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PHYSIOLOGY AND NUTRITION

Energy expenditure and dietary intake in professional football players in the Dutch Premier League: Implications for nutritional counselling

Naomi Y.J. Brinkmans[a], Nick Iedema[a], Guy Plasqui[b], Loek Wouters[b], Wim H.M. Saris[b], Luc J.C. van Loon[a,b] and Jan-Willem van Dijk[a]

[a]Institute of Sports and Exercise Studies, HAN University of Applied Sciences, Nijmegen, The Netherlands; [b]NUTRIM School of Nutrition and Translational Research in Metabolism, Maastricht University Medical Centre, Maastricht, The Netherlands

ABSTRACT

Selecting effective dietary strategies for professional football players requires comprehensive information on their energy expenditure (EE) and dietary intake. This observational study aimed to assess EE and dietary intake over a 14-day period in a representative group (n = 41) of professional football players playing in the Dutch Premier League (Eredivisie). Daily EE, as assessed by doubly labelled water, was 13.8 ± 1.5 MJ/day, representing a physical activity level (PAL) of 1.75 ± 0.13. Weighted mean energy intake (EI), as assessed by three face-to-face 24-h recalls, was 11.1 ± 2.9 MJ/day, indicating 18 ± 15% underreporting of EI. Daily EI was higher on match days (13.1 ± 4.1 MJ) compared with training (11.1 ± 3.4 MJ; $P < 0.01$) and rest days (10.5 ± 3.1 MJ; $P < 0.001$). Daily carbohydrate intake was significantly higher during match days (5.1 ± 1.7 g/kg body mass (BM)) compared with training (3.9 ± 1.5 g/kg BM; $P < 0.001$) and rest days (3.7 ± 1.4 g/kg BM; $P < 0.001$). Weighted mean protein intake was 1.7 ± 0.5 g/kg BM. Daytime distribution of protein intake was skewed, with lowest intakes at breakfast and highest at dinner. In conclusion, daily EE and PAL of professional football players are modest. Daily carbohydrate intake should be increased to maximize performance and recovery. Daily protein intake seems more than adequate, but could be distributed more evenly throughout the day.

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KEYWORDS
Football; soccer; doubly labelled water; energy expenditure; sports nutrition; carbohydrate; protein

Introduction

The energy cost of football matches and training sessions are thought to largely contribute to the daily energy expenditure of professional football players (Burke, Loucks, & Broad, 2006). Despite the growing number of studies investigating the physical demands of training sessions and match play, the daily energy expenditure has been less well studied using the gold standard doubly labelled water (DLW) method (Ainslie, Reilly, & Westerterp, 2003). Information on daily energy expenditure is important as it sets the target for the daily energy requirements (Burke et al., 2006). Adequate energy intakes are not only essential to fuel the energy demands of matches and training, but also for maintaining optimal immune function and reducing the risk for injury (Burke et al., 2006; Logue et al., 2018). On the other hand, strategically planned short periods of energy restriction or energy surplus can be used to manipulate the body composition or energy stores of professional football players (Burke et al., 2006; Volek et al., 2002). Despite the importance of energy requirements as a nutritional target, only two small studies assessed the daily energy expenditure of professional football players by the golden standard method, i.e., doubly labelled water (DLW) (Anderson et al., 2017; Ebine et al., 2002). Moreover, those studies included a small selection of football players from a single squad, which may not be representative for an entire football squad or competition. Obviously, there is need for large representative studies addressing the energy requirements of professional football players.

Carbohydrates are generally recognized as the main nutrient to cover the energy requirements of football players (Burke et al., 2006). This can be attributed to the strong reliance on muscle glycogen during matches. Indeed, most muscle fibres are glycogen depleted toward the end of the game (Krustrup et al., 2006). The importance of muscle glycogen storage and utilization by football players emphasizes the need for an adequate intake of carbohydrates (Williams & Rollo, 2015). In agreement, diets rich in carbohydrates (~8 g/kg body mass) have been associated with superior football-specific performance compared with diets containing smaller quantities of carbohydrates (Balsom, Wood, Olsson, & Ekblom, 1999; Souglis et al., 2013). Thus, carbohydrate intake should support optimal preparation, performance and recovery, and good health and immune function (Burke et al., 2006). The most recent guidelines for nutritional intake in football recommend a daily carbohydrate intake between 5–7 g/kg body mass on moderate training days, and from 7 up to 12 g/kg body mass for heavy training days or for match preparation (Burke et al., 2006; Nutrition for football: the FIFA/F-MARC Consensus Conference, 2006). Although many studies have addressed the nutritional intake of football players (Anderson et al., 2017; Bettonviel, Brinkmans, Russcher, Wardenaar, & Witard, 2016; Burke et al., 2006), carbohydrate intake has never been viewed in the light of daily energy expenditure. As such, it is unknown whether the current recommendations for carbohydrate intake, particularly those for heavy training

CONTACT Jan-Willem van Dijk janwillem.vandijk@han.nl Institute of Sports and Exercise Studies, HAN University of Applied Sciences, PO Box 6960, Nijmegen, GL 6503, The Netherlands
Supplementary data can be accessed here

days and matches, are feasible within the energy budget of professional football players.

