Energy Intake and Expenditure Assessed 'In-Season' in an Elite European Rugby Union Squad

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Abstract

Rugby Union is a complex, high-intensity intermittent collision sport with emphasis placed on players possessing high lean body-mass and low body-fat. After an 8-12 week pre-season focused on physiological adaptations, emphasis shifts towards competitive performance. However, there are no objective data on the physiological demands or energy intake (EI) and expenditure (EE) for elite players during this period. Accordingly, in-season training load using GPS and session RPE (sRPE), alongside six-day assessments of EE and EI were measured in 44 elite Rugby Union players. Mean weekly distance covered was 7827 ± 954 m and 9572 ± 1233 m with a total mean weekly sRPE of 1776 ± 355 and 1523 ± 434 AU for forwards and backs, respectively. Mean weekly EI was 16.6 ± 1.5 and 14.2 ± 1.2 MJ, and EE was 15.9 ± 0.5 and 14 ± 0.5 MJ. Mean carbohydrate intake was 3.5 ± 0.8 and 3.4 ± 0.7 $g.kg^{-1}$ body mass, protein intake was 2.7 ± 0.3 and 2.7 ± 0.5 $g.kg^{-1}$ body mass, and fat intake was 1.4 ± 0.2 and 1.4 ± 0.3 $g.kg^{-1}$ body mass. All players who completed the food diary self-selected a 'low' carbohydrate 'high' protein diet during the early part of the week, with carbohydrate intake increasing in the days leading up to a match, resulting in the mean EI matching EE. Based on EE and training load data, the EI and composition seems appropriate, although further research is required to evaluate if this diet is optimal for match day performance.

Keywords: Rugby, Pre-Season, GPS, Physiology, Nutrition

Introduction

Rugby Union (RU) is a high impact collision sport played over 80 minutes, which is split into two forty-minute halves. RU is characterized by frequent bouts of high intensity exercise such as sprinting, accelerations, tackling, scrummaging, rucking and mauling (Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008) and is predominantly aerobic in nature. Players are classified as either forwards or backs, with the forwards tending to be heavier and stronger compared with the backs who tend to be leaner and faster (Duthie, Pyne, & Hooper, 2003). During a typical rugby union game, players will cover 68 $m \cdot min^{-1}$ (Cahill, Lamb, Worsfold, Headey, & Murray, 2013), which is much lower than locomotive rates described for Australian football, ~123 $m \cdot min^{-1}$; (Kempton, Sullivan, Bilsborough, Cordy, & Coutts, 2015), rugby league, ~85 $m \cdot min^{-1}$ (Waldron, Twist, Highton, Worsfold, & Daniels, 2011) and soccer, ~104 $m \cdot min^{-1}$ (Varley, Gabbett, & Aughey, 2014). Activities such as rucking, mauling, scrummaging and lineouts are likely explanations for the lower locomotive rates observed between rugby union and other football codes.

A typical in-season in rugby union lasts approximately 34-36 weeks followed by 3-6 weeks of rest time depending on whether play off stages are reached. The central focus of the in-season is peak performance during competition. Strategies to prepare for, and optimally recover from competition are therefore the objectives of this period with emphasis also placed on the maintenance of body composition to values attained at the end of pre-season (Bradley et al., 2014). An understanding of players' day-to-day training and energy requirements is essential to avoid residual fatigue (Gamble, 2006), in the identification of appropriate recovery strategies, and to determine appropriate training loads to maximise performance (Fowles, 2006). While researchers have investigated the movement patterns and physiological demands of matches (Cunniffe, Proctor, Baker, & Davies, 2009; Duthie et al., 2003), there are no data currently available on the internal and external demands, or the energy intakes and expenditures of elite rugby union players during the in-season period.

The daily nutritional intake of an athlete should meet the fuel requirements of high training intensities and competition, promote optimal recovery, and provide essential micronutrients for general health and well being. Data have previously been published on the nutritional intakes of elite rugby union players during training (Bradley et al., 2014); however, these data looked specifically at the pre-season with training and nutrition tailored towards physiological adaptation. Transition from the pre-season to in-season shifts focus from physiological adaptation to competition preparation and recovery, with training programmes modified to reflect this transition and consequently nutritional intakes must also be modified to meet training and competition requirements. To the authors' knowledge, no data evaluating the nutritional intake of elite rugby union players during in-season training is available and, as such, evidence-based recommendations regarding the energy requirements to fuel a rugby player's training plan in-season are currently lacking.

