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PHYSIOLOGY AND NUTRITION

Daily energy requirements of male academy soccer players are greater than age-matched non-academy soccer players: A doubly labelled water investigation

Reuben G. Stables[a], Marcus P. Hannon[a], Adam D. Jacob[a], Oliver Topping[a], Nessan B. Costello[b], Lynne M. Boddy[a], Catherine Hambly[c], John R. Speakman[c], Jazz S. Sodhi[d], Graeme L. Close[a] and James P. Morton[a]

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ABSTRACT

This study aimed to test the hypothesis that the total daily energy expenditure (TDEE) of male academy soccer players is greater than players not enrolled on a formalised academy programme. English Premier League academy (ACAD: $n = 8$, 13 years, 50 ± 6 kg, $88 \pm 3\%$ predicted adult stature, PAS) and non-academy players (NON-ACAD: $n = 6$, 13 years, 53 ± 12 kg, $89 \pm 3\%$ PAS) were assessed for TDEE (via doubly labelled water) during a 14-day in-season period. External loading was evaluated during training (ACAD: 8 sessions, NON-ACAD: 2 sessions) and games (2 games for both ACAD and NON-ACAD) via GPS, and daily physical activity was evaluated using triaxial accelerometry. Accumulative duration of soccer activity (ACAD: 975 ± 23 min, NON-ACAD: 397 ± 2 min; $p < 0.01$), distance covered (ACAD: 54.2 ± 8.3 km, NON-ACAD: 21.6 ± 4.7 km; $p < 0.05$) and time engaged in daily moderate-to-vigorous (ACAD: 124 ± 17 min, NON-ACAD: 79 ± 18 min; $p < 0.01$) activity was greater in academy players. Academy players displayed greater absolute (ACAD: 3380 ± 517 kcal $\cdot$ d^{-1}, NON-ACAD: 2641 ± 308 kcal $\cdot$ d^{-1}; $p < 0.05$) and relative TDEE (ACAD: 66 ± 6 kcal $\cdot$ kg $\cdot$ d^{-1}, NON-ACAD: 52 ± 10 kcal $\cdot$ kg $\cdot$ d^{-1}; $p < 0.05$) versus non-academy players. Given the injury risk associated with high training volumes during growth and maturation, data demonstrate the requirement for academy players to consume sufficient energy (and carbohydrate) intake to support the enhanced energy cost of academy programmes.

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Doubly labelled water; association football; adolescents

Introduction

The aim of soccer academies is to develop players through improving their technical, tactical, physical, and psychosocial capabilities (Wrigley et al., 2012), where the end goal is to produce players to represent the first team at the host club or to be sold for financial gain (Elferink-Gemser et al., 2012). The apparent success of soccer academies is evidenced by the recent report that over 75% of professional contracts in the English Premier League (EPL) and English Football League (EFL) are held by homegrown players (Premier League, 2022). Such success may be underpinned by the introduction of "Elite Player Performance Plan" (EPPP) in 2011 (Premier League, 2011), a strategic plan that was co-created by the EPL, EFL and the Football Association (FA). According to the EPPP framework, clubs are audited and categorised from Category One (the best) to Four, largely dependent on the extent of support they provide to their players, taking into consideration factors such as productivity rates, training facilities, coaching, education, welfare provision and sport science and medicine support. However, despite the mandate from the EPPP for interdisciplinary specialists in the sports science and medicine team, a recent audit from our group (from all 89 soccer academies across England) reported that the provision of "nutrition-related support" is not readily comparable to the other disciplines of sport and exercise science, perhaps most evidenced by the lack of full-time and professionally accredited staff delivering nutrition-related services (Carney et al., 2023).

Nonetheless, emerging data clearly demonstrate the importance of consuming sufficient daily energy intake to support the energetic requirements of growth and maturation alongside the energy cost of increasing training demands. Indeed, the sustained periods of growth and maturation that players experience as they transition through the academy pathway (i.e., from under (U) 12 to U18 age groups) significantly increases both their resting metabolism and total daily energy requirements. For example, in a cohort of male academy players from the EPL, we observed that the increase in body mass (~30 kg), fat-free mass (~23 kg) and stature (~25 cm) between the ages of 12 and 18 coincides with an increased resting metabolic rate of approximately 400 kcal $\cdot$ d^{-1} (Hannon et al., 2020). Furthermore, in accordance with increases in absolute daily training and match load (i.e., increases in duration and total distance) throughout the development pathway (Hannon et al., 2021), we also observed significant increases in total daily energy expenditure (TDEE; ~750 kcal $\cdot$ d^{-1}) between U12 and U18 players (Hannon et al., 2021). In some individuals,

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total daily energy expenditure (as evident in U12, U15 and U18 players) was comparable to or exceeded (i.e., >3500 kcal · d^{-1}) that previously reported from adult players from the EPL (Anderson et al., 2017).

Despite such high training and energetic demands, we recently reported that academy players often "under-fuel" (i.e., fail to consume sufficient energy and carbohydrate intake in relation to recommended guidelines) before, during and after training (Stables et al., 2022), likely due to the busy schedules associated with schooling and travelling to and from training, the lack of dedicated resource provision and a lack of education for key stakeholders such as coaches and parents (Carney et al., 2023). Although the negative outcomes associated with "under-fuelling" are often considered from a performance perspective, a more concerning outcome is the potential impact upon growth and maturation with a specific risk to skeletal structures. In this regard, we also reported that the most prevalent injury occurring in academy players from England, Europe and South America was growth-related injuries in the anatomical location of the knee, lower back, sacrum and pelvis, the prevalence of which was most evident during periods of peak height velocity (Hall et al., 2020).

Although the importance of nutrition in supporting player development is becoming increasingly recognised, we acknowledge that the direct assessment of total daily energy expenditure in academy players is limited to the study of players from a single soccer academy (Hannon et al., 2021). In this way, our current understanding of the energetic requirements of academy soccer players may not be applicable to players from other academies where the club may have differing training demands and schedules. Furthermore, no researchers have yet quantified the daily energy expenditures of non-academy soccer players, and as such, the "energy cost" associated with partaking in a formalised academy programme is not yet known.

With this in mind, the aim of the present study was to quantify the total daily energy expenditure, external training demands and physical activity levels of academy soccer players when compared with age matched non-academy soccer players. To this end, players from a Category One academy from the English Premier League and players competing at "grassroots" level were assessed for energy expenditure (using the doubly labelled water method), external training load (via GPS technology) and daily physical activity levels (via triaxial accelerometry) during a 14-day in-season data collection period. We deliberately recruited players from the U13 age-groups given that this period is often associated with the highest rate of growth during adolescence (i.e., peak height velocity; Hannon et al., 2020). We hypothesised that academy players would present with significantly greater total daily energy expenditure than non-academy players, in accordance with the greater training demands associated with formalised coaching programmes.

Methods

Participants

Sixteen male soccer players (outfield, $n = 15$, goalkeeper $n = 1$) volunteered to participate in this study. To satisfy the eligibility criteria of this study, players were enrolled in a Category One academy from the English Premier League (ACAD: $n = 8$) and aged matched non-academy players participating in "grassroots" standard soccer (NON-ACAD: $n = 8$). Sample size was estimated according to our primary outcome variable of total daily energy expenditure (TDEE). On the basis of our previous assessments of TDEE in U12/13 male academy players (2859 ± 265 kcal · d^{-1}) and an estimated activity energy expenditure of 500 kcal · d^{-1} (Hannon et al., 2020), we assumed an estimated mean difference in TDEE between groups of 500 kcal · d^{-1} with a group standard deviation of 250 kcal · d^{-1} for TDEE for each group. These data would provide an effect size of dz = 2 where a total sample size of 12 (6 in each group) would provide an alpha value of 0.05 and statistical power of 0.80 (G* Power, version 3.1). Two players from the non-academy group were later removed from the study due to failure to comply with sample collection. Participant characteristics of the subjects who completed the study are presented in Table 1. All procedures conformed to the standards of the Declaration of Helsinki, written informed parental/guardian consent and player assent was obtained, and ethical approval was granted by Liverpool John Moores University.

