Significant Changes in Resting Metabolic Rate Over a Competitive Match Week Are Accompanied by an Absence of Nutritional Periodization in Male Professional Soccer Players.

CARTER, Jennie L, LEE, David J, PERRIN, Craig G, RANCHORDAS, Mayur <http://orcid.org/0000-0001-7995-9115> and COLE, Matthew <http://orcid.org/0000-0001-9046-2505>

Citation:

CARTER, Jennie L, LEE, David J, PERRIN, Craig G, RANCHORDAS, Mayur and COLE, Matthew (2023). Significant Changes in Resting Metabolic Rate Over a Competitive Match Week Are Accompanied by an Absence of Nutritional Periodization in Male Professional Soccer Players. International journal of sport nutrition and exercise metabolism, 33 (6), 349-359. [Article]

Introduction

During professional soccer matches, the ability to maintain high intensity running and levels of skill proficiency are key attributes of a top-class player and successful teams (Mohr et al., 2003). It has long been established that speed, agility, strength, and a combination of aerobic and anaerobic abilities are vital in soccer (Bangsbo, 1994), whilst Allen et al. (2023) suggest that the physical demands (total distance, high-intensity distance, and sprinting distance) of elite soccer have increased further in recent years. Thus, due to these high physiological demands, the influence of nutritional intake on soccer performance has been well documented, particularly in relation to energy and carbohydrate (CHO) requirements, and plays a key role in optimising fuelling and recovery from training and matches (Collins et al., 2021).

Resting metabolic rate (RMR) is a major component of total daily energy expenditure (TDEE) and is the energy required to maintain homeostasis at rest and can be used as an indicator of energy availability (Ihle & Loucks, 2004). Thus, determining RMR and energy expenditure (EE) is essential because it provides crucial information to develop nutritional strategies and sets the target for daily energy requirements (Burke et al., 2006). Within the context of professional soccer, sufficient energy is critical to support the demands of training and competition, support growth and development (Spear, 2002), promote training adaptations and optimise performance (Petrie et al., 2004). Long-term energy restriction can cause impaired physiological function; increased risk of fatigue, illness and injury; and maladaptation to the prescribed training (Mountjoy et al., 2014). A range of predictive equations have been developed to estimate RMR, however these equations may be limited as they are often developed from non-athletic populations (Cunningham, 1980) and may not consider Fat Free Mass (FFM) (Schofield et a, 2019). Hannon et al. (2020) found common prediction equations significantly underestimate RMR in youth professional soccer players (by as much as -844 kcal·day^{-1}) suggesting that they are not fit for purpose. Consequently, the use of improper prediction equations could potentially be detrimental to a player if used to advise energy requirements, given the effects of chronic low energy availability (Mountjoy et al., 2018), and it is therefore crucial that RMR is accurately measured instead. The most precise method of assessing RMR is indirect calorimetry requiring both oxygen ($\dot{V}O_2$) and carbon dioxide ($\dot{V}CO_2$) to be measured (Fullmer et al., 2015). Limited research has been conducted on assessing RMR using indirect calorimetry within professional male soccer players. Hannon et al. (2020) reported RMR values of 1875 ± 180 kcal·day^{-1} and 1941 ± 197 kcal·day^{-1} for U18s and U23s male professional soccer players, respectively, which to our knowledge is the only study to assess RMR in professional soccer players. Despite there being apparent fluctuations in training load in both academy (Hannon et al., 2021) and senior players (Anderson et al., 2016), to date, no research has investigated whether RMR varies across the competitive week in professional soccer players. Interestingly, within senior professional rugby union players Hudson et al. (2020) reported significant mean increases in RMR the day after a match, compared with the day before the match. They suggested this may be due to the number of collisions experienced in a rugby match. Whilst soccer does not involve collisions, there are some similarities between the two sports, therefore it would be of interest to identify whether similar observations are seen in professional soccer players because, if so, this could have important fuelling and recovery implications for soccer players.

In addition to understanding how RMR may vary across the competitive week, it would also be beneficial to understand how energy and CHO intake varies within professional soccer players. As periodisation is evident in training programs (Anderson et al., 2016), energy intake (EI) should be adjusted to account for the energy demands of a particular day. Determining the current dietary practices and intakes of professional soccer players is important to enable practitioners to develop programs that will improve nutritional intake and therefore, enhance health and performance. However, very few studies have assessed whether professional male soccer players periodise their nutritional intake across the competitive week to reflect alterations in training or match demands (Anderson et al., 2017; Brinkmans et al., 2019). Previous research has assessed the EI in senior (Anderson et al., 2017) and professional academy soccer players (Briggs et al., 2015; Hannon et al., 2021) demonstrating that intake is inadequate to meet the demands of training and competition (Briggs et al., 2015; Brinkmans et al., 2019). Anderson et al. (2017) reported mean daily EI of senior professional soccer players was greater on match day compared to training day. Additionally, there was a greater daily CHO intake on match day (6.4 ± 2.2 g·kg^{-1} BM·day^{-1}) compared with training days (4.2 ± 1.4 g·kg^{-1} BM·day^{-1}), similar to the findings of a subsequent study by Brinkmans et al., (2019). However, players did not consume sufficient CHO to optimize muscle glycogen storage in the day before (<5 g·kg^{-1} BM·day^{-1}), or in recovery (<4 g·kg^{-1} BM·day^{-1}) from matches (Anderson et al., 2017). Therefore, if professional male soccer players are consuming insufficient CHO intake following a match, coupled with the possibility of elevations in RMR causing an increased energy requirement, this could have a detrimental impact on exercise recovery.