For team sports such as Rugby Union, daily carbohydrate (CHO) intakes have traditionally been high. However, in recent years many rugby players have adopted a lower CHO diet during the beginning of a training week in attempts to maintain or reduce body fat (Morton, Robertson, Sutton, & MacLaren, 2010) maximize adaptations to training (Morton et al., 2009). Thereafter, intakes are increased in the day(s) leading up to a match to maximize glycogen stores. For example, Bradley et al. (2014) reported carbohydrate intakes of 3.3 ± 0.7 and 4.1 ± 0.4 $g \cdot kg^{-1}$ for forwards and backs, respectively, during a rugby union pre-season. These data are similar to those reported in professional soccer players (3.4 $g \cdot kg^{-1}$(Maughan, 1997)), but lower than intakes generally suggested for team sports engaged in moderate exercise programmes where values of 5-7 $g \cdot kg^{-1}$ have been recommended (Burke, Hawley, Wong, & Jeukendrup, 2011). To date however there are no data on typical macronutrient intakes of elite rugby players during in-season training.

To implement a valid nutritional plan it is important to understand the day-to-day energy requirements of an athlete. Due to the physicality of rugby, the measurement of energy expenditure (EE) is somewhat difficult given that many of the tools available would not be suitable either through danger to the athlete or to the equipment. Currently the doubly labelled water (DLW) stable isotope method is considered the gold standard for measuring EE (Ekelund, Yngve, Westerterp, & Sjostrom, 2002), despite not allowing day-to-day comparisons to be made. Multi-sensor, wearable body monitoring technology might therefore provide an effective means of assessing daily EE in rugby players.

Although Bradley et al., (2014) has reported the training demands and nutritional intakes of an elite rugby union pre-season, to date there are no studies showing the training demands and energy intakes and expenditures during the competitive season. Due to the importance of competitive performance, these data would be of great significance to the strength and conditioning professional to allow informed decisions to be made with regards to players' diets during this competitive period. Therefore the aim of this study was to 1) characterize the weekly external and internal training demands of a rugby union in-season using GPS technology and session RPE (sRPE); 2) evaluate the typical energy intakes and macro- and micronutrient intakes, and 3) analyse the energy expenditures of elite rugby union players during the in-season period.

Methods

Study design

Players began in-season training at the rugby club after a 12-week pre-season period. The first week of in-season training started in early October and this was classed as Week 13. Players then began 3 x 12-week in-season training macrocycles as prescribed by the club. During the 'in season', running activity was monitored at every training session using GPS technology and session RPE (sRPE) was used to quantify the overall training load. Body composition assessment and food diaries were completed as part of the club's normal in-season training regime and were routinely performed by all of the players who were therefore familiar with each test. During weeks 32 (n = 5), 33 (n = 5) and 34 (n = 4) of the season 14 players wore Senseware armbands and completed a detailed seven-day food diary to assess energy expenditure and nutrient intake. A typical in-season training week is depicted in Table 1.

Participants

Forty-four elite rugby union players currently playing in the European Rabo Direct Pro 12 league volunteered for this study. Based on playing position, these were divided in sub-groups of forwards (n= 24) and backs (n = 20). The sample population was collected on the first team squad that included 12 current international players and four British & Irish Lions. Of the 44 players that completed the ‘in-season’ season, all completed sRPE and anthropometric assessments every 8-weeks. All 44 players also trained wearing the GPS units at some stage during the competitive season although only 17 players wore units during any one training session due to the availability of equipment. Only 14 players (seven forwards and seven backs) from the squad of 44 players completed the energy expenditure and dietary analysis due to time constraints on the players and limited equipment. A summary of the participant characteristics can be seen in Table 2. The local ethics committee of Liverpool John Moores University granted ethical approval for the study. All participants provided written informed consent before commencement of the study and all participants were greater than 18 years of age (age range 21-34 years old).