Study design

In a cross-sectional design, players were assessed for TDEE, daily physical activity, and pitch-based loading (comprising both training and game-related activity) over a 14-day in-season period. A 14-day data collection period was chosen for assessment of TDEE so as to provide a time-scale that was deemed long enough to provide an accurate representation of the typical training and physical activity levels that are habitually completed by both groups of players. Data were collected during a 4-week period during April and May 2022 where the academy players were sampled for the initial 2-week period and the non-academy players were sampled during the subsequent 2-week period. The specific timing of the two-week microcycle was selected for the earliest time of convenience for both groups following ethical clearance. During this time, players continued with their usual schooling, training and

Table 1. Baseline player characteristics.

	Academy	Non-academy
n	8	6
Age	13.4 ± 0.2	13.1 ± 0.5
(years)	(13.1–13.6)	(12.8–13.5)
Maturity offset	− 0.56 ± 0.65	− 0.78 ± 0.77
(years)	(- 1.4–0.3)	(- 2.2–0.0)
Current percent of	88.8 ± 2.7	89.2 ± 2.3
PAS (%)	(85.6–92.6)	(85.2–91.0)
Stature	165.7 ± 7.2	162.9 ± 6.4
(cm)	(155.8–178.0)	(152.0–168.7)
Body mass	51.2 ± 8.4	52.7 ± 12.4
(kg)	(41.2–65.9)	(36.2–73.4)
Fat-free mass	45.9 ± 8.2	39.6 ± 6.0
(kg)	(35.2–60.2)	(30.7–48.8)
Resting metabolic rate	1824 ± 90*	1699 ± 45
(kcal · day^{-1})	(1706 – 1983)	(1656 – 1779)

(PAS) Predicted Adult Stature. *Denotes significant difference between squads (main effect, $p < 0.05$). Data are presented as means ± SD with range displayed in parentheses.

Table 2. An overview of pitch-based training and match schedules with GPS metrics for each squad. GPS metrics shown are an average of two in-season microcycles.

	MD − 1	MD	MD +1	MD +2	MD − 4	MD − 3	MD − 2
Academy	Saturday 09:30–11:00 Training	Sunday 10:30–12:00 Match	Monday OFF	Tuesday 17:30–19:30 Training	Wednesday 15:00–19:00 Training	Thursday 17:30–19:30 Training	Friday OFF
Total Distance (km)	5.4 ± 0.6	7.3 ± 0.9[acde*]		6.1 ± 0.6	6.1 ± 0.8	5.8 ± 0.9	
Average Speed (m · min^{-1})	61.9 ± 7.3	87.1 ± 7.6 [acde*]		62.5 ± 6.5	70.7 ± 5.4	73.7 ± 12.6	
High Speed Running (m)	160 ± 57	324 ± 104 [acde*]		70 ± 38	103 ± 29	109 ± 80	
Accelerations (n)	28 ± 8	32 ± 10*		39 ± 7	32 ± 6	33 ± 10	
Decelerations (n)	32 ± 7	40 ± 11[*d]		34 ± 7	27 ± 7	30 ± 10	
Non-academy	Friday OFF	Saturday 10:30–12:00 Match	Sunday OFF	Monday OFF	Tuesday OFF	Wednesday OFF	Thursday 18:00–20:00 Training
Total Distance (km)		4.4 ± 2.0					6.3 ± 0.5
Average Speed (m · min^{-1})		51.6 ± 23.7					60.8 ± 5.6
High Speed Running (m)		38 ± 7					57 ± 60
Accelerations (n)		9 ± 6					8 ± 5
Decelerations (n)		12 ± 9					11 ± 6

[a], [c], [d] and [e]Denote significant difference from match day (MD) – 1, MD + 2, MD-4 and MD-3, respectively. *Denotes significant difference from MD external loading between the academy and non-academy group, all $p < 0.05$.

game schedules and the research team did not influence the content of any soccer-related activity or additional physical activity. To aid compliance for dietary self-reporting, players were also assessed for self-reported energy and macronutrient intake during the first 7 days of the study period only. An overview of the weekly training and match schedules of both groups is shown in Table 2 and a schematic overview of the study is presented in Figure 1.

Baseline measures

On the evening before day 1 and after providing a baseline urine sample, players were assessed at baseline for stature, body mass and maturity status. Participants wore minimal training kit (t-shirt and shorts) for assessments of stature, sitting height and body mass. Participants' body mass (SECA, model – 875, Hamburg, Germany), stature and sitting height (SECA, Hamburg, Germany) were measured to the nearest 0.1 kg, 0.1 cm and 0.1 cm, respectively. Absolute fat mass, percentage fat mass and fat-free mass were calculated via hydrometry (Edelman et al., 1952). As the value of deuterium is known, it is possible to calculate total body water to an error lower than 2% (Scholeller, 1996). Absolute fat-free mass was then used to calculate resting metabolic rate using the population-specific prediction equation developed by Hannon et al. (2020). Somatic maturity was calculated using maturity offset (Mirwald et al., 2002), allowing for calculation of predicted adult stature (PAS) and current percentage of adult stature achieved (%PAS) (Sherar et al., 2005).

Quantification of training load

Pitch-based training load was measured using global positioning system (GPS) technology (Vector, Catapult, Melbourne, Australia). Each player was provided a GPS unit (81 mm × 43 mm × 16 mm) and custom-made manufacturer provided vest (Catapult, Melbourne, Australia) to wear on the upper back between both scapulae during each pitch-based training session and match. Each unit was alarmed to turn on 30 min prior to the start of each session to sample total distance (m), high

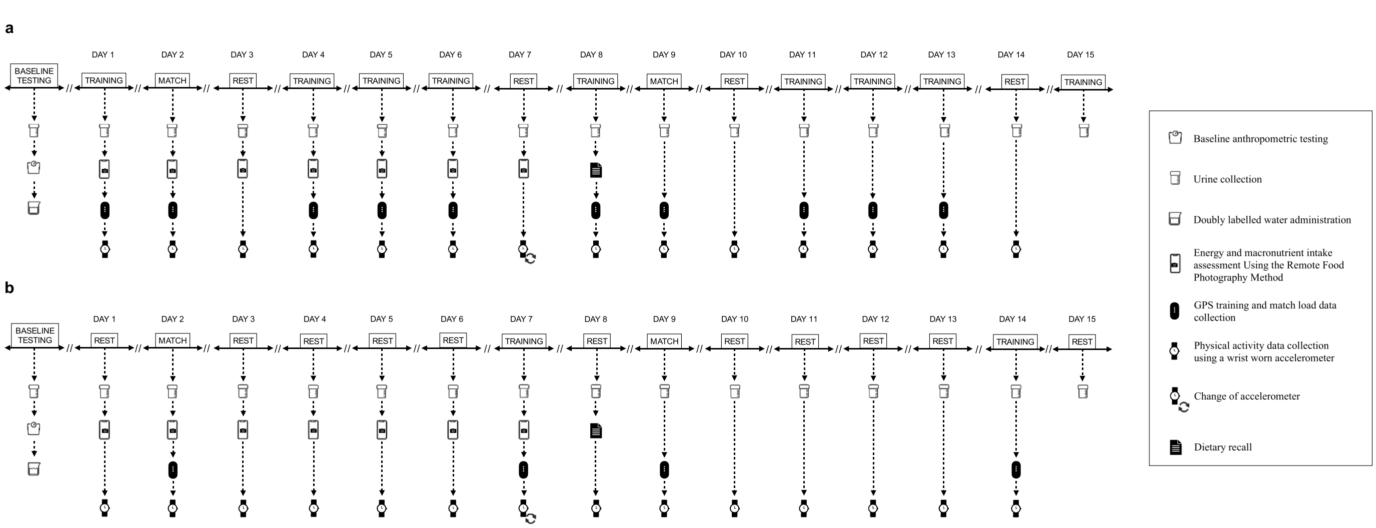

Figure 1. Schematic overview of the study period for the (a) academy and (b) non-academy group.