To the authors knowledge, no research has yet assessed the daily variations in RMR across a competitive week in professional soccer players. Additionally, there are very few studies that have investigated the EI of professional soccer players across the competitive week. Thus, the aims of the present study were to: a) assess RMR; b) assess energy and CHO intake; and c) assess alterations in training load, match load, and muscle soreness; in male professional soccer players throughout an in-season competitive week. Understanding how energy requirements and energy intakes may vary over the competitive week will support nutrition practitioners in developing optimal nutrition strategies for fuelling and recovery.

Methods

Participants

A convenience sample of twenty-four professional soccer players from the Professional Development Phase in the English Premier League were recruited for this study (mean ± SD, age: 18 ± 1.6 years; body mass: 77.1 ± 7.5 kg; fat-free mass: 62.7 ± 6.7 kg; stature: 1.80 ± 0.07 m). All playing positions were included (midfielder n = 5; defender n = 12; forward n = 5; goalkeeper n = 2). All participants gave their written informed consent to participate in the investigation following approval from the Ethics Committee of Birmingham City University, UK.

Research Design

RMR and EI was measured in-season from November 2021 to May 2022 during a micro-cycle to ensure players were accustomed to the training load and rigors of match play. Timepoints throughout the study are described relative to match day (MD) using +/- symbols for days before (-) or after (+) MD. The first measurement started on MD-3 and measurements were repeated daily (consecutively) following this, except for MD RMR as this was deemed too disruptive to the player's pre-match routine. Training and match load, and muscle soreness were recorded throughout the week. See Table 1 for a typical training week schedule.

INSERT TABLE 1 HERE

Resting Metabolic Rate

RMR was measured a total of six times for each participant. All measures were undertaken at the same time between 7.30-9.30 am and players arrived at the training ground following an overnight fast, with their last meal at least 8 hours prior to the measurement. It was ensured participants abstained from caffeine, alcohol, and nicotine overnight, and avoided physical activity for 14 hours prior to measurement (Fullmer et al., 2015). A private, quiet room was utilized to conduct the measurements with temperature maintained at an ambient condition of 20-22°C (Fullmer et al., 2015). Players lay in a comfortable supine position and were reminded to stay awake throughout the assessment. Prior to measurement players rested for 20 minutes (Fullmer et al., 2015). Following this, RMR was measured for 20 minutes. The ventilated hood was located over the participant's head and expired gas was collected via the dilution canopy method (Vyntus CPX canopy, CareFusion, Hoechberg, Germany). A visual check every 5 minutes ensured no gas was escaping. The gas analyser was calibrated daily using the manufacturer's automated flow and digital volume transducer calibration (15.92 % O_2 and 5.03 % CO_2). Following best practice guidelines, the first 5 minutes of measurements were discarded (Fullmer et al., 2015). Measurements were subsequently recorded for 15 minutes continuously at 10 second intervals for $\dot{V}O_2$ and $\dot{V}CO_2$. $\dot{V}O_2$ and $\dot{V}CO_2$ were determined using the Haldane transformation (Haldane, 1918) and energy expenditure (kcal·day^{-1}) calculated using the Weir equation (Weir, 1949). CHO and fat oxidation rates were calculated according to standard equations (Zuntz, 1901). The coefficient of variance for our protocol was measured at 1.59% for RMR which was similar to previous work using identical methods (1.13%; Hudson et al., 2020). The limits of agreement were 188.6 kcal·day^{-1} above and below the mean of the reliability data.

Anthropometric measures

Body mass (kg) (SECA, model-875, Hamburg, Germany), and stature (m) (SECA, model-217, Hamburg, Germany) were measured on the first day of assessment, according to The International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Esparza-Ros et al., 2019), in the morning with minimal clothing and items such as jewelry removed. Fat free mass was measured using Dual-Energy X-Ray Absorptiometry (DXA) (Hologic QDR Series, Discovery W, Bedford, MA, USA) which has been acknowledged as gold standard in the assessment of body composition (Haarbo et al., 1991). The same trained operator performed and analysed all DXA scans, which were completed in a fasted state in the morning and in accordance with best practice guidelines (Nana et al., 2016). Whole body and regional fat-free and fat mass was included for analysis. These measures were recorded as a sub-total (whole-body minus the head) similar to previous research (Hannon et al., 2020).

Assessment of energy and macronutrient intake

EI was assessed using the remote food photographic method (RFPM), known as 'Snap-N-Send' which has been shown to be a valid and reliable dietary assessment tool in athletes (Costello et al., 2017) and utilised in previous research (Anderson et al., 2017; Hannon et al., 2021). Dietary intake was recorded for 7 days (consisting of: MD-3, MD-2, MD-1, MD, MD+1, MD+2, MD+3) which is considered a reasonable period to provide precise estimations of habitual energy and nutrient intake while reducing variability in coding error (Braakhuis et al., 2003). In addition, this enabled assessment of how EI may vary across the competitive week. On the day before data collection, players were informed by the lead researcher (a Sport and Exercise Nutrition Register (SENr) Practitioner) how to accurately and comprehensively complete the Snap-n-Send tool, ensuring accurate recording of the time of food consumption, amount (weighed amount or household measures such as tablespoons, teaspoons, cups), and description of food (cooking and preparation methods, ingredients, and brands). Photographs were sent through an instant messaging application (WhatsApp). To increase accuracy and avoid underestimation associated with the RFPM (Stables et al., 2021), if the photo or food descriptions were unclear, the player would be contacted in real time to clarify details. Additionally, where food was consumed within the training ground, the lead researcher assisted participants with dietary recording (descriptions, investigating cooking methods and recipes with chefs etc.). If there was any food or drink left following consumption, participants would send a photo of what had not been consumed. A 24 h recall was also undertaken with each participant each morning prior to their RMR assessment to cross reference, check for missing data, confirm amounts, and seek further clarity if required, which was then added to the participants record.