Procedures

Quantification of weekly external and internal training load

Distances covered by forwards and backs during field sessions over four ‘typical’ in-season weeks were assessed using GPS technology. Seventeen GPS units were rotated around the team ensuring that all positions were accounted for during each training session. Movements were recorded using a Minimax S4 GPS unit (Catapult Innovations, Melbourne, Australia) sampling at a frequency of 10 Hz. A recent review has demonstrated that 10 Hz units provide more accurate and reliable data compared with lower sampling frequency devices (Cummins, Orr, O'Connor, & West, 2013). Indeed, the 10 Hz units used in this study are two to three times more accurate at detecting changes in velocity, and up to six-fold more reliable than devices sampling at 5 Hz (Varley, Fairweather, & Aughey, 2012). The CV of these units across a range of speeds have been reported as 3.1 to 8.3% at a constant velocity, 3.6 to 5.9% for accelerations and 3.6 to 11.3% for decelerations (Varley et al., 2012). GPS units were used to collect data on total distance (m) and relative distance covered in standing (0-2.0 $m \cdot s^{-1}$), walking (2.0-4.4 $m \cdot s^{-1}$), jogging (4.4- 5.6 $m \cdot s^{-1}$), high-speed running (5.6-7.5 $m \cdot s^{-1}$) and sprinting (7.5 + $m \cdot s^{-1}$) based on the clubs in-house classification of speed zones. Tri-axial accelerometers and gyroscopes sampling at 100 Hz, also provided data on the number of maximal accelerations (>5 $m \cdot s^{-2}$), physical collisions, and repeated high-intensity efforts (RHIE). A RHIE was defined as three consecutive efforts (sprint, contact or acceleration) each separated by less than 21 s (Gabbett, Wiig,

& Spencer, 2013). The unit was worn in a fitted neoprene vest, on the upper back of the players. Quantification of gym and pitch session training loads was also assessed using the session rating of perceived exertion (sRPE), (Foster et al., 2001). Using a modified 10-point Borg Scale (Borg, Hassmen, & Lagerstrom, 1987) individual RPEs were provided by each player ~20 minutes after a training session from which sRPE (AU) was calculated by multiplying RPE by total training time or total number of repetitions x RPE for field or gym sessions, respectively.

Energy intake (EI)

A six-day food diary was used to analyze the macronutrient and micronutrient and reported as days away from a match (Game day -5, -4, -3, -2, -1 and game day +1) in megajoules (MJ). This time period is believed to provide reasonably accurate and precise estimations of habitual energy and macronutrient consumption (Braakhuis, Meredith, Cox, Hopkins, & Burke, 2003). Players were instructed to document a complete account of all foods and fluids ingested over a six-day period, with careful attention to detail such as timing of intakes, volumes and quantities, and specific brand names where possible. The nutrient intakes were calculated using Nutritics professional diet analysis software (Nutritics LTD, Ireland) to obtain energy and macro- and micronutrient composition. Each athlete's individual physical activity was known from the weekly training schedule.

Energy expenditure (EE)

SenseWear Pro2 wearable armband (SWA; BodyMedia, USA) was used to assess the energy expenditure of the players. Five armbands were rotated between the athletes over a three-week period during the same macrocycle. Athletes wore the armband 24-hours a day for six consecutive days, except during water or heavy contact based activities. The SWA were removed on match day to avoid disruption during match preparations and also due to contacts sustained during competition. Studies have demonstrated that the SWA provides accurate results for energy expenditure during low-to-moderate intensity physical exercise with a threshold for accurate measurements at intensities of around ten METs (Drenowatz & Eisenmann, 2011). However, given that the compendium of physical activities indicates an intensity of 8.3 METs for rugby union competition (Ainsworth et al., 2011), the use of SWA for rugby union appears appropriate. The armband was worn on the back of the upper right arm and utilized a two-axis accelerometer, heat flux sensor, galvanic skin response sensor, skin temperature sensor, and a near-body ambient temperature sensor to capture data leading to the calculation of energy expenditure. SenseWear computer software (BodyMedia, USA) was used to analyze player energy expenditure and reported as days away from competition (Game day -5, -4, -3, -2, -1 and game day +1) in MJ. 07:00 was chosen as the 24-hour start point determined by average player wake-up time according to the clubs daily monitoring.