speed running metres (>5.5 m · s^{-1}), metres per minute (m · min^{-1}), accelerations (>3 m · s^{-1}), and decelerations (<3 m · s^{-1}) at 10 Hz providing a valid and reliable assessment of soccer-specific movement (Coutts & Duffield, 2010; Varley et al., 2012). To ascertain when academy soccer players are capable of achieving the training and match intensities of adult EPL players, absolute speed thresholds commonly used within the adult game were deliberately selected (Anderson et al., 2016; Malone et al., 2015).

Measurement of total daily energy expenditure (TDEE) and body composition using the doubly labelled water (DLW) method

Measurement of total energy expenditure over the 14-day study period was quantified using the DLW method as previously used in EPL academy soccer players (Hannon et al., 2021). On the evening before day 1 of the study between the hours of 17:00–18:00, participants were invited to each respective training ground and asked to provide a baseline urine sample. A single oral bolus dose of deuterium (^{2}H) and oxygen (^{18}O) in stable isotopes in the form of water ($^2H_2{}^{18}O$) was then consumed by each player. Doses were calculated according to each individual player's body mass taken 1 week prior to the start of the study, with a desired enrichment of 10% ^{18}O and 5% $^2H_2$, using the calculation:

$$\text{dose (mL)} = 0.65\ (\text{body mass, g}) \times \text{DIE/IE}$$

where 0.65 is the approximate proportion of the body comprising water, DIE is the desired initial enrichment (DIE = 618.923 body mass, kg$^{-0.305}$), and IE is the initial enrichment (10%) 100,000 ppm (Speakman, 1997). Each player was provided with a glass bottle containing the precise dose required (weighed to 4 d.p.) and asked to consume all of the dose. To ensure that the entire dose of DLW was consumed, additional water was added to the dosing vessel, which was also consumed. Time of dosing was recorded.

On the morning of day 1 (07:00–11:00) players provided a second urine sample in a 30 ml bottle. This allowed initial isotope enrichment to be determined following total body water equilibrium. Thereafter, participants provided urine samples every morning (second pass of the day) for the duration of the study, recording the time of each pass, to determine elimination rates of both isotopes via the multipoint method (Westerterp, 2017). All urine samples were collected in a 30 ml tube and subsequently aliquoted and stored in 1.8 ml cryovials at –80°C until later analysis in compliance with the Human Tissue Act (2004). Samples were encapsulated into capillaries and vacuum distilled, with the resulting water being used for analysis. This water was then analysed using a liquid water analyser (Berman et al., 2012) alongside three laboratory standards for each isotope and three international standards (Standard Light Arctic Precipitation, Standard Mean Ocean Water and Greenland Ice Precipitation) to account for machine day-to-day variation and correct delta values to parts per million. Isotope elimination rates were converted to energy expenditure using the Speakman et al. (2021) two-pool equation with a mean food quotient of 0.85. Energy expenditure data is expressed as a daily average over the 14-d study period, as well as total energy expenditure values of week 1, week 2 and the 14-d period combined.

Quantification of energy and macronutrient intake

Self-reported daily energy and macronutrient intake was quantified using the remote food photographic method (RFPM). This method has previously been validated in adolescent team sport athletes (Costello et al., 2017) and used by our group to evaluate self-reported energy and macronutrient intakes in male professional adults (Anderson et al., 2017) and academy (Hannon et al., 2021; Stables et al., 2022) soccer players.

Prior to data collection, all participants and parents/guardians were invited to an educational workshop where the study methodology was explained in detail. Players and parents/guardians of players were initially instructed on the rationale for collecting energy and macronutrient intake data and how these analyses can be used to positively impact player health and performance. Participants were shown a video detailing "step by step" how to use the RFPM and instructed on additional details to include (i.e., branding, weights and cooking methods). Participants were shown common problems (i.e., difficulty to identify food items or a loss of phone signal) when collecting this data and how to rectify them (i.e., provide ingredients and individual weights or record the time of consumption which could be sent as soon as possible once signal had returned). This workshop was also prerecorded and sent to each parent/guardian along with a written step-by-step guide as a point of reference throughout data collection. Prior to the start of data collection, each participant completed a one-day RFPM pilot, preceded by the principal investigator recording their energy and macronutrient intake over a 24-h period to show the quality of images expected, how to compose a detailed description and how to address common issues.

Participants were instructed to take two images of any food or drink consumed using their smartphone; one at 45 degrees and one at 90 degrees (allowing for a better estimation of portion size than one image alone) and send both images to the principal investigator. Participants were instructed to provide a detailed description of each eating occasion encompassing all ingredients (where possible), branding, weights, cooking methods and pre-existing nutritional information from food labels. Post-consumption, participants were required to send a final image detailing any food or drink remaining with weights of anything which had not been consumed. All images were sent using the instant messaging application Threema (Threema GmbH, Pfäffikon, Switzerland). In relation to the academy players and in those instances where food was consumed on-site, the principal investigator was also present at the host club training ground to assist with data collection on behalf of the participants (i.e., self-record images and weights at mealtimes) and make written records of energy and macronutrient intakes, specifically for food and drink provided by the club. No food or drink was provided to the non-academy group. A database of any food and drink provided by the host club was created by the principal investigator to reduce participant burden as the amount of information required for certain foods and drinks (e.g., "homemade energy balls") were on file. Academy players were provided with hot breakfast before matches at weekends, then pre-training snacks and cold post-training food options (e.g., cereal bar, fruit, chicken wrap, pasta pot, flapjack, fruit juice and milkshake) through the week.

At the end of the first 7 days of the study, each player completed a dietary recall to highlight any missed data and cross-reference data collected by the principal investigator (Capling et al., 2017). During this process, the principal investigator clarified all timings, quantities, branding and weights provided by the participant and prompted the participant to recall any missed items. Energy and macronutrient intake was analysed by a Sport and Exercise Nutrition register (SENr) accredited nutritionist, then cross-referenced by two other Sport and Exercise Nutrition register (SENr) accredited nutritionists, each analysing 98 days' worth of photo food records to determine the validity of results using dietary analysis software Nutritics (Nutritics, v5, Dublin, Ireland). Energy intake was reported as kilocalories in both absolute and relative terms, and macronutrient intake was reported in grams for both absolute and relative terms. Inter-rater reliability of analyses was blinded and determined via a one-way analysis of variance (ANOVA). When comparing energy and macronutrient analysis, there was no significant difference between nutritionists' analyses in the academy (energy, $p = 0.99$, CHO, $p = 0.73$, protein, $p = 0.73$, and fat, $p = 0.91$) or non-academy players (energy $p = 0.89$, CHO $p = 0.81$, protein, $p = 0.88$, and fat, $p = 0.97$).