Energy and macronutrient intake was obtained using a professional dietary analysis software (Nutritics Ltd, v5, Ireland). All the dietary information was inputted into the software by the lead researcher to ensure consistency. Due to previous research reporting poor inter-practitioner reliability upon analysing nutritional intake (Stables et al., 2021), a second SENr nutritionist also analysed a sample of dietary logs to ensure reliability of nutrition intake data. Inter-rater reliability was determined via an independent t-test. No significant differences were observed between researchers for energy (p

= 0.823, 95% CI −120 to 148) or CHO ($p = 0.799$, 95% CI −17.4 to 22.2) intake. Meals were either consumed at: the club's training ground (where a buffet breakfast, lunch, pre and post-match meals, drinks, snacks and supplements are provided); a hotel (where players may be on MD); on the coach during travel on MD or; the players' home environment or restaurants. For the meals provided at the training ground, at the hotel or on the coach, menus were provided on a buffet style basis. All meals were consumed ad libitum by players during the study, and it was not mandatory to eat the meals provided by the club.

Quantification of training and match load

Global positioning system (GPS) technology (Apex Pro Series, STATSports, Belfast, UK) was used to measure pitch-based training and match load. This has been demonstrated to produce valid and reliable estimates of instantaneous and constant velocity movements during linear, multidirectional, and soccer-specific activities (Beato et al., 2018). The total distance (m) covered, high speed running (> 7m·s^{-1} (m)), and number of accelerations (> 3.3 m·s^{-1}) and decelerations (< 3.3 m·s^{-1}) were recorded at 18 Hz, providing a valid and reliable assessment of soccer specific movement (Beato et al., 2018). Muscle soreness was self-reported daily (except for MD) from a Visual Analogue Scale of 1-10 (1 being extreme soreness, 10 being no soreness).

Statistical Analysis

EI and RMR were recorded as absolute kilocalories (kcal) per day and relative to kilogram (kg) of FFM (kcal·kg^{-1} FFM·day^{-1}) (one participant was excluded as FFM data was missing due to absence of DXA scan), whilst carbohydrate intake was recorded as relative to total body mass (g·kg^{-1} BM·day^{-1}). The sample size varied each day as a small number of participants failed to attend some testing sessions due to varying reasons (e.g., travelling to matches; the wide-ranging schedule demands on professional soccer players; and other unforeseen circumstances).

Participants were considered missing at random therefore a linear mixed model was used to avoid list-wise deletion and to account for the hierarchal structure of each participant having observations across numerous days. For each dependent variable, the "lme4" package in R (R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/) examined the fixed effect of "Match Day" with each participant assigned a random intercept. This is similar to the approach used by Budzynski-Seymour et al. (2021). The model for each measure was: lmer (dv ~ MD

+ (1 | Participant ID)). Estimated marginal means for the variables on each day were obtained using the "emmeans" package. Pairwise contrasts were used to assess differences between individual days. A Bonferroni correction was applied to contrasts for RMR and Soreness measures, whereas a Sidak adjustment was applied to Dietary Intake and GPS variables as these were assumed to be independent between observations. The alpha threshold for significance for all variables was set at $p<0.05$.

Results

RMR

Daily RMR across the match week is displayed in Figure 1 (absolute) and Figure 2 (relative to FFM).

INSERT FIGURE 1 HERE

INSERT FIGURE 2 HERE

RMR following the match was significantly higher than pre-match values (MD+1 = 2234 ± 226 kcal·day^{-1} vs. MD-3 = 2010 ± 235 kcal·day^{-1}: p = 0.0075, +224 kcal·day^{-1}; 3.5 kcal·kg^{-1} FFM·day^{-1}; MD+1 vs. MD-2 = 2017 ± 241 kcal·day^{-1}: p = 0.0096, +217 kcal·day^{-1}, +3.5 kcal·kg^{-1} FFM·day^{-1}; and MD+1 vs. MD-1 = 1973 ± 186 kcal·day^{-1}: p = 0.0004, +261 kcal·day^{-1}, +3.9 kcal·kg^{-1} FFM·day^{-1}). In comparison to MD+1, RMR did not significantly decrease by MD+2 (MD+1 vs. MD+2 = 2133 ± 230 kcal·day^{-1}: p = 1.0000, -101 kcal·day^{-1}, -1.59 kcal·kg^{-1} FFM·day^{-1}), however did significantly decrease by MD+3 (MD+1 vs. MD+3 = 1993 ± 176 kcal·day^{-1}: p = 0.0036, -241 kcal·day^{-1}, -3.9 kcal·kg^{-1} FFM·day^{-1}). There were no significant differences on all other days (p > 0.05).

$\dot{V}O_2$ and $\dot{V}CO_2$

$\dot{V}O_2$ and $\dot{V}CO_2$ across the match week is displayed in Figures 3 and 4, respectively.