Statistical analysis

Statistical tests were performed using the Statistical Package for the Social Sciences (SPSS, Version 18). All data were initially checked for normality. Differences between positional groups in mean weekly external (GPS) and internal (sRPE) training load measures were assessed using separate independent *t*-tests. Differences between EE and EI for forwards and backs were analyzed using a two-way mixed design analysis of variance (ANOVA). Differences between macronutrient intakes across time were analyzed using a one-way repeated measures ANOVA. If Mauchley's test of sphericity indicated a minimum level of violation, as assessed by a Greenhouse Geisser epsilon (ε) of ≥ 0.75, data were corrected using the Huynh-Feldt ε. If Mauchley's test of sphericity was violated (Greenhouse Geisser ε of ≤ 0.75) data was corrected using the Greenhouse Geisser ε (Field, 2007). If any significant F values were observed least significant difference (LSD) tests were performed *post hoc* to determine where any significant differences occurred. An alpha value of $P \leq 0.05$ was utilized for all tests. All data are expressed as mean (SD).

Results

Weekly external and internal training load

The backs had significantly higher mean weekly total distances (*P*<0.0005) than forwards, comprising more standing (*P*=0.002), walking (*P*=0.002), jogging (*P*<0.0005) high-speed running (*P*<0.0005) and sprinting (*P*=0.004). The backs performed more accelerations (*P*=0.0005) but less contacts (*P*<0.0005) than forwards during a training week. However, there was no difference in the weekly number of RHIE during training between the forwards and backs (*P*=0.15). The total weekly sRPE was not different between positions (P=0.13), with values of 1776 (355) AU and 1523 (434) AU for forwards and backs, respectively. All external and internal training load data are presented in Table 3.

Energy intake and expenditure

Energy intake (EI) and expenditure (EE) over the six assessment days, presented in megajoules (MJ), are shown in Figure 1. Mean EI and EE was 16.6 (1.25) MJ and 15.9 (0.53) MJ, and 14.2 (1.2) MJ and 14 (0.47) MJ for forwards and backs, respectively. There was a significant time x condition interaction for EI and EE intake over the course of the training week (*P*<0.0005). *Post hoc* analysis confirmed that there was a significant change in EI (*P*<0.0005) and EE (*P*<0.0005) intake over the week. EI was significantly lower than EE on GD-5 (*P*=0.022) and GD-4 (*P*=0.002), and significantly higher on GD-1 (*P*=0.002) and GD+1 (*P*=0.014) for the forwards. EI was significantly lower than EE on GD-5 (*P*= 0.01), GD-4 (*P*<0.0005) and GD-3 (*P*=0.042), and significantly higher on GD-1 (*P*<0.0005) and GD+1 (*P*<0.0005) for the backs. EE (*P*=0.024) and EI (*P*=0.046) were significantly different from GD-5 for forwards. EE (*P*=0.033) and EI (*P*=0.045) were significantly different from GD-5 for the backs on GD-2 and GD-1 respectively. The forwards elicited significantly higher weekly EI (*P*=0.0006) and EE (*P*=0.002) than the backs.

Macronutrient profile

Macronutrient intakes from six-day food diaries (presented in $g{\cdot}kg^{-1}$ body mass) can be seen in Figure 2. There was no difference (*P*=0.53) in mean weekly CHO intake between the forwards and backs, with values of 3.5 (0.8) $g{\cdot}kg^{-1}$ (38% total calories) and 3.4 (0.7) $g{\cdot}kg^{-1}$ (37% total calories), respectively. Similarly, mean weekly protein intake between the forwards was 2.7 (0.5) $g{\cdot}kg^{-1}$ (30% total calories) compared to backs 2.7 (0.3) g·kg^{-1} (30% of total calories) and was not different (*P*=0.97). Mean fat intake was also similar between positions (*P*=0.8), with values of 1.4 (0.2) and 1.4 (0.3) g·kg^{-1} (32 and 33% of total calories) for forwards and backs, respectively.