Quantification of physical activity

Free-living physical activity was assessed using the Actigraph GT9X triaxial accelerometer (Actigraph, Pensacola, Florida), which has been validated against traditional hip-worn accelerometers (Rowlands et al., 2014). An accelerometer was worn on the non-dominant wrist at all times during the 14-day data collection period (including during sleep, training and matches and water-based activities) and initialised to sample physical activity at 30 Hz using ActiLife software (ActiLife v6, Actigraph, Pensacola, Florida). To mitigate any changes in behaviour, all data on the watch display was removed apart from the 24-h time. As the accelerometer battery would not last for the 14-day period, at the end of the first 7 days, participants were provided with a second accelerometer for the second half of the study period. All physical activity data was exported using ActiLife software (ActiLife v6, Actigraph, Pensacola, Florida) and stored as raw GT3X files. These were then converted to csv files for analyses using the R software package GGIR (Van Hees et al., 2014). GGIR completed autocalibration and wear time identification (>16 h per day was classed as a valid day), with 10 valid days over the 14-day period necessary to denote valid inclusion (Van Hees et al., 2014). The default non-wear setting was used, whereby if invalid data were present, data was replaced by the average at similar time points on different days of the week (Rowlands et al., 2018). Therefore, the outcome variables were based on the complete 24-h cycle (1440 min) for all participants with valid data. GGIR automatically converted triaxial accelerometer signals into one omnidirectional measure of acceleration (ENMO, Euclidean Norm Minus One) (van Hees VT et al., 2013) to provide a composite summary of acceleration. Average day ENMO values were averaged per 5-s epoch over each day and expressed in milligravitational units (mg). The distribution of time spent in intensity zones of increasing intensity (0–150 mg, 150–300 mg, 300–450 mg, 450–600 mg and >600 mg) (Rowlands et al., 2018) and time spent completing moderate to vigorous physical activity (>200 mg, MVPA) was calculated. The negative curvilinear relationship between the intensity of physical activity and the time spent at any given activity was calculated to provide a physical activity intensity gradient (IG) for each individual (Rowlands et al., 2018).

Statistical analysis

All data were initially assessed for normality of distribution using the Shapiro–Wilk test. Comparisons between academy and non-academy players in baseline data (Table 1), TDEE (Figure 5), mean daily energy and macronutrient intake (Figure 4), accumulative weekly and 14-day external loading (Figure 2), match day external loading (Table 2) and physical activity-related data (Table 3) were assessed using Student's t-tests for independent samples, where ninety-five percent confidence intervals (95% CI) for the differences are also presented. Within group comparisons for differences in time spent in physical activity threshold zones (Table 3) and self-reported energy and macronutrient intake between days were also assessed using a one-way repeated measures analysis of variance (ANOVA) (Figure 4). Given that academy players completed multiple training sessions across the data collection period, differences in external loading between days in the academy players were assessed using a one-way repeated measures ANOVA (Table 2) whilst comparisons between external loading of match day and the training day (only one training day was completed within the weekly micro-cycle) within the non-academy players (Table 2) were assessed using Student's t-test for paired samples. Where significant main effects were present, Bonferroni *post hoc* analysis was conducted to locate specific differences. Relationships between TEE and body mass, stature, RMR, FFM training and match duration, average speed and total distance were assessed using a Pearson's correlation (Figure 6). All data in text, tables and figures are expressed as means and SD with $p < 0.05$ indicating statistical significance. Statistical tests were performed using SPSS for Windows (version 27, SPSS Inc, Chicago, IL).

Results

Accumulative soccer training and match load

The accumulative training and match load completed by both groups of players is presented in Figure 2. The total duration of activity completed in week 1 (ACAD: 591 ± 157 min, NON-ACAD: 190 ± 3 min; 95% CI, 260 to 542, $p < 0.05$), week 2 (ACAD: 506 ± 190 min, NON-ACAD: 205 ± 2 min; 95% CI, 130 to 471, $p < 0.05$) and over the total 14-day assessment period (ACAD: 975 ± 23 min, NON-ACAD: 397 ± 2 min; 95% CI, 557 to 599, $p < 0.01$) was greater in academy players compared with non-academy players (see Figure 2 A). In accordance with a greater exercise duration, the total distance covered in week 1 (ACAD: 31.2 ± 5.6 km, NON-ACAD: 11.6 ± 2.6 km; 95% CI, 14.3 to 25.1, $p < 0.05$), week 2

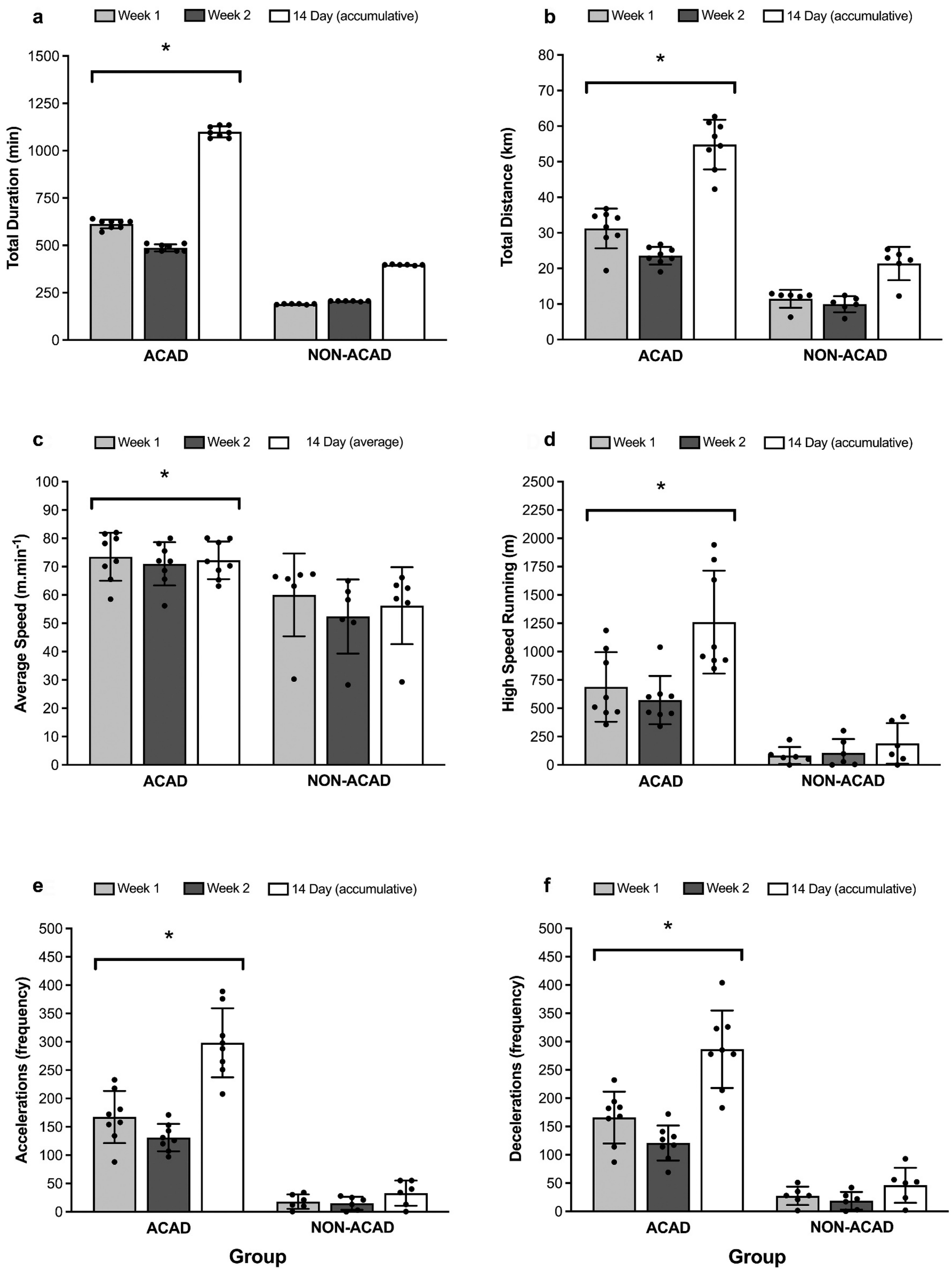

Figure 2. Overview of accumulative training and game duration and external load characteristics. (a) total duration (b) total distance (c) average speed (d) total high-speed running (e) total accelerations and (f) total decelerations across academy training sessions ($n = 8$) and matches ($n = 2$) and non-academy group training sessions ($n = 2$) and matches ($n = 2$). Black dots represent individual data points. *Denotes significant difference from the non-academy group for week 1, week 2 and 14-day period, $p < 0.05$.