Besides the adequate intake of carbohydrates, the intake of adequate amounts of protein is considered crucial to facilitate optimal recovery from and skeletal muscle adaptations to exercise (Morton, McGlory, & Phillips, 2015; Tipton & Wolfe, 2004). The recommended total daily protein requirements for football players ranges between 1.2 and 1.7 g/kg body mass/day (Nutrition for football: the FIFA/F-MARC Consensus Conference, 2006; Boisseau, Vermorel, Rance, Duche, & Patureau-Mirand, 2007; Lemon, 1994; Tipton & Wolfe, 2004). Along with the total daily protein requirements, it has been suggested that strategic timing and distribution of protein intake leads to maximal skeletal muscle adaptations and recovery (Phillips & Van Loon, 2011). In this regard, 20–25 g of protein with each main meal and 30–40 g of protein before the night have been advocated to achieve optimal training adaptations and recovery (Phillips & Van Loon, 2011; Trommelen & van Loon, 2016). Recommendations for daily protein intake are generally met by professional football players (Anderson et al., 2017; Burke et al., 2006; Wardenaar et al., 2017). However, considerably less data is available with regard to protein intake distribution throughout the day (Anderson et al., 2017; Bettonviel et al., 2016).

The adoption of nutritional strategies that meet the evolving demands of football requires comprehensive information on the energy requirements, and current dietary habits of professional football players. The aim of this study was to determine energy expenditure and food intake in a large group professional football players in the Dutch Premier League (Eredivisie). For this purpose, energy expenditure was determined in 41 professional football players by the doubly labelled water method, along with the assessment of energy and macronutrient intake by repeated face-to-face 24-h recalls. The information generated by this study sets the stage for defining feasible and effective nutritional guidelines for professional football players, ultimately improving nutritional counselling and nutritional intake in professional football to support optimal health and performance.

Methods

Participants

A total of 45 male professional football players aged 18 years or higher, were recruited from first team squads of three major professional football clubs playing in the Dutch Eredivisie (n = 15 per club). All clubs were ranked in the top 10 of the Dutch Eredivisie over the past 5 years. Eighteen players in the cohort were playing for the national team of their country, whereas another 13 players were playing for the national youth team of their country. The characteristics of the football players are reported in Table 1. The study was approved by the Independent Review Board Nijmegen Medical Ethical Committee (NL54343.072.15) and conducted according to the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants. This trial was registered at the Netherlands Trial Register as NTR5572.

Study design and study period

The football players participated in an observational study comprising measurements of energy expenditure, food intake, match- and training load, and body composition. All data were collected during the 2015–2016 Dutch Eredivisie season, in the period November 2015 until April 2016. For each club, data were collected in an in-season period of 3 to 4 weeks during which players continued their normal routine. Planning of data collection was fully aligned with trainers and coaches to prevent interference with normal daily routines, training sessions or preparations for a match.

Energy expenditure

Total energy expenditure was measured over a 14-day period by the DLW method according to the Maastricht protocol (Westerterp, Wouters, & van Marken Lichtenbelt, 1995). Briefly, in the evening after collecting a baseline urine sample (day 0), the football players consumed a weighted amount of $^{2}H_2{}^{18}O$, resulting in an initial body water enrichment of approximately 130 p.p.m. for ^{2}H and 230 p.p.m. for ^{18}O. Subsequently, urine samples were collected from the second voiding in the mornings of day 1, day 8 and day 15 upon arrival at the club. On day 1, day 8 and day 15, a second urine sample was collected in the early afternoon. Urine samples were aliquoted in 2 mL airtight glass vials, and frozen and stored at −20°Celsius until analysis. Urine samples were analysed with an isotope ratio mass spectrometer (Optima; VG Isogas, Middlewich, Cheshire, UK). Carbon dioxide production was calculated from the difference between the elimination rates of ^{2}H and ^{18}O. Total daily energy expenditure was calculated from carbon dioxide production, assuming a respiratory quotient of 0.85.

The physical activity level (PAL) was calculated by dividing daily EE by the basal metabolic rate (BMR). The BMR was calculated according to the revised Harris Benedict Equation (Roza & Shizgal, 1984).

Table 1. Subject characteristics.

	Total group (n = 41)	Goalkeeper (n = 4)	Defender (n = 12)	Midfielder (n = 13)	Attacker (n = 12)	P-value
Age (y)	23 ± 4	24 ± 3	25 ± 4	22 ± 4	21 ± 3	0.04^{E}
Height (cm)	182 ± 6	189 ± 2	185 ± 4	179 ± 5	181 ± 8	0.01^{B}
Body Mass (kg)	77.6 ± 8.0	89.6 ± 3.7	79.2 ± 7.4	71.7 ± 4.9	78.5 ± 7.1	$<0.001^{A,B,C,D}$
BMI (kg/m^2)	23.3 ± 1.5	25.2 ± 0.9	23.0 ± 1.4	22.4 ± 1.0	24.0 ± 1.6	$0.001^{A,B,F}$
Body Fat (%)	11.6 ± 2.4	12.5 ± 3.0	11.1 ± 2.8	11.3 ± 2.3	12.3 ± 2.0	0.56
Lean Body Mass (kg)	68.6 ± 7.2	78.5 ± 5.3	70.5 ± 7.6	63.5 ± 4.2	68.8 ± 5.8	$0.001^{B,C,D}$

Data are expressed as mean±sd. Differences between playing positions were analysed by one-way ANOVA. Significance values obtained from post-hoc analyses: ^{A} p-value <0.05 for goal keeper vs. defender, ^{B} p-value <0.05 for goal keeper vs. midfielder, ^{C} p-value <0.05 for goal keeper vs. attacker, ^{D} p-value <0.05 for defender vs. midfielder, ^{E} p-value <0.05 for defender vs. attacker, ^{F} p-value <0.05 midfielder vs. attacker.