INSERT FIGURE 3 HERE

Post-match $\dot{V}O_2$ was significantly higher when compared to pre-match values (MD+1 = 0.323 ± 0.032 L·min^{-1} vs. MD-3 = 0.277 ± 0.040 L·min^{-1}: p = 0.0001, + 0.046 L·min^{-1}; MD+1 vs. MD-2 = 0.290 ± 0.033 L·min^{-1}: , p = 0.0071, + 0.033 L·min^{-1}; and MD+1 vs. MD-1 = 0.282 ± 0.030 L·min^{-1}: p = 0.0002, +0.041 L·min^{-1}). In comparison to MD+1, $\dot{V}O_2$ did not significantly decrease by MD+2 (MD+1 vs. MD+2 = 0.304 ± 0.036 L·min^{-1}: -0.019 L·min^{-1}, p = 0.6158), although did significantly decrease by MD+3 (MD+1 vs. MD+3 = 0.283 ± 0.044 L·min^{-1}: -0.040 L·min^{-1}, p = 0.0009).

INSERT FIGURE 4 HERE

There were no significant differences in $\dot{V}CO_2$ across the match week ($p > 0.05$).

CHO and Fat Oxidation

There were no significant differences in resting CHO oxidation rates across the match week (MD-3 = 0.221 ± 0.032 g·min^{-1}; MD-2 = 0.204 ± 0.020 g·min^{-1}; MD-1 = 0.246 ± 0.023 g·min^{-1}; MD+1 = 0.186 ± 0.026 g·min^{-1}; MD+2 = 0.240 ± 0.027 g·min^{-1}; MD+3 = 0.271 ± 0.035 g·min^{-1}; $p > 0.05$). Similarly, there were no significant differences in resting fat oxidation rates (MD-3 = 0.050 ± 0.007 g·min^{-1}; MD-2 = 0.062 ± 0.005 g·min^{-1}; MD-1 = 0.040 ± 0.005 g·min^{-1}; MD+1 = 0.085 ± 0.006 g·min^{-1}; MD+2 = 0.054 ± 0.006 g·min^{-1}; MD+3 = 0.030 ± 0.008 g·min^{-1}; $p > 0.05$).

Energy Intake

Absolute and relative EI across the match week is displayed in Figures 5 and 6, respectively.

INSERT FIGURE 5 HERE

INSERT FIGURE 6 HERE

There were no significant differences in daily absolute or relative EI across the match week (Absolute EI (kcal·day^{-1}): MD-3 = 2597 ± 843; MD-2 = 2679 ± 641; MD-1 = 2743 ± 1143; MD = 2582 ± 867; MD+1 = 2580 ± 934; MD+2 = 2714 ± 931; MD+3 = 2295 ± 817, $p > 0.05$. Relative EI (kcal·kg^{-1} FFM·day^{-1}): MD-3 = 42.2 ± 14.5; MD-2 = 43.2 ± 11.6; MD-1 = 44.7 ± 19.2; MD = 42.1 ± 14.7; MD+1 = 42.1 ± 16.5; MD+2 = 44.1 ± 16.8; MD+3 = 37.5 ± 14.9, $p > 0.05$.

Carbohydrate Intake

Relative carbohydrate intake across the match week is displayed in Figure 7.

INSERT FIGURE 7 HERE

There were no significant differences in daily relative carbohydrate intake across the competitive match week (MD-3 = 3.5 ± 1.5; MD-2 = 3.5 ± 1.1; MD-1 = 3.9 ± 1.9; MD = 4.2 ± 1.6; MD+1 = 3.6 ± 1.7; MD+2 = 4 ± 2.0; MD+3 = 3.3 ± 1.5 g·kg^{-1} BM·day^{-1}: $p > 0.05$).

Training and match demands, and muscle soreness

All GPS and muscle soreness data can be found in Table 2.

INSERT TABLE 2 HERE

Total Distance Covered

The total distance covered was significantly higher on MD compared to all other days ($p < 0.001$).

High Speed Running

The distance of high-speed running covered was significantly higher on MD compared to all other days ($p < 0.001$).

Accelerations

The number of accelerations was significantly higher on MD than MD-3, MD-2, MD-1, MD+1, and MD+2 ($p < 0.001$). There was no significant difference in the number of accelerations on MD and MD+3 ($p > 0.05$).

Decelerations

The number of decelerations was significantly higher on MD compared to all other days ($p < 0.001$).

Muscle Soreness

Perception of muscle soreness was significantly higher post-match vs. pre-match values (MD+1 vs. MD-3: $p = 0.021$; MD+1 vs. MD-2: $p = 0.009$; and MD+1 vs. MD-1: $p < 0.001$). This remained significantly elevated on MD+2 vs. MD-1 ($p = 0.035$), but significantly reduced by MD+3 vs. MD+1 ($p = 0.002$).

Discussion

The purpose of the current study was to: (a) assess RMR; (b) assess energy and CHO intake and; (c) assess training load, match load, and muscle soreness; in male professional soccer players throughout an in-season competitive week. Our data shows that despite increases in resting metabolic rate of ~12.4% (261 kcal·day^{-1}) in the day immediately following a soccer match, professional soccer players do not periodise their energy and CHO intake throughout the competitive week to account for these potential increases in energy demands. This finding agrees with previous work which has also reported significant elevations in RMR in the days immediately following intense exercise (Hackney et al., 2008; Hudson et al., 2020). To the authors' knowledge, our study is the first of its kind to report this observation specifically in professional soccer players, thereby highlighting an important consideration for practitioners when implementing effective recovery nutrition strategies. Furthermore, although statistically insignificant, MD+2 identified a ~160 kcal·day^{-1} (7.8%) mean daily increase in RMR from MD-1, which demonstrates that elevations in RMR persist 36-48hrs after a match. It was not until MD+3 that RMR levels returned to the status observed pre-match.