(ACAD: 22.9 ± 3.3 km, NON-ACAD: 10.4 ± 2.4 km; 95% CI, 8.9 to 15.9, $p < 0.01$) and over the 14-day period (ACAD: 54.1 ± 8.5 km, NON-ACAD: 21.6 ± 4.7 km; 95% CI, 24.3 to 40.8, $p < 0.05$) was also greater in academy players compared with non-academy players (see Figure 2 B).

In relation to proxy measures of exercise intensity, average speed was also greater in academy players versus non-academy players (see Figure 2 C), as evident in week 1 (ACAD: 74 ± 9 m · min^{-1}, NON-ACAD: 60 ± 15 m · min^{-1}; 95% CI, 0 to 27, $p < 0.05$), week 2 (ACAD: 71 ± 8 m · min^{-1}, NON-ACAD: 55 ± 14 m · min^{-1};

Table 3. Average daily ENMO (Euclidean Norm Minus one; mg), intensity gradient (IG; mg), moderate-to-vigorous activity (MVPA, mg) and time spent within different physical activity zones (minutes) between academy and non-academy groups across the 14-day assessment period.

Physical Activity (PA)	ACAD	NON-ACAD	95% CI
14-day ENMO	62 ± 8* mg (42–80)	45 ± 7 mg (28–76)	8.7 to 26.7
14-day IG	− 2.0 ± 0.1* mg (−2.2 − −1.9)	− 2.7 ± 0.1 mg (−2.9 − −2.3)	0.6 to 0.8
14-day PA 0–150 mg	1312 ± 27 min [bcde] (1273–1365)	1341 ± 25 min [bcde] (1303–1369)	− 58.5 to 2.0
14-day PA 150–300 mg	80 ± 16 min [*cde] (47–109)	62 ± 14 min [cde] (50–82)	1.1 to 35.1
14-day PA 300–450 mg	20 ± 5 min (11–30)	16 ± 6 min (10–25)	− 1.9 to 10.5
14-day PA 450–600 mg	9 ± 3 min (5–13)	11 ± 4 min (6–18)	− 5.9 to 1.9
14-day PA >600 mg	13 ± 4 min* (7–20)	7 ± 3 min (3–10)	2.3 to 9.9
MVPA >200 mg	124 ± 17 min* (69–158)	79 ± 18 min (42–149)	24.6 to 65.1

*Denotes significant difference between groups. [b]Denotes significant difference from 150 to 300 mg, [c]denotes significant difference from 300 to 450 mg, [d]denotes significant difference from 450 to 600 mg, [e]denotes significant difference from >600 mg. Data are displayed as mean ± SD with range in parentheses, and 95% confidence intervals for differences are also presented.

95% CI, 4 to 29, $p < 0.05$) and the 14-day period (ACAD: 72 ± 7 m · min^{-1}, NON-ACAD: 57 ± 14 m · min^{-1}; 95% CI, 3 to 27, $p < 0.05$).

The accumulative distance completed as high-speed running (i.e., >19.8 km · h^{-1}) was also greater in academy versus non-academy players (see Figure 2D), as was the case for week 1 (ACAD: 689 ± 307 m, NON-ACAD: 77 ± 76 m; 95% CI, 330 to 893, $p < 0.01$), week 2 (ACAD: 572 ± 213 m, NON-ACAD: 56 ± 80 m; 95% CI, 315 to 717, $p < 0.01$) and the total 14-day period (ACAD: 1261 ± 454 m, NON-ACAD: 152 ± 149 m; 95% CI, 658 to 1531, $p < 0.01$). As a further marker of exercise intensity, the total number of accelerations (see Figure 2E) completed in week 1 (ACAD: 167 ± 46, NON-ACAD: 16 ± 13; 95% CI, 109 to 193, $p < 0.01$), week 2 (ACAD: 131 ± 24, NON-ACAD: 15 ± 12; 95% CI, 93 to 139, $p < 0.01$) and the 14-day period (ACAD: 299 ± 22, NON-ACAD: 30 ± 10; 95% CI, 211 to 326, $p < 0.01$) and decelerations in week 1 (ACAD: 166 ± 46, NON-ACAD: 25 ± 16; 95% CI, 97 to 183, $p < 0.01$), week 2 (ACAD: 121 ± 31, NON-ACAD: 19 ± 16; 95% CI, 72 to 132, $p < 0.01$) and over the 14-day period (ACAD: 286 ± 24, NON-ACAD: 46 ± 12; 95% CI, 175 to 306, $p < 0.01$) were also markedly greater in academy players compared with non-academy players.

Daily training and match load

An overview of mean daily loading patterns is presented in Table 2. Match duration (ACAD: 62 ± 9 min, NON-ACAD: 92 ± 1 min; 95% CI, 22 to 30, $p < 0.01$) was greater in the non-academy group. However, total distance (ACAD: 7.3 ± 0.9 km, NON-ACAD: 4.4 ± 2.0 km; 95% CI, 1.2 to 4.7, $p < 0.05$), average speed (ACAD: 87.1 ± 7.6 m · min^{-1}, NON-ACAD: 51.6 ± 23.7 km; 95% CI, 16.3 to 54.6, $p < 0.01$), high-speed running (ACAD: 324 ± 104 m, NON-ACAD: 38 ± 39 m; 95% CI, 188 to 384, $p < 0.01$), accelerations (ACAD: 32 ± 10, NON-ACAD: 9 ± 6; 95% CI, 13 to 32, $p < 0.01$) and decelerations (ACAD: 40 ± 11, NON-ACAD: 12 ± 10; 95% CI, 16 to 40, $p < 0.01$) were all greater in academy players versus non-academy players.

No comparisons were made between groups in relation to external loading of training sessions given that training did not occur at comparable time-points in relation to matches. In relation to variations in daily external loading patterns throughout the week in the academy players, significant differences were observed in duration ($p < 0.01$), total distance ($p < 0.01$), average speed ($p < 0.01$), high-speed running metres ($p < 0.01$), accelerations ($p < 0.01$) and decelerations ($p < 0.01$). Pairwise comparisons between days for each of the aforementioned external load variables are presented in Table 2.

Physical activity

Comparisons in physical activity data between groups are presented in Table 3. Academy players displayed significantly greater mean ENMO ($p < 0.01$) with non-academy players displaying more negative intensity gradient ($p < 0.01$) over the 14-day period. In relation to time spent in specific physical activity threshold zones, academy players spent more time in the 150–300 mg ($p = 0.02$) and >600 mg zones ($p < 0.01$), resulting in greater moderate to vigorous physical activity (MVPA; $p < 0.01$) compared with non-academy players.