Nutritional intake

Energy and macronutrient intake was assessed by three unannounced face-to-face 24-h dietary recalls for a match-, training, and rest day, respectively. The recalls were conducted by nine research dietitians who were specifically trained for this task. The dietitians were familiar with the meals (including recipes), drinks, sports nutrition products and supplements offered by the club. During the recalls, the dietitians used the clubs' cutlery and crockery to let players indicate portion sizes. Recalls were assessed with the validated 5-step multiple-pass method to increase accuracy (Conway, Ingwersen, Vinyard, & Moshfegh, 2003), and a checklist at the end (Van Staveren, Ocké, & De Vries, 2012). All recalls were checked for completeness and processed with Compl-eat™ software (Wageningen University, Division of Human Nutrition) by a single researcher.

The recalls were conducted in the morning or afternoon after a match-, training-, and rest day, respectively, in random order. A match day was considered valid if a player played for at least 60 min during a match. If a player did not play any matches, an additional recall was scheduled for a training day to ensure three recalls for each player. The recall for a training day was scheduled following a regular training day with a field training, either 2 days following a match or 3 days prior to a match.. The recalls for a resting day were scheduled after a day without any training session(s) or match. The number of match-, training-, and rest days was not equally distributed over the 14-day assessment period. Therefore, weighted means were calculated for each individual to estimate mean daily energy- and macronutrient intake over the 14-day period.

Body composition

The application of DLW also allowed the assessment of total body water by deuterium dilution according to the Maastricht protocol (Westerterp et al., 1995). Total body water was derived from the first 2 urine samples, the background sample taken in the evening before dosing and the urine sample from the second voiding the next morning. Subsequently, fat free mass was calculated from total body water by assuming a fat free mass hydration factor of 0.73 (Wang et al., 1999).

Body mass and height were measured in the morning before training on day 1, with an accuracy of ±0.1 kg and ±0.1cm, respectively (Dongshan Jenix, DS-103, Seoul, Korea). Body mass was measured again in the morning before training on day 8 and 15.

Training and match load

Training load was measured with local position measurement (LPM) technology (Inmotio Object Tracking BV, Amsterdam, Netherlands). Match load was measured by camera tracking technology (STATS SportVU). Both the training sessions and matches were analysed for duration, total distance covered, distance covered per min, and distance covered at five different speed zones.

Statistical analysis

During the data collection period, two players became injured and two players were put on a specific diet. As such, these players could not continue their normal physical activity pattern or dietary routine, and were excluded from the data analysis. Data analyses were conducted with the remaining 41 subjects using SPSS (IBM SPSS Statistics, version 23). The difference between daily energy expenditure and daily energy intake was analysed by a paired student t-test. Differences in energy- and macronutrient intake on match, training, and rest days were analysed by one-way repeated measures ANOVA. Differences between playing positions were analysed by one-way ANOVA. In case of a significant effect of day type or playing position, pairwise comparisons with Bonferroni correction were applied to locate differences between days or positions. Associations between energy expenditure, body mass, fat free mass, training load and match load were explored by Pearson correlation. Data are presented as mean ± SD or median (IQR).

Results

Subjects' characteristics

The cohort of the 41 football players included 4 goalkeepers, 12 backs, 13 midfielders and 12 forwards. The anthropometric characteristics of the football players are provided in Table 1.

Training and Match Load

Over the 14-day study period, players played 2.3 ± 0.5 matches, participated in 8.7 ± 1.0 training sessions and had 3.1 ± 1.0 rest days. Table 2 provides an overview of the average work performed during training sessions and matches. Total time on the field and total distance covered were significantly greater during matches than in training

Table 2. Average training and match load.

		Training (n = 39)		Match (n = 34)		P_{abs}	P_{rel}
Time on field, min		78 ± 11		90 ± 6		<0.001	-
Max. speed, km/h		25 ± 2		31 ± 2		<0.001	-
Total distance, m		5405 ± 835		10,293 ± 1710		<0.001	-
Distance, m/min		70 ± 8		115 ± 19		<0.001	-
Speed zone 1, m (%)	0.0–6.9 km/h	1580 ± 920	(30 ± 20)	2713 ± 1378	(28 ± 18)	<0.001	0.596
Speed zone 2, m (%)	7.0–11.9 km/h	1560 ± 482	(28 ± 6)	3032 ± 630	(29 ± 5)	<0.001	0.435
Speed zone 3, m (%)	12.0–14.9 km/h	1461 ± 775	(26 ± 13)	2438 ± 1539	(23 ± 13)	0.001	0.259
Speed zone 4, m (%)	15.0–17.4 km/h	495 ± 271	(9 ± 5)	1024 ± 513	(10 ± 4)	<0.001	0.663
Speed zone 5, m (%)	≥17.5 km/h	306 ± 149	(6 ± 3)	1076 ± 444	(10 ± 4)	<0.001	<0.001

Data are expressed as mean±sd. Training data are shown for n = 39 players as of n = 2 players no training data were available. Match data are shown for n = 34 players as n = 7 players did not meet the criterion to play for at least 60 min or no match data were available. P_{abs} represent the p-value for the comparison of absolute distance between training and match. P_{rel} represents the p-value for the comparison of relative distance between training and match.

sessions. In addition, a greater proportion of the total distance covered was spent at the highest speed zone, and thus higher intensity, during matches compared with training sessions. Supplementary Table 1 provides training and match data specified for different playing positions. Generally, workload during training sessions and matches appears much lower in goalkeepers compared with field players.

Energy expenditure and energy intake

Average daily EE measured over the 14-day period was 13.8 ± 1.5 MJ (3285 ± 354 kcal), whereas the weighted average daily EI over this period was 11.1 ± 2.9 MJ (2658 ± 693 kcal) (Table 3). As the players' body mass did not change during the 14-day period (day 1: 77.6 ± 8.1 kg, day 15: 77.6 ± 8.0 kg; $P = 0.89$), the difference between EE and EI likely represented underreporting of the food intake by 18 ± 15%.