$\dot{V}O_2$ was also significantly increased on MD+1 (~13.6%) when compared to MD-1 and, similar to the trend observed for RMR, did not return to pre-match levels until MD+3. This finding is in agreement with that of Hudson et al (2020) who, albeit in a different sport, reported RMR and $\dot{V}O_2$ to be significantly increased following a match in senior professional rugby union players. They proposed that the elevated RMR was a consequence of a raised energy requirement due to a combination of either prolonged excessive post-exercise oxygen consumption (EPOC) (Kolkhorst et al., 1994), or a high eccentric-focussed physical load (Hackney et al., 2008) inducing the degradation and resynthesis of damaged muscle fibres (Burt et al., 2014). This proposed mechanism aligns to the current study within soccer as research by Silva et al. (2013) suggests that muscle damage markers (creatine kinase) in professional soccer players are increased for up to 48 hrs following a competitive match. Interestingly, the current study shows that players reported muscle soreness to be significantly higher on MD+1 and MD+2 compared to pre-match values, which further supports this proposed mechanism. Additionally, physical load was significantly higher on MD compared to training days, which we propose may be the cause of increased muscle soreness observed, and potentially increased RMR.

In terms of $\dot{V}CO_2$, it is interesting that despite reporting very similar increases in RMR and $\dot{V}O_2$, the present study differs from that of Hudson et al (2020) where they also reported significant increases in $\dot{V}CO_2$ in the 48-72hrs after rugby match play. In their work, Hudson et al (2020) attribute the elevations in $\dot{V}CO_2$ to the volume and intensity of collisions encountered during match-play, as the greatest increases were seen in the forwards, who underwent more physical collisions during the game. In the current study no changes were observed in $\dot{V}CO_2$ and thus it is possible that the differing demands of football match play - larger running distances with a higher number of accelerations/decelerations, but a lower volume and intensity of collisions – induces a different muscle damage response which does not sufficiently elevate $\dot{V}CO_2$. This may indicate that, despite observing similar elevations in post-match RMR, there are different aetiologies of muscle damage experienced within the two sports which induce this, but further research is needed to fully verify this theory.

Our findings show that training load varies throughout the competitive week, which aligns with previous research (Anderson et al., 2016). However, there are no significant differences in EI throughout the competitive week, for both absolute values and when FFM is considered. For example, we show that mean EI on MD-3 (2595 kcal·day^{-1}) was similar to that of MD (2582 kcal·day^{-1}). Previous work has emphasised the need for soccer players to adapt their EI to account for the changes in energy demands across the week (Collins et al., 2021), but our findings would suggest that professional players within our population were not adhering to this recommendation. In contrast, Anderson et al. (2017) and Brinkmans et al. (2019) reported mean daily EI of senior professional soccer players were significantly greater on MD compared to training day. To note, the mean age of players was higher in these latter studies (27 ± 3 and 23 ± 4 years, respectively) which may suggest senior players are better at periodising EI, when compared to younger professional players in our study. To our knowledge, our research is the first to assess whether there are any alterations in EI to reflect changes in RMR across the competitive match week in professional soccer players. The outcomes of the present study suggest that younger players may need more dedicated nutrition support (e.g., education) to fully understand the importance of periodising EI to account for potential increases in energy demands.

The importance of CHO for soccer performance has been acknowledged since the 1970s (Saltin, 1973). Similar to EI, CHO intake should be periodised throughout the competitive week to account for the changes in energy demands (Anderson et al., 2022). In our study, the average training day CHO intake was 3.5 g·kg^{-1} BM·day^{-1}, similar to previous research within professional soccer players (4 g·kg^{-1} BM·day^{-1}, Anderson et al., 2017). Given the lower absolute daily loads on typical training days, such daily intakes may be sufficient to support fueling and recovery during training (Collins et al., 2021). The recommended CHO intake one day prior to, on MD and the day post-match are 6-8 g·kg^{-1} BM·day^{-1} to elevate glycogen stores (Collins et al., 2021). However, the current study shows that the average CHO intake the day prior to the match was 3.9 g·kg^{-1} BM·day^{-1}, on MD was

4.2 g·kg^{-1} BM·day^{-1}, and the day post-match was 3.6 g·kg^{-1} BM·day^{-1}. This is far below the recommendation by Collins et al. (2021), indicating that the players from our study may be insufficiently fuelled for the increased physical and recovery demands of matches. Although Brinkmans et al. (2019) and Anderson et al. (2017) reported significantly higher CHO intake on MDs compared with training days in professional senior soccer players, intakes were inadequate to optimise fuelling and recovery. Given a primary objective following a match is to reduce the time needed to fully recover and rapidly replenish glycogen stores (Collins et al., 2021) this is of key concern due to the impairment on recovery. CHO intake on MD+1 would be even more paramount during periods of congested fixtures where energy demands, and the risks of low energy availability are likely to be higher (Collins et al., 2021). Given muscle soreness (indicating muscle damage) was significantly higher on MD+1 in our study, this may impair glycogen synthesis (Costill et al., 1990) which further highlights the need for additional CHO. To add more context to average CHO intakes, it should be noted that high inter-player variability is evident. For example, on MD-1 CHO intake ranged from 1.5 g·kg^{-1} BM·day^{-1} to 7.5 g·kg^{-1} BM·day^{-1}, meaning some players are significantly under-fuelling whilst others are sufficiently fuelling, which further highlights the importance of individualised nutrition support for soccer players. It is evident nutritional interventions should focus on improving professional soccer players energy and CHO intakes in the day before, day of, and day after a match. These interventions should consider the barriers and enablers to nutritional adherence previously identified within professional soccer players (Carter et al., 2022).