For forwards CHO intake changed during the week (*P*=0.004), with *post hoc* analysis confirming a higher CHO intake on GD-4 (*P*=0.036) and GD-1 (P=0.008) compared with GD-5 (the first day of the week). This coincided with changes in protein intake during the same period (*P*=0.008), which comprised an increase in protein intake on GD-1 (*P*<0.0005) and GD+1 (*P*=0.049) compared with GD-5. Fat intake for forwards did not change during the week (*P*=0.093). CHO intake also changed during the week for backs (*P*=0.003), with a higher CHO intake on GD-2 (*P*=0.003) and GD-1 (*P*=0.014) compared with GD-5. Similarly, there was a significant difference in protein intake across the week (*P*<0.0005), with *post hoc* analysis confirming an increase in protein intake on GD-4 (*P*=0.045) and GD-2 (*P*=0.026), GD-1 (P<0.0005) and GD+1 (*P*=0.004) compared with GD-5. Fat intake did change during the week (*P*=0.003), whereby values increased on GD-1 (P=0.0005) and GD+1 (P=0.014) compared with GD-5.

Micronutrient profile

Daily average micronutrient intakes for the squad taken from six-day food diaries can be seen in Table 3. Mean micronutrient intakes met and exceeded RDA’s for physical activity for all minerals and vitamins apart from vitamin K which fell 24µg under this RDA but met and exceeded the RDA for general health.

Discussion

The aims of the present study were 1) to quantify the external and internal training loads during a typical in-season training week for elite rugby union players and 2), evaluate the EI and EE of elite rugby players during the competitive season. It is reported for the first time that distances of ~8-10 km are covered by elite rugby union forwards and backs during a typical in-season week, which equates to a total weekly internal load of ~1500 - 1800 AU. We also report that the daily EE and EI of elite rugby union players during this same training period are 14-16 and 14-17 MJ, respectively. Our data also demonstrate considerable variation in the day-to-day energy EE with peak EE occurring early in the week and tapering down in preparation for competition. Interestingly, although EI also varied on a day-to-day basis, the temporal pattern did not match EE with EI being the lowest when EI was the highest and EI increasing in preparation for game-day. This inverse pattern may be essential to allow players to load with carbohydrate in preparation for game day without excessive total energy intake during the week which over the course of the season may lead to unwanted gains in body fat.

GPS analysis of the training sessions revealed that weekly total distances of 7.8 ± 1 km and 9.6 ± 1.2 km were covered by forwards and backs, respectively. These distances were achieved over a five-day period as players were given rest days before and after game day. Backs covered more distance in all speed zones, along with a greater number of maximal accelerations but less collisions than forwards. These differences probably reflect the contrasting training regimes between rugby union forwards and backs. For example, forwards engage in more activities that involve tackling, rucking, mauling and line-outs, while the backs perform more acceleration and ball-in-hand running play. Interestingly, the frequency of RHIE was similar for positional groups despite clear differences in the movement characteristics of forwards and backs. This is probably explained by how the GPS software detects RHIE, which is defined as three consecutive efforts (sprint, contact or acceleration) each separated by <21 s (Gabbett et al., 2013). So, while both positional groups perform a similar number of high intensity bouts, the movement actions that determine the RHIE are likely to be different between forwards and backs.

Weekly sRPE of ~1778 and ~1522 AU were observed for forwards and backs. These values are lower than those seen in an elite rugby union players during pre-season (~2900-3400 AU; (Bradley et al., 2014) and reflects the periodization of a rugby training programme. Indeed, lower training loads during the competitive season are deliberately administered to allow optimal recovery and for players to peak around games, whereas higher training loads are used in the pre-season when physiological adaptation is key and competition not a priority. Despite experiencing a higher external load during a training week, forwards did exhibit a higher internal load (sRPE) than backs. While sRPE is an appropriate measure of training load in rugby players (Lovell, Sirotic, Impellizzeri & Coutts, 2013), variances in perceptual responses will be influenced by several internal and external factors. Here, differences in perceived weekly load between positions is probably explained by higher number of collisions experienced in training by forwards. Indeed, collisions have been purported to contribute significantly to the variance in sRPE between players during rugby training (Lovell et al., 2013). Our findings reaffirm the complexity of factors influencing perceptual measures of training load and the necessity to adopt both internal and external measures to monitor training in rugby.