The absolute daily EE did not differ between the different playing positions ($p = 0.65$). However, when corrected for body mass, the daily EE was different between playing position (main effect $p = 0.004$), with the lowest daily EE observed in goalkeepers (157 ± 12 kJ/kg body mass (37.6 ± 2.9 kcal/kg body mass)) and the highest daily EE observed in midfielders (186 ± 14 kJ/kg body mass (44.4 ± 3.2 kcal/kg body mass)). With an average value of 1.75 ± 0.13, the PAL did not significantly differ between playing positions (Table 3; main effect $p = 0.29$).

It is interesting to note that daily EE correlated well with body mass ($r = 0.67$, $p < 0.001$; Figure 1(a)), and even better with lean body mass ($r = 0.70$, $p < 0.001$; 1B).

Energy and macronutrient intake on training, match, and rest days

Table 4 provides an overview of the energy and macronutrient intake during training, match and rest days. Players reported a significantly higher energy intake on a match day (13.1 ± 4.1 MJ) compared with training (11.1 ± 3.4 MJ; $p = 0.026$) and rest days (10.5 ± 3.1 MJ; $p = 0.007$). In a similar fashion, carbohydrate intake was higher during match day (5.1 ± 1.7 g/kg body mass) compared with training (3.9 ± 1.5 g/kg body mass; $p = 0.005$), and rest days (3.7 ± 1.4 g/kg body mass; $p = 0.001$). Energy and carbohydrate intake did not significantly differ between training and rest days.

Despite differences in carbohydrate intake, the protein intake was comparable between training (1.7 ± 0.6 g/kg/ body mass) and match days (1.8 ± 0.6 g/kg/body mass). However, protein intake on rest days (1.5 ± 0.5 g/kg body mass) was lower compared with training and match days ($p < 0.05$ for both comparisons). Overall, 72% of the protein in the diet was derived from animal sources versus 28% from plant sources. The amount of protein derived from animal and plant sources specified per meal moment are shown in Supplemental Figure 1.

With an intake of ~1.2–1.3 g/kg, absolute fat intake was not significantly different between days. However, when expressed as percentage of total energy intake, relative fat intake appeared to be lower on match days (27.6 ± 6.7 En%) compared with rest days (32.4 ± 8.9 En%; $p < 0.05$).

Total water intake (including water in food products) significantly differed between days ($p < 0.001$), with the highest intake on match days (4.4 ± 1.7 L), followed by training (3.6 ± 1.1 L) and rest days (2.7 ± 0.9 L).

Table 3. Daily energy expenditure, and energy and macronutrient intake for total group and different playing positions.

		Total group (n = 41)	Goalkeeper (n = 4)	Defender (n = 12)	Midfielder (n = 13)	Attacker (n = 12)	p-value
Daily EE	kcal/day	3285 ± 354	3365 ± 231	3333 ± 489	3180 ± 294	3322 ± 297	0.65
	kcal/kg BM/day	42.4 ± 3.5	37.6 ± 2.9	42.0 ± 3.3	44.4 ± 3.2	42.4 ± 2.6	0.004[B]
	kcal/kg LBM/day	48.0 ± 3.9	43.0 ± 3.7	47.3 ± 3.8	50.1 ± 3.3	48.3 ± 3.1	0.01[B]
	MJ/day	13.8 ± 1.5	14.1 ± 1.0	14.0 ± 2.0	13.3 ± 1.2	13.9 ± 1.2	0.65
	kJ/kg BM/day	178 ± 15	157 ± 12	176 ± 14	186 ± 14	177 ± 11	0.004[B]
	kJ/kg LBM/day	201 ± 16	180 ± 15	198 ± 16	210 ± 14	202 ± 13	0.01[B]
PAL		1.75 ± 0.13	1.64 ± 0.13	1.76 ± 0.16	1.78 ± 0.12	1.76 ± 0.11	0.29
Daily EI	kcal/day	2658 ± 693	2606 ± 586	2864 ± 699	2534 ± 550	2602 ± 874	0.68
	MJ/day	11.1 ± 2.9	11.0 ± 2.5	12.0 ± 2.9	10.6 ± 2.3	10.9 ± 3.7	0.71
Protein	g	129 ± 36	134 ± 45	136 ± 45	125 ± 33	126 ± 29	0.87
	g/kg	1.7 ± 0.5	1.5 ± 0.5	1.7 ± 0.5	1.8 ± 0.5	1.6 ± 0.4	0.70
	en%	20.3 ± 3.7	20.1 ± 3.1	19.9 ± 5.0	20.0 ± 2.0	21.1 ± 4.1	0.87
Carbohydrate	g	306 ± 86	322 ± 64	328 ± 90	286 ± 53	301 ± 116	0.66
	g/kg	4.0 ± 1.2	3.6 ± 0.8	4.2 ± 1.4	4.0 ± 0.8	3.8 ± 1.4	0.80
	en%	46.6 ± 6.2	50.9 ± 4.6	46.3 ± 5.7	46.5 ± 7.4	45.6 ± 5.7	0.53
Fibre	g	23 ± 7	27 ± 10	24 ± 7	23 ± 5	20 ± 8	0.31
	g/1000kcal	9 ± 2	11 ± 3	9 ± 2	9 ± 2	8 ± 2	0.08
	en%	1.7 ± 0.4	2.0 ± 0.6	1.6 ± 0.4	1.8 ± 0.4	1.5 ± 0.4	0.10
Fat	g	94 ± 33	80 ± 19	104 ± 30	92 ± 34	93 ± 39	0.62
	g/kg	1.2 ± 0.5	0.9 ± 0.2	1.3 ± 0.4	1.3 ± 0.5	1.2 ± 0.5	0.45
	en%	30.8 ± 4.9	26.6 ± 2.2	31.8 ± 3.8	30.9 ± 6.0	31.2 ± 4.9	0.33
Water	L	3.5 ± 1.0	4.8 ± 1.5	3.6 ± 1.0	3.2 ± 0.8	3.3 ± 0.7	0.02[B,C]