Future studies should assess the impact of congested fixtures on RMR to investigate whether this is further elevated, as meeting energy requirements is even more crucial during this period to support recovery (Ranchordas et al., 2017). Additionally, it would be useful to compare RMR within different playing positions to assess whether there are differences. Furthermore, it would of interest to assess whether changes in RMR are as magnified when players meet energy and carbohydrate requirements leading up to and following the match.

Limitations

We are aware the findings are based on one Premier League soccer club; however, training and match schedules are typical in other clubs. Additionally, although training load was captured within the soccer club, physical activity outside of the club was not recorded. Another limitation is the potential of participants under-reporting dietary intake on the RFPM and 24 h recall. However, as outlined in the methods, robust steps were undertaken to minimise this. Finally, we did not measure markers of muscle damage and inflammation, however, given that our data were collected in a professional setting this is not always feasible as coaches typically limit the invasiveness of data collection on professional athletes.

Conclusion

In summary we report for the first time the changes in RMR over the competitive week in professional soccer players. We observed a significant increase of 12.4% in RMR, and an increase in $\dot{V}O_2$ on MD+1 compared to MD-1 which may have a significant impact on nutritional practice. We determined that players do not periodise nutritional intake across the competitive week, consuming inadequate CHO on MD-1, MD and MD+1 which could impair physical performance. Moreover, during periods of fixture congestion, inadequate EI may further compromise performance and recovery. Therefore, nutrition practitioners should focus on implementing behaviour change interventions to promote effective fuelling and recovery nutrition practice in the day prior to the match, MD and within the 1-2 days following a match.

<u>Acknowledgements</u>

All authors contributed to the study design, providing critical review throughout all aspects of the study. All authors have had an opportunity to review of the manuscript and agree with the final submission. The authors would like to thank all the players and staff for the time taken to perform the RMR analysis and the soccer club for their support.

<u>Conflicts of Interest</u>

The authors declare no conflicts of interest.

<u>Declaration of Funding</u>

No funding was provided for this research.

References

Allen, T., Taberner, M., Zhilkin, M., & Rhodes, D. (2023). Running more than before? The evolution of running load demands in the English Premier League. *International Journal of Sports Science & Coaching*. https://doi.org/10.1177/17479541231164507

Anderson, L., Orme, P., Di Michele, R., Close, G.L., Morgans, R., Drust, B., & Morton, J.P. (2016). Quantification of training load during one-, two- and three-game week schedules in professional soccer players from the English Premier League: implications for carbohydrate periodization. *Journal of Sports Science, 34*(13), 1250-1259.

Anderson, L., Orme, P., Naughton, R.J., Close, G.L., Milsom, J., Rydings, D., O'Boyle, A., Di Michele, R., Louis, J., Hambly, C., Speakman, J.R., Morgans, R., Drust, B., & Morton, J.P. (2017). Energy Intake and Expenditure of Professional Soccer Players of the English Premier League: Evidence of Carbohydrate Periodization. *International Journal of Sport Nutrition and Exercise metabolism*, *27(3),* 228-238.

Anderson, L, Drust, B, Close, G.L., & Morton, J.P. (2022). Physical loading in professional soccer players: Implications for contemporary guidelines to encompass carbohydrate periodization. *Journal of Sports Science, 40*(9),1000-1019.

Bangsbo, J. (1994) Fitness Training in Football—A Scientific Approach. August Krogh Institute. Denmark.

Beato, M, Coratella, G, Stiff, A., & Lacono, A.D. (2018). The Validity and Between-Unit Variability of GNSS Units (STATSports Apex 10 and 18 Hz) for Measuring Distance and Peak Speed in Team Sports. *Frontiers in Physiology*, *21*(9), 1288.

Braakhuis, A.J., Meredith, K., Cox, G.R., Hopkins, W.G., & Burke, L.M. (2003). Variability in estimation of selfreported dietary intake data from elite athletes resulting from coding by different sports dietitians. *International Journal of Sport Nutrition*, 13, 152–165.

Briggs, M.A., Cockburn, E., Rumbold, P.L.S., Rae, G., Stevenson, E.J., & Russell, M. (2015). Assessment of Energy Intake and Energy Expenditure of Male Adolescent Academy-Level Soccer Players during a Competitive Week. *Nutrients, 7*(10), 8392-8401.

Brinkmans, N.Y.J., Ledema, N., Plasqui, G., Wouters, L., Saris, W.H.M., Van Loon, L.J.C., & Van Dijk, J.W. (2019). Energy expenditure and dietary intake in professional football players in the Dutch Premier League: Implications for nutritional counselling. *Journal of Sports Sciences*, *37*(24), 2759-2767.

Budzynski-Seymour, E., Jones, M., & Steele, J. (2021). The Influence of Public Health England’s Change4LifeDisney Branded 10-minute ShakeUps on Children’s Post Activity Affective Response. *Communications in Kinesiology*, *1*(2).

Burke, L.M., Loucks, A.B., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences*, *24*(7), 675–685.

Burt, D.G., Lamb, K., Nicholas, C., & Twist, C. (2014). Effects of exercise-induced muscle damage on resting metabolic rate, sub-maximal running and post-exercise oxygen consumption. *European Journal of Sport Science*, *14*(4), 337-44.