Energy expenditure changed during the training week for both forwards and backs, with higher EE elicited during the first four days of the training week and significantly reducing around competition (Figure 1). The six-day food diary also revealed changes in EI during the training week for both forwards and backs, following an inverse trend to EE (Figure 1). Fluctuations in EI represent lower intakes during the first 4-days of the training week concurrent with higher EE. This is likely attributed to rugby players attempting to reduce or maintain body fat before significantly increasing EI by increasing carbohydrate intake leading up to competition in an attempt to increase muscle glycogen stores. It is possible that players might have intentionally (Bingham, 1987; Deakin, 2000) underreported their total energy intake. However, since approximately half of the daily nutrition consumed was observed by the authors, including a meal provided on arrival at the club, whey protein before and after training, and a lunch provided post-training, this seems unlikely.

Although our data indicate lower training loads and total distances compared to those of rugby union players in pre-season (Bradley et al., 2014), mean EI was slightly higher in-season for both forwards (15.8 cf.

14.8 MJ) and backs (14.1 cf. 13.3 MJ). We attribute this to players increasing total EI in the days leading up to competition. It must be stressed, however, that the pre-season study used a 24-hour dietary recall, which might compromise the comparison between the two studies. Interestingly, while EE and EI differ on a day-to-day basis, mean EE and EI were surprisingly similar for forwards (16.6 and 15.8 MJ) and backs (14.2 and 14.1 MJ). This suggests that although athletes might fail to meet energy requirements on some training days, light training days or rest days before a game correspond with players increasing EI (mainly through CHO increases) to maximise muscle glycogen stores. The lower EI early in the week may be necessary to prevent a positive energy balance that over the course of a season could result in unwanted gain in body-fat.

Interestingly, all the players in the present study self-selected what could be classed as a low CHO / high protein diet for the first four days of the training week, and increased CHO intake the day before game day. This practice contravenes earlier recommendations for CHO intakes of 8-12 $g \cdot kg^{-1}$ (Burke, Kiens, & Ivy, 2004), as well as more recent guidelines that state values of 6-10 $g.kg^{-1}$ (Burke et al., 2011) for athletes engaged in moderate to high intensity exercise lasting 1-3 hours. Therefore it could still be argued that players in the current study failed to meet the daily recommended CHO requirements. However, current guidelines also clearly state that CHO intakes should be designed to meet the fuel requirements of the training programme (Burke et al., 2011). We therefore propose that players are attempting to match carbohydrate intakes with training demands such that CHO intakes of 4-6 $g \cdot kg^{-1}$ body mass are not '*low*' and are in fact '*appropriate'* for this group of athletes providing CHO intake is increased in the day before and after a game. Given that CHO intake altered significantly over the week and was the main macronutrient contributor in the daily EI fluctuations, we suggest that the players are indeed following the recent guidelines and matching their CHO intakes to the fuel requirements of the training programme. Players could be using some periods of lower CHO intake to enhance training adaptions (Morton et al., 2009) and for the maintenance of low body fat (Morton et al., 2010), yet still increasing glycogen stores in preparation for competition (Hawley, Schabort, Noakes, & Dennis, 1997). Interestingly, backs utilized a two-day load compared with a single day by the forwards. This might reflect 1) a lower CHO intake in the first three days to reduce body fat or 2) a purposeful attempt to increase glycogen more aggressively than the forwards due to the varying physiological challenges of the positions.

This cycling of CHO intake reported in the present study might be a suitable way of maintaining weekly energy balance yet still allowing sufficient CHO intake as to increase muscle glycogen and thus enhance match day performance. Playing performance is however unquestionably improved with a high CHO diet leading up to team sport based games (Hawley et al., 1997; Jardine, Wiggins, Myburgh, & Noakes, 1988), and although we have reported a significant increase in CHO intake in the days leading up to competition, the intakes reported in this study are still below recommended CHO intake for elite athletes (Burke et al., 2011). It is still possible that such intakes are not optimal for match day performance and future studies should now attempt to measure pre and post game muscle glycogen demands in elite rugby.

