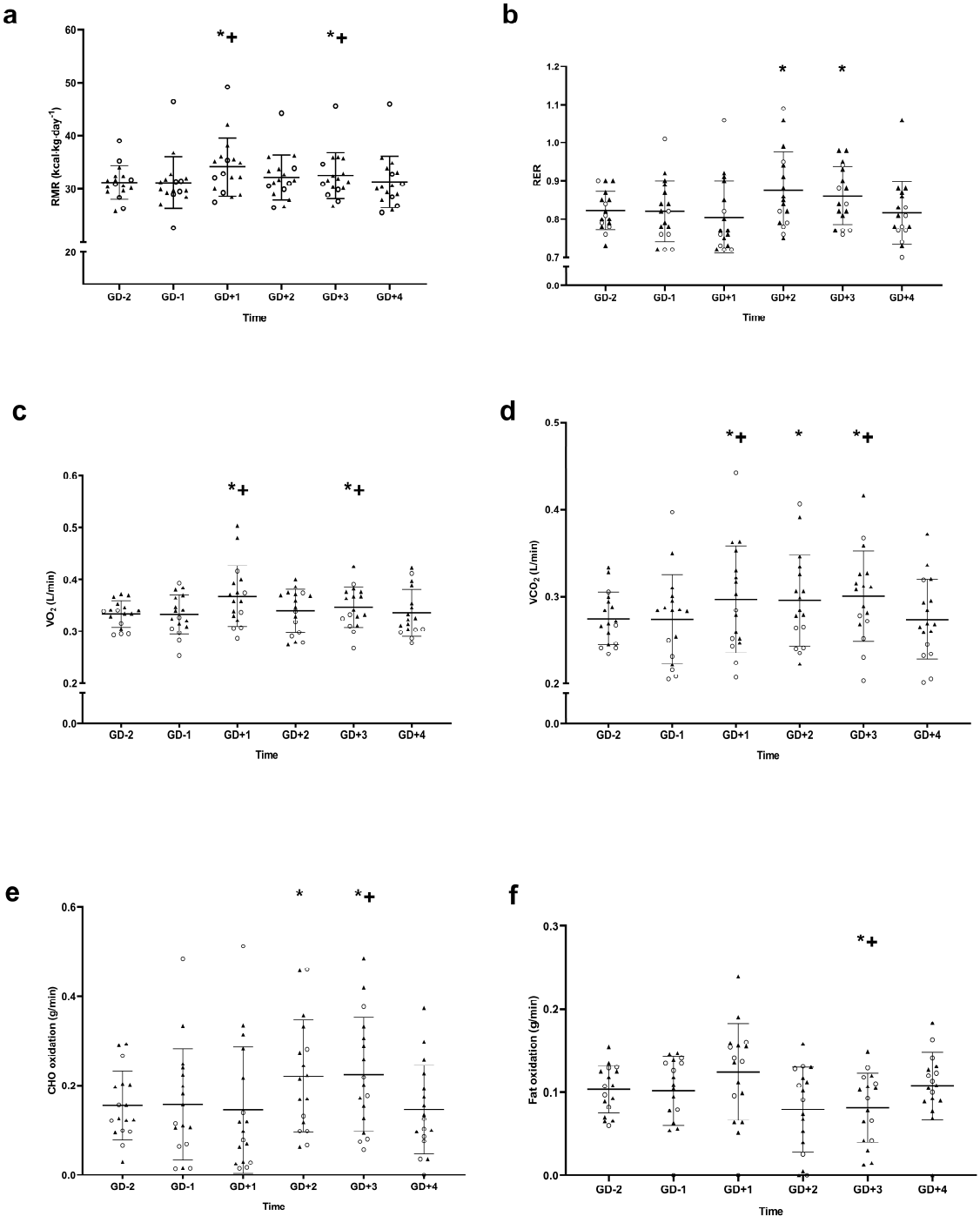

Figure 1. Gas exchange measurements across the microcycle. a. RMR (kcal·kg·day^{-1}). b. RER. c. VO2 (L/min). d. VCO2 (L/min). e. Carbohydrate (CHO) oxidation (g/min). f. Fat oxidation (g/min).

Measurements displayed as mean± S.D. with individual data points for all participants.

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