Carter, J.L, Lee, D.J, Ranchordas, M.K., & Cole, M. (2022). Perspectives of the barriers and enablers to nutritional adherence in professional male academy football players. *Science and Medicine in Football,* 1-12.

Collins, J, Maughan, R.J, Gleeson, M, Bilsborough, J, Jeukendrup, A, Morton, J.P, Phillips, S.M, Armstrong, L, Burke, L.M, Close, G.L, Duffield, R, Larson-Meyer, E, Louis, J, Medina, D, Meyer, F, Rollo, I, Sundgot-Borgen, J, Wall, B.T, Boullosa, B, Dupont, G, Lizarraga, A, Res, P, Bizzini, M, Castagna, C, Cowie, C.M, D'Hooghe, M, Geyer, H, Meyer, T, Papadimitriou, N, Vouillamoz, M., & McCall, A. (2021). UEFA expert group statement on nutrition in elite football. Current evidence to inform practical recommendations and guide future research. *British Journal of Sports Medicine*, *55*(8), 416.

Costello, N., Deighton, K., Dyson, J., Mckenna, J., & Jones, B. (2017). Snap-N-Send: A valid and reliable method for assessing the energy intake of elite adolescent athletes. *European Journal of Sport Science*, *17*(8), 1044-1055.

Costill, D.L., Pascoe, D.D., Fink, W.J., Robergs, R.A., Barr, S.I., & Pearson, D. (1990). Impaired muscle glycogen resynthesis after eccentric exercise. *Journal of Applied Physiology (1985)*, *69*(1), 46-50.

Cunningham, J.J. (1980). 'A reanalysis of the factors influencing basal metabolic rate in 419 normal adults'. *The American Journal of Clinical Nutrition, 33(*11), 2372–2374.

Esparza-Ros, F., Vaquero-Cristóbal, R., & Marfell-Jones, M. (2019). International Standards for Anthropometric Assessment (UCAM Universidad Católica de Murcia, Ed.). *The International Society for the Advancement of Kinanthropometry.*

Ihle, R., and Loucks, A. (2004) Dose-response relationships between energy availability and bone turnover in young exercising women. *Journal of Bone and Mineral Research. 19(8),* 1231–1240.

Fullmer, S., Benson-Davies, S., Earthman, C.P., Frankenfield, D.C., Gradwell, E., Lee, P.S., Piemonte, T., & Trabulsi, J. (2015). Evidence analysis library review of best practices for performing indirect calorimetry in healthy and non-critically ill individuals. *Journal of the Academy of Nutrition and Dietetics, 115*(9), 1417-1446.

Haarbo, J, Gotfredsen, A, Hassager, C., & Christiansen, C. (1991). Validation of body composition by dual energy X-ray absorptiometry (DEXA). *Clinical Physiology, 11*(4), 331–341.

Hackney, K.J., Engels, H.J., & Gretebeck, R.J. (2008). Resting energy expenditure and delayed-onset muscle soreness after full-body resistance training with an eccentric concentration. *Journal of Strength and Conditioning Research*, *22*(5), 1602-1609.

Kolkhorst, F.W., Londeree, B.R., & Thomas, T.R. (1994). Effects of consecutive exercise days of jogging or cycling on the resting metabolic rate and nitrogen balance. *The Journal of Sports Medicine and Physical Fitness*, *34*(4), 343-350.

Haldane, J. S. (1918). Methods of air analysis. London, U.K: Charles Griffin & Co. Ltd.

Hannon, M.P., Carney, D.J., Floyd, S., Parker, L.J.F., McKeown, J, Drust, Unnithan, V.B., Close, G.L., & Morton, J.P. (2020). Cross-sectional comparison of body composition and resting metabolic rate in Premier League academy soccer players: Implications for growth and maturation, *Journal of Sports Sciences*, *38*(11-12), 1326-1334.

Hannon, M,P., Parker, L.J.F., Carney, D.J., McKeown, J, Speakman, J.R, Hambly, C, Drust, B, Unnithan, V.B, Close, G.L., & Morton, J.P. (2021). Energy Requirements of Male Academy Soccer

Players from the English Premier League. *Medicine and Science in Sports and Exercise, 53*(1), 200-210.

Hudson, J.F., Cole, M., Morton, J.P., Stewart, C.E., & Close, G.L. (2020). Daily Changes of Resting Metabolic Rate in Elite Rugby Union Players*. Medicine and Science in Sports and Exercise*, *52*(3), 637-644.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue*. Journal of Sports Sciences*, *21*(7), 519-528.

Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., Meyer, N., Sherman, R., Steffen, K., Budgett, R., & Ljunggvist, A. (2014). The IOC consensus statement: Beyond the Female Athlete Triad–Relative Energy Deficiency in Sport (RED-S). *British Journal of Sports Medicine, 48(*7), 491-497.

Mountjoy, M., Sundgot-Borgen, J.K., Burke, L.M., Ackerman, K.E., Blauwet, C., Constantini, N., Lebrun, C., Lundy, B., Melin, A.K., Meyer, N.L., Sherman, R.T., Tenforde, A.S., Klungland Torstveit, M., & Budgett, R. (2018). IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update, *British Journal of Sports Medicine*, *52*(11), 687-697.

Nana, A, Slater, G.J, Hopkins, W.G, Halson, S.L, Martin, D.T, West, N.P., & Burke, L.M. (2016). Importance of Standardized DXA Protocol for Assessing Physique Changes in Athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *26*(3), 259-267.