Self- reported energy and macronutrient intake

Mean absolute and relative energy and macronutrient intake is presented in Figure 3. Absolute energy (ACAD: 2178 ± 319 kcal · d^{-1}, NON-ACAD: 1768 ± 362 kcal · d^{-1}; 95% CI, 13 to 807, $p < 0.05$) and carbohydrate (ACAD: 279 ± 42 g · day^{-1}, NON-ACAD: 217 ± 24 g · d^{-1}; 95% CI, 20 to 104, $p < 0.05$) intake was greater in the academy group. There was no difference between absolute protein (ACAD: 86 ± 18 g · day^{-1}, NON-ACAD: 71 ± 19 g · day^{-1}; $p = 0.13$) and fat (ACAD: 79 ± 18 g, NON-ACAD: 69 ± 25 g; $p = 0.37$) intake. There was no difference between relative energy (ACAD: 44 ± 12 kcal · kg · d^{-1}, NON-ACAD: 35 ± 9 kcal · kg · d^{-1}; $p = 0.13$), carbohydrate (ACAD: 5.6 g · kg · d^{-1}, NON-ACAD: 4.3 g · kg · d^{-1}; $p = 0.09$), protein

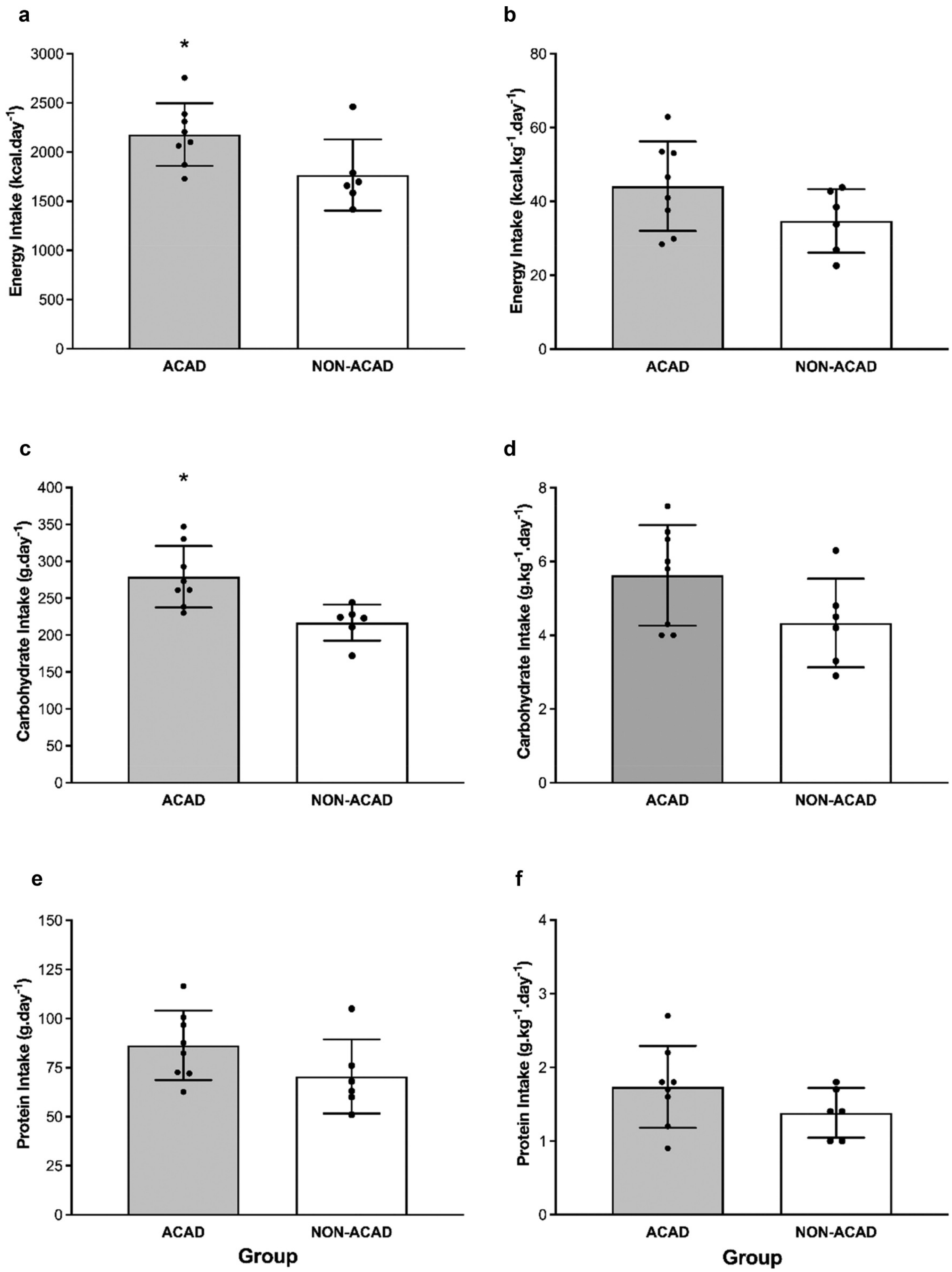

Figure 3. Overview of the mean daily absolute energy (a), carbohydrate (c), and protein (e) intake, and their relative values (b), (d) and (f) respectively, across the training week between groups. *Denotes significant difference between groups, $p < 0.05$. Grey bars represent energy and macronutrient intake in the academy group, white bars represent the non-academy group. Black dots represent individual data points.

(ACAD: 1.7 ± 0.6 g · kg · day^{-1}, NON-ACAD: 1.4 ± 0.3 g · kg · day^{-1}; $p = 0.19$) and fat (ACAD: 1.6 ± 0.6 g · kg · day^{-1}, NON-ACAD: 1.4 ± 0.5 g · kg · day^{-1}, $p = 0.39$) intake between groups.

Self-reported energy and macronutrient intake within both squads and a breakdown of energy intake provided by the host club across the weekly microcycle is presented in Figure 4. Within the academy group, there was no difference across the training week for absolute energy ($p = 0.47$), carbohydrate ($p = 0.12$) and protein ($p = 0.59$) intake. Similarly, there was no difference between days for energy ($p = 0.28$), carbohydrate ($p = 0.29$) and protein ($p = 0.20$) in the non-academy group.