Energy and macronutrient intake includes sports nutritional products and supplements.
Data are expressed as mean±sd. BM, body mass; LBM, lean body mass; EE, energy expenditure; EI, energy intake; PAL, physical activity level. Differences between positions were analysed by one-way ANOVA. Significance values obtained from post-hoc analyses: [A] p-value <0.05 for goal keeper vs. defender, [B] p-value <0.05 for goal keeper vs. midfielder, [C] p-value <0.05 for goal keeper vs. attacker, [D] p-value <0.05 for defender vs. midfielder, [E] p-value <0.05 for defender vs. attacker, [F] p-value <0.05 midfielder vs. attacker.

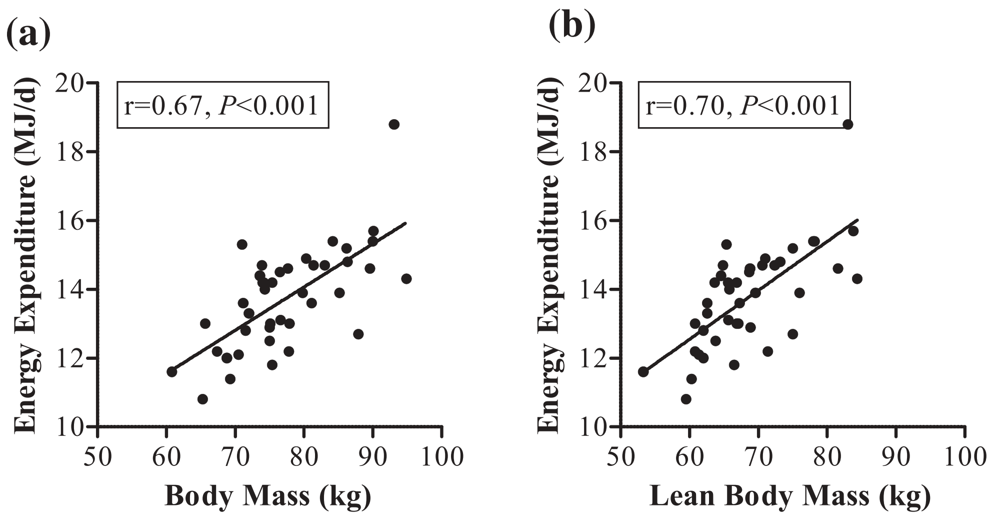

Figure 1. Correlations between daily EE and body mass (panel A) and lean body mass (panel B).

Table 4. Energy and macronutrient intake during training, match, and rest days.

		Training (n = 41)	Match (n = 37)	Rest (n = 39)	p-value
Energy	kcal	2637 ± 823	3114 ± 978	2510 ± 740	<0.001[A,C]
	MJ	11.1 ± 3.4	13.1 ± 4.1	10.5 ± 3.1	<0.001[A,C]
Protein	g	133 ± 43	139 ± 46	116 ± 33	0.007[B,C]
	g/kg	1.7 ± 0.6	1.8 ± 0.6	1.5 ± 0.5	0.006[B,C]
	en%	21.1 ± 5.5	18.4 ± 4.2	19.4 ± 4.9	0.49
Carbohydrate	g	296 ± 104	393 ± 137	289 ± 113	<0.001[A,C]
	g/kg	3.9 ± 1.5	5.1 ± 1.7	3.7 ± 1.4	<0.001[A,C]
	en%	45.5 ± 8.0	51.2 ± 7.1	46.5 ± 9.7	0.003[A,C]
Fibre	g	24 ± 8	24 ± 8	20 ± 9	0.01[B,C]
	g/1000kcal	9 ± 3	8 ± 2	8 ± 3	0.012[A]
	en%	1.8 ± 0.5	1.5 ± 0.4	1.5 ± 0.5	0.015[A]
Fat	g	95 ± 41	99 ± 41	94 ± 40	0.83
	g/kg	1.2 ± 0.6	1.3 ± 0.6	1.2 ± 0.5	0.74
	en%	31.2 ± 6.4	27.6 ± 6.7	32.4 ± 8.9	0.005[C]
Water	L	3.6 ± 1.1	4.4 ± 1.7	2.7 ± 0.9	<0.001[A,B,C]

Data are expressed as mean±sd. Differences between days were analysed by RM ANOVA. Not all players played a match or had a rest day. For some players it was unable to assess a 24-h recall after a rest day. Significance values obtained from post-hoc analyses: [A] p-value <0.05 for training vs. match, [B] p-value <0.05 for training vs. rest, [C] p-value <0.05 for match vs rest.

Protein intake distribution

As shown in Figure 2, protein intake was highest at dinner, followed by lunch and breakfast. Overall, 56% of the players did not meet the recommendation to consume a minimum of 20 g of protein at breakfast. At lunch and dinner, respectively 24% and 5% of the players did not achieve the target of 20 g protein at each main meal. Only a small proportion of players achieved an intake of 20 g protein with the snacks consumed between main meals or before the night.