Protein intakes of 2.7 $g \cdot kg^{-1}$ reported in the present study was similar to values reported in an elite rugby union pre-season (2.5 and 2.6 g $g \cdot kg^{-1}$; (Bradley et al., 2014). These intakes are much higher than the 1.4 $g \cdot kg^{-1}$ reported in soccer (Maughan, 1997) and 1.8 $g \cdot kg^{-1}$ described for strength based athletes (Tipton & Wolfe, 2004). However, to maintain muscle mass whilst decreasing body fat, protein intakes of 2.5 $g \cdot kg^{-1}$ have been recommended (Mettler, Mitchell, & Tipton, 2010) suggesting that the protein intakes in this study might in fact have been appropriate. Moreover, the athletes in the present study would have deliberately timed protein intakes around training in an attempt to maximise muscle protein synthesis, which might explain in these higher protein intakes. The backs significantly increased protein intake from four days before the match. However, this higher protein intake early in the week could simply be the lower CHO intake in this group early in the week with protein being used as a CHO substitute. Dietary fat intakes in the present study were approximately 1.4 $g \cdot kg^{-1}$ body mass, slightly higher than the current recommendations (Bishop, Blannin, Walsh, Robson, & Gleeson, 1999) but similar to those seen in elite Australian athletes (Burke et al., 2003). Consumption of oily fish, meats, and the use of cooking oils accounts for most of the fat intake, and although intakes were high, given the importance of healthy fats for performance it would be unwise to suggest a reduction in dietary fat intake.

Micronutrient intakes met and exceeded the RDAs for physical activity (Whiting & Barabash, 2006) for all minerals and vitamins apart from vitamin K, which fell slightly below the guidelines for physical activity (-24 µg, less than 1 small stem of broccoli, see Table 3). These values did, however, meet and exceeded the RDA for general health. Although supplement use is common practice in sport with 40 to 100% of athletes using supplements (Baume, Hellemans, & Saugy, 2007), it seems inappropriate to supplement the athletes in this study with a multi-vitamin or a mega dose single vitamin supplement given the lack of any micronutrient deficiencies (Whiting & Barabash, 2006). The exception to this could be vitamin D with recent data suggesting the current RDA for general health is too low (Holick & Chen, 2008) and deficiencies are commonplace in many athletes (Close et al., 2013). Future studies might wish to investigate blood vitamin D concentrations in elite rugby players to further investigate this hypothesis.

Although this study provides novel data for the literature it is not without limitations, many of which are a direct consequence of collecting data from elite athletes outside of the controlled laboratory environment. These data were collected on a single professional rugby team, which may not accurately represent every rugby club, and therefore future studies might choose to collect data from a variety of teams. Finally, energy expenditure was not assessed on game day due to dangers associated with the use of the utilized EE technology in contact sports where physical collisions could cause damage to both player and equipment. The use of DLW over the course of a seven-day training week should now be performed. Energy intake was not assessed on game day to avoid adding to player’s game day stresses while performing at an elite standard.

To conclude, for the first time this study has attempted to quantify the training demands and assess energy expenditure, intake and micronutrient intakes of elite rugby players during the in-season. We report that mean energy intake and expenditure followed an inverse trend, with expenditure exceeding intake during the first four-days of the training week and then reversed in the day leading up to competition with intake exceeding expenditure. This is likely due to a heavier training load and players desire to maintain body fat during the beginning of the training week, followed by a decrease in training load and increase in CHO intake leading up to competition in order to maximise glycogen stores. Interestingly, mean energy intake exceeded expenditure for both forwards and backs despite CHO consumption falling short of recommended guidelines. This is likely attributable to relatively low training loads and running distances that attempt to provide sufficient stimulus to maintain player strength and fitness during the in-season, while reducing residual fatigue and promoting competition preparation. Alongside no micronutrient deficiencies, the current dietary practices of these elite rugby players are sufficient to fuel training during the in-season, providing energy intake and CHO are increased leading up to a match. However, whether this intake is optimal for game day performance remains unknown.

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