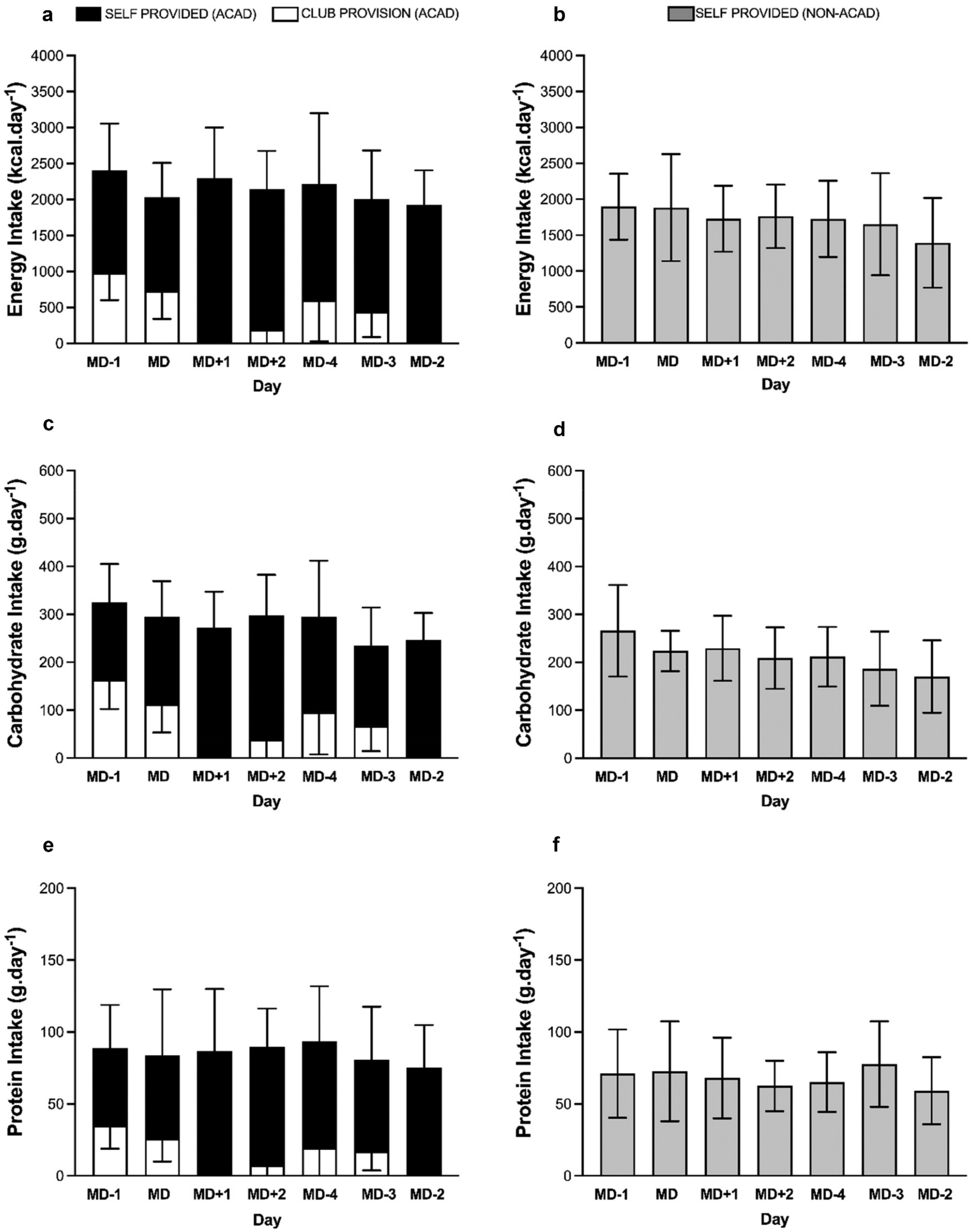

Figure 4. Overview of mean daily absolute energy and macronutrient intake throughout the week one training microcycle. Absolute energy (a), carbohydrate (c) and protein intake (e) of the academy group presented in black and white bars, with white bars representing food and drink provision from the host club. Absolute energy (b), carbohydrate (d) and protein intake (f) of the non-academy groups is presented in light grey bars.

Energy expenditure

Energy expenditure of both groups is presented in Figure 5. Absolute energy expenditure in week 1 (ACAD: 3323 ± 500 kcal · d^{-1}, NON-ACAD: 2670 ± 215 kcal · d^{-1}; 95% CI, 175 to 1131, $p < 0.05$), week 2 (ACAD: 3512 ± 843 kcal · d^{-1}, NON-ACAD: 2522 ± 453 kcal · d^{-1}; 95% CI, 158 to 1822, $p < 0.05$) and over the total 14-day assessment period (ACAD: 3380 ± 517 kcal · d^{-1}, NON-ACAD: 2641 ± 308 kcal · d^{-1}; 95% CI, 218 to 1258, $p < 0.05$) was greater in academy players compared with non-academy players. Similarly, relative energy expenditure in week 1 (ACAD: 65 ± 6 kcal · kg · day^{-1}, NON-ACAD: 53 ± 10 kcal · kg · day^{-1}; 95% CI, 3 to 22, $p < 0.05$), week 2 (ACAD: 69 ± 12 kcal · kg · day^{-1}, NON-ACAD: 45 ± 8 kcal · kg · day^{-1}; 95% CI, 8 to 32, $p < 0.05$) and over the 14-day period (ACAD: 66 ± 6 kcal · kg · d^{-1}, NON-ACAD: 52 ± 9 kcal · kg · d^{-1}; 95% CI, 5 to 24, $p < 0.05$) was greater in the academy group.

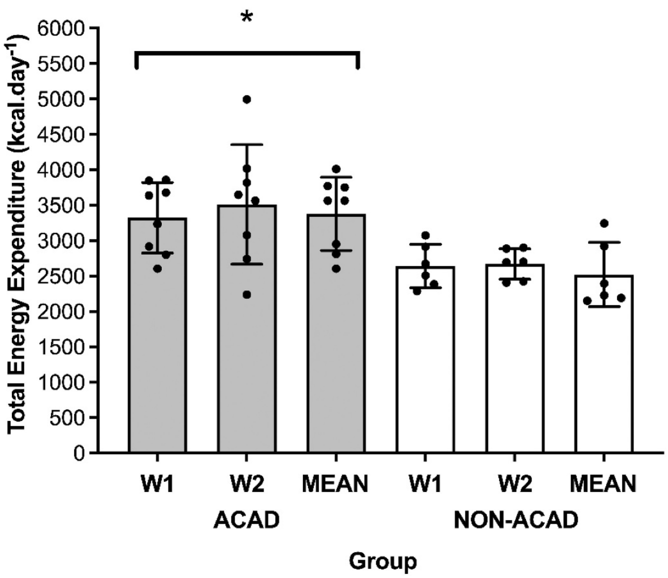

Figure 5. Mean total daily energy expenditure for week one, week two and over the 14-day period. Grey bars represent mean academy data, white bars represent mean non-academy data. Black dots represent individual data points. *Denotes significant difference from the non-academy group, $p < 0.05$.

Factors affecting total daily energy expenditure

As shown in Figure 6, there was a significant correlation between TDEE and stature ($r^2 = 0.62$; $p < 0.05$), fat-free mass ($r^2 = 0.88$; $p < 0.05$) and RMR ($r^2 = 0.87$; $p < 0.01$). There was also a positive relationship between TDEE and training and match duration ($r^2 = 0.65$; $p < 0.05$) and total distance covered ($r^2 = 0.73$; $p < 0.05$). There was also a positive correlation between mean daily ENMO ($r^2 = 0.64$; $p < 0.05$) and TDEE. There was no correlation between TDEE and body mass, physical activity intensity gradient nor average speed.

Discussion

In using the doubly labelled water method, the present data confirm the hypothesis that the total daily energy expenditure of academy soccer players is significantly greater than age-matched non-academy soccer players. This increased energy expenditure is likely due to the significantly greater training and competition demands that are placed upon academy players, as stipulated by the mandate from the EPPP for academy players to engage in a specific duration of formalised coaching. From a practical perspective, our data highlight the requirement for academy soccer players to consume sufficient daily energy intake to meet the energy cost of growth, maturation and the apparent enhanced energy requirements of the training and game schedule associated with formalised academy soccer programmes.

To address our aims, we recruited players from a “Category One” academy from the English Premier League whilst also studying a cohort of age-matched non-academy soccer players who were playing at a “grassroots” standard of competition. When considered across the 14-day period, we observed greater energy expenditure in academy players (3380 ± 517 kcal · d^{-1}; range, 2811–4013) compared with the non-academy players (2641 ± 308 kcal · d^{-1}; range, 2288 – 3075). Importantly, the present data extend our previous observations from another Category One academy (Hannon et al., 2021) where we also reported similar absolute daily energy expenditures in U12/13 (2859 ± 265 kcal · d^{-1}; range 2275 – 3903), U15 (3029 ± 262 kcal · d^{-1}; range 2738–3726) and U18 players (3586 ± 487 kcal · d^{-1}; range 2542 – 5172). Furthermore, evaluation of both mean and individual data in both the U13 players studied here and previously (Hannon et al., 2021) also demonstrate comparable absolute energy expenditures to our previous assessments from adult players (3566 ± 585 kcal · d^{-1}) from the EPL (Anderson et al., 2017).