Discussion

In the current study we determined energy expenditure and food intake over a 14-day period in a large number of professional football players playing in the Dutch Eredivisie. With an average daily energy expenditure of ~13.8 MJ (3285 kcal) and PAL value of 1.75 ± 0.13, the daily energy requirements of professional football players can be considered modest compared with other team sports. The weighted mean daily EI of 11.1 ± 2.9 MJ as assessed by face-to-face 24h recalls was 18 ± 15% lower than the daily EE. Given the lack of changes in body mass during the assessment period, the discrepancy between daily EE and EI is likely explained by underreporting of food intake. The dietary intake analyses revealed sufficient protein intake, whereas carbohydrate intake was substantially lower than current recommendations proposed for football players.

The current study is one of the few studies that addressed the daily EE in professional football players by the gold standard DLW method. By including a large cohort of football players (n = 41) from three major football clubs in the Dutch Eredivisie, the cohort can be considered representative for an entire football squad or football competition. The average daily EE of 178 ± 15 kJ/kg body mass (42.4 ± 3.5 kcal/kg body mass) observed in the present study is comparable with the average daily EE (187 ± 35 kJ/kg body mass (44.7 ± 8.4 kcal/kg body mass)) recently reported in six professional football players in the English Premier League (EPL) (Anderson et al., 2017), but somewhat lower than the daily EE (213 ± 32 kJ/kg body mass (50.9 ± 7.6 kcal/kg body mass)) and PAL (2.19 ± 0.31) reported for seven Japanese professional football players (Ebine et al., 2002). Although the differences between the daily EE and PAL in Japanese and European football players

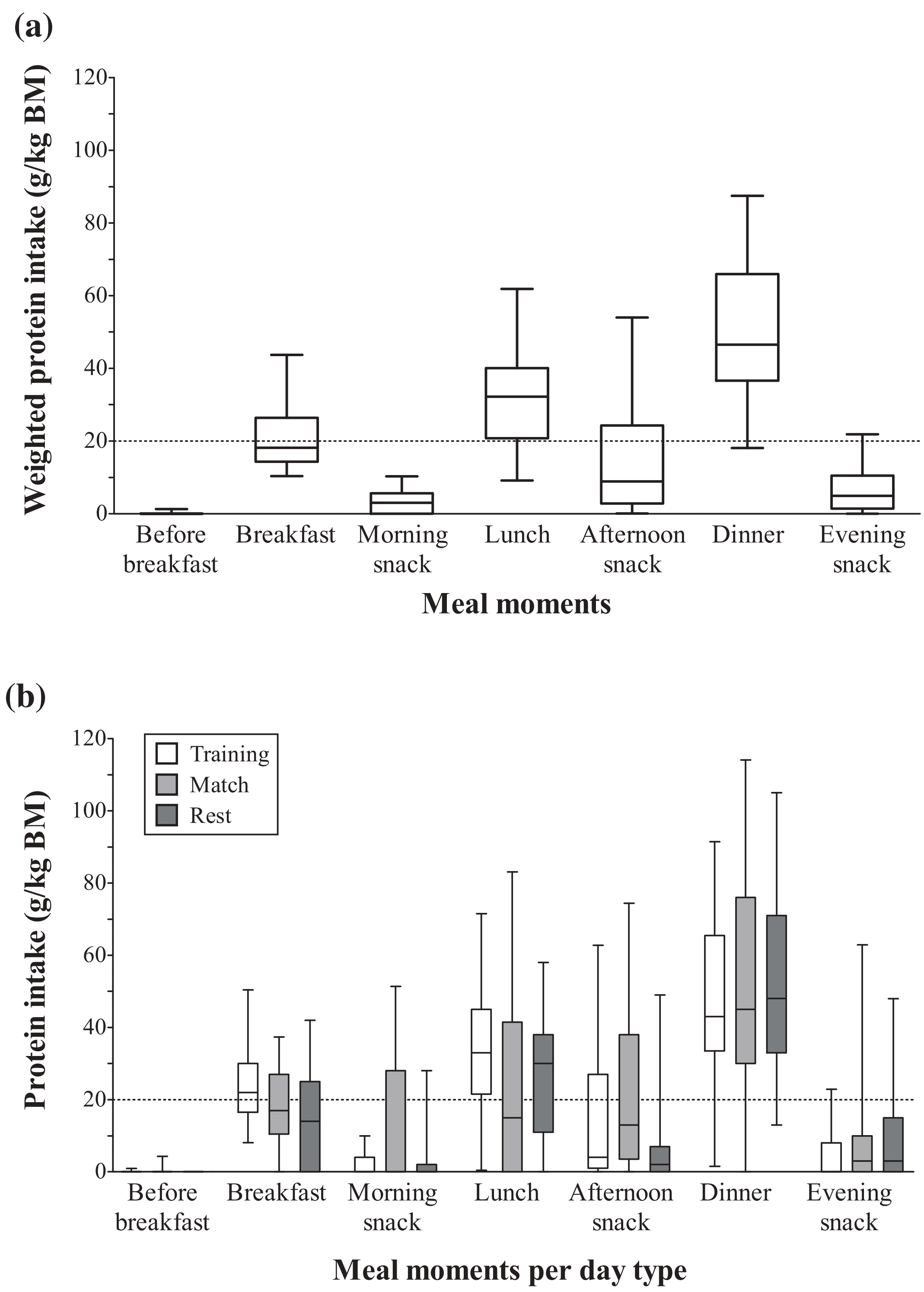

Figure 2. Protein intake distribution throughout the day. The protein intake distribution is reported as the weighted average over the 14-day period (panel A), and for training, match and rest days separately (panel B). The boxplots represent medians with 1st and 3rd quartiles, with whiskers indicating 5–95 percentile of the data.

are difficult to explain, it can be speculated that ethnic differences in EE, as well as differences in training regimens, habitual physical activity patterns and climatological conditions may play a role.