Petrie, H.J., Stover, E.A. and Horswill, C.A. (2004). Nutritional concerns for the child and adolescent competitor. *Nutrition, 20*(7-8), 620-631.

Ranchordas, M.K, Dawson, J.T., & Russell, M. (2017). Practical nutritional recovery strategies for elite soccer players when limited time separates repeated matches*. Journal of the International Society of Sports Nutrition*, *14*:*35*.

Saltin, B. (1973). Metabolic fundamentals in exercise. *Medicine and Science in Sports and Exercise, 5*(3), 137-146.

Schofield, K. L., Thorpe, H., & Sims, S.T. (2019). Resting metabolic rate prediction equations and the validity to assess energy deficiency in the athlete population. *Experimental Physiology*, *104*(4), 469–475

Silva, J.R., Ascensão, A., Marques, F., Seabra, A., Rebelo, A., & Magalhães, J. (2013). Neuromuscular function, hormonal and redox status and muscle damage of professional soccer players after a high-level competitive match. *European Journal of Applied Physiology*. *113*(9), 2193-2201.

Stables, R.G., Kasper, A.M., Sparks, S.A., Morton, J.P., & Close, G.L. (2021). An Assessment of the Validity of the Remote Food Photography Method (Termed Snap-N-Send) in Experienced and Inexperienced Sport Nutritionists. *International Journal of Sport Nutrition and Exercise Metabolism, 31*(2), 125-134.

Spear, B.A. (2002). Adolescent growth and development. *Journal of the American Dietetic Association*, *102*(3), 23-29.

Weir, J.B. D.B. (1949). ‘New methods for calculating metabolic rate with special reference to protein metabolism’, *The Journal of Physiology*, *109*(1–2), 1–9.

Zuntz, N. (1901). Ueber die Bedeutung der verschiedenen Nahrstoffe. (About the importance of different nutrients). *Archive European Journal of Physiology*, *83*, 557-571.

Figure Legends

Figure 1. Absolute changes in RMR (kcal·day^{-1}) across the competitive match week (Mean ± SD). *Significantly higher than MD-3, MD-2, and MD-1 ($p<0.01$). #Significantly lower than MD+1 ($p<0.01$). Key: MD = match day.

Figure 2: Relative changes in RMR (kcal·kg^{-1}FFM·day^{-1}) across the competitive match week (Mean ± SD). *Significantly higher than MD-3, MD-2, and MD-1 ($p<0.01$). #Significantly lower than MD+1 ($p<0.01$). Key: MD = match day.

Figure 3: Changes in $\dot{V}O_2$ (L·min^{-1}) across the competitive match week (Mean ± SD). *Significantly higher than MD-3, MD-2, and MD-1 ($p<0.01$). #Significantly lower than MD+1 ($p<0.001$). Key: MD = match day.

Figure 4: Changes in $\dot{V}CO_2$ (L·min^{-1}) across the competitive match week (Mean ± SD). Key: MD = match day.

Figure 5: Absolute energy intake (kcal·day^{-1}) across the competitive match week (Mean ± SD). Key: MD = match day.

Figure 6: Relative energy intake (kcal·kg^{-1} FFM·day^{-1}) across the competitive match week (Mean ± SD). Key: MD = match day.

Figure 7: Relative carbohydrate intake (g·kg^{-1} BM·day^{-1}) across the competitive match week (Mean ± SD). Key: MD = match day.

Tables

Table 1. An overview of the pitch based and match schedule for each squad.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
U23	Match	Recovery	Day off	Training	Training	Training	Training
(am)		11:00 – 12:00		10:45 – 12:30	10:45 – 12:30	10:45 – 12:30	10:45 – 12:30
(pm)	19:00 Kick Off			Gym 14:00-15:00		Gym 14:00-15:00	
U18	Training	Training	Day off	Training	Training	Match	Day off
(am)	10:45 – 12:30	10:45 – 12:30		10:45 – 12:30	10:45 – 12:30	11:00 Kick Off	
(pm)		Gym 14:00-15:00		Gym 14:00-15:00			

Table 2. Comparison of muscle soreness and metrics recorded for training and match play throughout the competitive week

Day	MD-3	MD-2	MD-1	MD	MD+1	MD+2	MD+3
Total distance (m)	3283 ± 1975*	4441 ± 1973*	3491 ± 1214*	**12326** ± 1973	98 ± 468*	2936 ± 1991*	7964 ± 4280*
High Speed Running (>7m·s^{-1} (m))	78 ± 76*	223 ± 144*	74 ± 64*	**774** ± 310	0 ± 0*	98 ± 142*	460 ± 409*
Accelerations (< 3.3 m·s^{-1})	41 ± 31*	52 ± 35*	40 ± 21*	**92** ± 31	1 ± 6*	34 ± 25*	69 ± 32
Decelerations (< 3.3 m·s^{-1})	29 ± 21*	44 ± 29*	34 ± 17*	**99** ± 31	1 ± 4*	30 ± 20*	67 ± 37*
Muscle Soreness Score (Lower score = higher soreness)	7.90 ± 1.50$^{\#}$	8.00 ±1.27$^{\#}$	8.29 ± 0.86$^{\#}$	**Not collected**	6.88 ± 0.80†	7.31 ± 1.43‡	8.15 ± 1.14

Key: MD = match day
*Denotes values significantly different (p<0.05) when compared with match day (shown in bold).
$^{\#}$ = significantly different when compared with MD+1 (p<0.05).
† = significantly different when compared with MD+3 (p<0.0019).
‡ = significantly different when compared with MD-1 (p <0.0351).