Compared with other team sports, the daily EE of football players can be considered modest. A recent study in elite rugby players reported a daily EE of ~237 kJ/kg body mass (~57 kcal/kg body mass) and mean PAL of 2.9 as assessed by the DLW method (Morehen et al., 2016). Another study that applied the DLW approach in elite rugby players reported a daily EE of 213 kJ/kg body mass (51 ± 9 kcal/kg body mass) and PAL of 1.93 ± 0.33) in players under 20 years, while the daily EE and PAL value were respectively 201 kJ/kg body mass (48 ± 11 kcal/kg body mass) and 2.14 ± 0.64 in players under 24 years (Smith et al., 2018). The DLW method also revealed a high daily EE and PAL in junior elite basketball players (~239 kJ/kg body mass (~57 kcal/kg body mass) and 2.9 ± 0.5, respectively) (Silva et al., 2013). Altogether, these data indicate large variation in daily energy requirements between different team sports. This underlines the fact that energy requirements cannot be generalized across different team sports and emphasizes the need for objective measurements of energy requirements in professional team sports. Moreover, nutritional guidelines for team sports may require more differentiation in energy and macronutrient intake recommendations between sports.

It is interesting to note that the daily EE observed in the current study correlated well with body mass ($r = 0.67$, $P < 0.001$) and even better with lean body mass ($r = 0.70$, $P < 0.001$). This finding suggests that body mass, and lean body mass in particular, can explain much of the variation in EE ($r^2 = 0.46$ and 0.49, respectively). Indeed, when correcting the daily EE for body mass, the individual variation in daily EE is low, as evidenced by the small standard deviation (42.4 ± 3.5 kcal/kg body mass). Given the strong associations between (lean) body mass and daily EE, it can be speculated that (lean) body mass explains more of the variation in daily EE of professional football players than individual differences in match load, training load, and habitual physical activity. This might be attributed to the large homogeneity of daily physical activity patterns in professional football players, with many days being characterized by a training session in the morning and relatively low physical activity levels throughout the rest of the day. Nevertheless, individual differences in training and match load and habitual physical activity may also explain some of the variation in daily EE. In agreement, goalkeepers are characterized by a lower training and match load compared with the field players (see Supplementary Table 1. Training and match load per playing position), along with a lower daily EE. From a practical perspective, the strong association between body mass and daily EE can be used to provide simple estimates of the players' average daily EE. In this regard, multiplying the player's body mass by the average daily EE observed in the current study (~180 kJ (~42.5 kcal)) provides a good estimate of the average daily energy requirements. Taking small to moderate individual variation or playing position into account, we suggest that players who are subjected to high training and match loads require more energy (~190 kJ (~45 kcal) per kg body mass), whereas less active players and goal keepers may require no more than ~170 kJ (~40 kcal) kg body mass.

In the present study, the weighted daily EI (11.1 ± 2.9 MJ (2658 ± 693 kcal)) assessed by face-to-face 24h recalls was 18 ± 15% lower than the daily EE (13.8 ± 1.5 MJ (3285 ± 354 kcal)) measured by DLW. Although this finding suggests a negative energy balance, it should be noted that the body mass of the football players remained stable over the 14d assessment period. Therefore, the EI assessment was likely subjected to underreporting, rather than undereating. This is not surprising, as underreporting is a common phenomenon in nutrition research (Black et al., 1993; Hebert et al., 2014). The 18 ± 15% underreporting of EI observed in the present study is in close agreement with other studies in elite athletes that validated EI against the DLW method. In this regard, Capling et al. (2017) recently reported an average under-estimation of 19% in eleven studies comparing self-reported EI to EE measured by the DLW-method. It should be noted that the underreporting may be partly explained by selective underreporting of undesirable and/or energy dense food (Magkos & Yannakoulia, 2003), which may potentially lead to greater underreporting of carbohydrate and fat compared with protein intake.

The average intake of carbohydrates observed in the present study was higher on match days (5.1 ± 1.7g/kg body mass) compared with training (3.9 ± 1.5g/kg body mass) and rest days (3.7 ± 1.4g/kg body mass). In line, the percentage of energy derived from carbohydrates was substantially higher on match days (51%) compared to training (46%) and rest days (47%), indicating a selective increase in carbohydrate content of the diet on match days. A similar pattern of daily carbohydrate intake has recently been reported by the studies of Bettonviel et al. (2016) and Anderson et al. (2017). Altogether, these findings suggest that players modulate the intake of carbohydrates based on anticipated differences in workload between training and match days. Despite this differentiation, the intake of carbohydrate is far from adequate according to the current nutritional guidelines for football players. These guidelines generally recommend a daily carbohydrate intake of 5 to 7g/kg body mass on moderate training days, and from 7 up to 12 g/kg body mass for heavy training days or in preparation for a match (Burke et al., 2006; Hawley, Tipton, & Millard-Stafford, 2006). Even when considering modest underreporting of carbohydrate intake, the recommended carbohydrate intake was not met by the majority of football players. As carbohydrate intake is crucial for performance in football, nutritional counselling in professional football should focus more on achieving adequate intakes of carbohydrate.

The use of the DLW method in the present study allows the evaluation of carbohydrate intake in the light of the daily EE. In this regard, the higher range of carbohydrate intake recommended by the current guidelines (up to 12 g/kg body mass/day) may strongly exceed the energy requirements of professional football players. For a football player of 80 kg, a daily carbohydrate intake of 12 g/kg body mass translates to 16.1 MJ (3840 kcal). When considering a protein intake of 1.6 g/kg body mass/day (2.1 MJ (512 kcal)), and fat intake of 1.2 g/kg body mass/day (3.6 MJ (864 kcal)), the total daily EI would be as much as 21.8 MJ (5216 kcal). This calculation demonstrates that the higher range of the recommended carbohydrate intake would strongly exceed the daily energy requirements of professional football players. Even when taking carbohydrate periodization into account, thereby allowing higher EI on match days, a carbohydrate intake of up to 8 g/kg body mass/day seems an upper limit for professional football players. Our finding suggests that future guidelines should reconsider the current recommendations to consume up to 12 g/kg body mass/day of carbohydrate. When taking the energy balance of football players into consideration, it seems more appropriate to aim for a carbohydrate intake of 7–8 g/kg body mass/day on match and heavy training days.

In the present study, we observed a weighted mean daily protein intake of 1.7 ± 0.5 g/kg body mass/day. As such, the recommended daily protein intake for football players (1.2 to 1.7 g/kg body mass/day) (Boisseau et al., 2007; Burke et al., 2006; Lemon, 1994; Phillips & Van Loon, 2011; Tipton & Wolfe, 2004) is more than adequately covered. This finding agrees with previous studies in professional football players, reporting protein intakes ranging from 1.6 to 1.9g/kg body mass/day (Bettonviel et al., 2016; Devlin, Leveritt, Kingsley, & Belski, 2017; Reeves & Collins, 2003; Ruiz et al., 2005; Wardenaar et al., 2017), and even up to 2.5g/kg body mass/day (Anderson et al., 2017). When considering modest underreporting of food intake as seen in the current study, the true protein intake may even exceed the current recommendations. Although this does not seem worrisome from a health perspective, it can be speculated that excessive protein intakes are compensated by low or inadequate intakes of carbohydrate. Therefore, the optimal balance between protein and carbohydrate intake should be closely monitored by a nutritionist.

Although the total daily intake of protein is adequate, the distribution of protein intake throughout the day is quite skewed over the main meals, with the highest intakes observed at dinner and lowest intakes at breakfast. In fact, the majority of football players does not meet the recommendation to consume at least 20 g protein at breakfast. This skewed pattern of protein intake has recently been reported in smaller cohorts of professional football players in the English Premier League (Anderson et al., 2017) and the Dutch Eredivisie (Bettonviel et al., 2016), and in a large cohort of Dutch elite and sub elite athletes competing in various sports (Gillen et al., 2017). Hence, the skewed protein intake pattern seems a common phenomenon in professional football players and other elite athletes. Along with the importance of an even protein distribution over the main meals, the ingestion of protein before the night has been postulated as a potent strategy to optimize recovery and support muscle reconditioning (Trommelen & van Loon, 2016). In this regard, a protein bolus of 30–40 g before sleep is being considered optimal to support skeletal muscle remodelling (Trommelen & van Loon, 2016). With a median intake of 4.9 g, the protein intake between dinner and sleep as observed in the present study was far from optimal. Altogether, our findings with regard to protein distribution imply that many professional football player could benefit from a more balanced protein intake throughout the day, with special attention for protein ingestion before sleep. This can be achieved by redistributing some of the protein ingested at dinner to the breakfast meal and evening snack.

Although the current study has several strengths and practical implications, we should acknowledge some limitations as well. By assessing the average daily EE over a 14-day period, we were unable to assess EE on a day-to-day basis. Hence, the study provides no insight in the day-to-day variation in EE within players. In line, the DLW method does not allow the assessment of EE during isolated training sessions or matches. Consequently, we were unable to assess energy availability of the football players (Loucks, Kiens, & Wright, 2011). Food intake was not assessed on all days during the 14-day period. Nonetheless, the assessment of food intake on a match, training, and rest day allowed us to calculate weighted averages of energy and macronutrient intake over the 14-day period. The training and match load in the current study were assessed by respectively LPM and video tracking technology. Although the LPM system is known as accurate (Stevens et al., 2014), the system was not used during all training sessions. As such, we can only provide the average load for training sessions and matches, rather than the cumulative training and match load over the 14-day period. Consequently, we were unable to address the contribution of training and match load to the total EE. This remains an issue for further investigation.

In conclusion, with an average daily EE of ~13.8 MJ (3285 kcal), the daily energy requirements of professional football players can be considered modest. Much of the inter-individual variation in EE can be explained by (lean) body mass, implicating that a simple estimate of the daily EE can be based on the players' body mass. Despite evidence for the differentiation of carbohydrate intake on match, training, and rest days, the daily intake of carbohydrate is generally below the recommendations for football players. The total daily intake of protein is more than sufficient, although the distribution of protein intake throughout the day is skewed. As such, nutritional counselling should focus more on achieving adequate intakes of carbohydrates and a more even distribution of protein throughout the day. Finally, our data suggest that current carbohydrate recommendations should be reconsidered and aligned with the daily energy requirements of professional football players.

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Author contributions

Designed: NYJB, LJCvL, JWvD; Data collection: NYJB, NI, LW, JWvD; Analytical measures: GP, LW, NYJB; Data analysis: NYJB, NI, JWvD; Wrote manuscript: NYJB; Revised: GP, WHMS, LJCvL, JWvD. None of the authors had a conflict of interests. All authors approved the final version of the manuscript prior to submission and are accountable for data accuracy and integrity.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Wim H.M. Saris http://orcid.org/0000-0003-0985-0047
Luc J.C. van Loon http://orcid.org/0000-0002-6768-9231
Jan-Willem van Dijk http://orcid.org/0000-0001-9674-1505

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