Given that we observed no differences in body mass, stature or fat-free mass (see Table 1) between the academy and non-academy players, our data suggest that the reported differences in total daily energy expenditure between groups are most likely related to the greater energy cost associated with formalised coaching. Indeed, as stipulated by the EPPP, players within the youth development phase of Category One soccer academies are required to receive a minimum of 10-h coaching exposure per week (Premier League, 2011). Accordingly, we observed distinct differences in physical loading patterns between groups where the academy players were exposed to a greater exercise duration (975 ± 23 min) and completed a greater distance (54.1 ± 8.5 km) over the 14-day period compared with non-academy players (397 ± 2 min and 21.6 ± 4.7 km, respectively). In this regard, when considering the whole sample, positive correlations were evident between total energy expenditure and both training and match duration and total distance covered (i.e., training volume; see Figure 6). In relation to external load metrics, the average weekly total distance completed by the U13 players reported here (27 ± 4 km) was greater than that previously reported in U12/U13 academy players (20 ± 2 km) but comparable to both U18 (26 ± 3 km) (Hannon et al., 2021) and adult EPL players (27 ± 2 km) (Anderson et al., 2017). When taken together, these data clearly demonstrate that the training and match schedules of academy soccer programmes (even within the U13 age-group) induce exercise volumes and daily energy expenditures that are comparable to adult professional players, albeit at a time when such individuals are not yet fully mature and may not have access to appropriate nutrition support (Carney et al., 2023).

In addition to a greater exercise volume, the present data also demonstrate that academy players are exposed to significantly greater intensity of physical loading compared with non-academy players, as evidenced by both GPS metrics and evaluation of accelerometry data. Indeed, the intensity of training and matches was greater in academy players versus non-academy players, as indicated by a higher average speed (see Figure 2C), high-speed running distance (see Figure 2D) and frequency of acceleration and deceleration (see Figure 2E-F respectively). In relation to daily physical activity levels, evaluation of triaxial accelerometry data also demonstrates that academy players spend more time engaged in moderate-to-vigorous activity compared with non-academy players (see Table 3). It is noteworthy, however, that both academy and non-academy players also displayed greater time engaged in MVPA

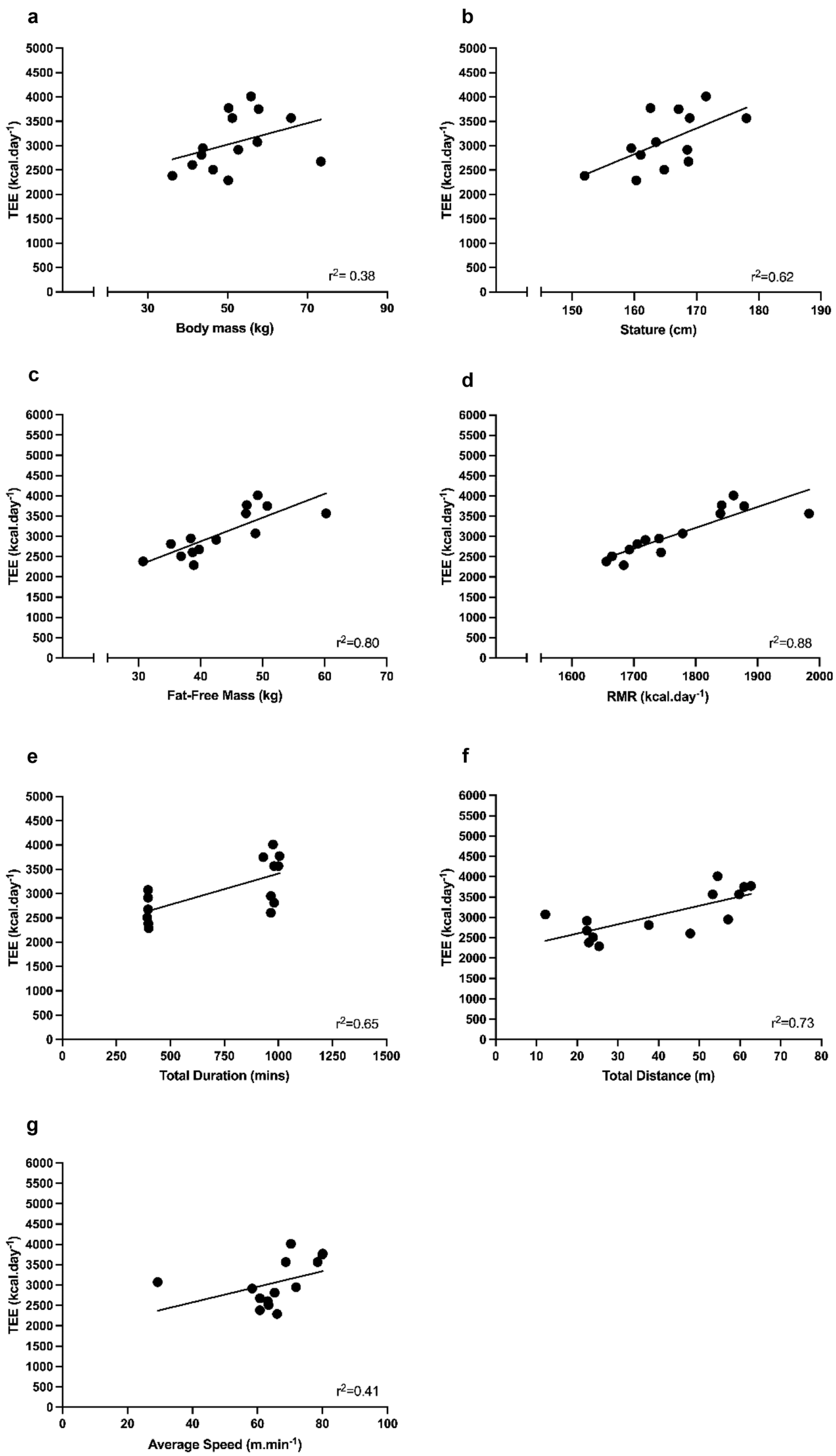

Figure 6. The relationship between mean daily TEE of both groups and body mass (A; $p = 0.38$), stature (B; $p = 0.02$), FFM (C; $p < 0.01$) and RMR (D; $p < 0.01$). In addition, the relationship between mean daily TEE and training and match-play duration (E; $p = 0.01$), total distance (F; $p < 0.01$) and average speed (G; $p = 0.03$).

compared to children and adolescents in the general population (Fairclough et al., 2023). Although we did not specifically evaluate the timing and type of physical activity completed by both groups in relation to soccer versus non-soccer activity (e.g., additional sports, school playground activity, physical education, etc.), it is reasonable to suggest that it was soccer training that accounted for the majority of this additional moderate-to-vigorous activity in the academy players. Although it is acknowledged that moderate-to-vigorous physical activity (Tobias et al., 2007) and increased training volume (Varley et al., 2017) is facilitative of bone formation and skeletal development in adolescents, it is noteworthy that sub-optimal carbohydrate intake before, during and/or after acute exercise (Hammond et al., 2019; Sale et al., 2015) can also impair acute bone turnover. Such data are of relevance to the present population when considering that academy players habitually "under fuel" by failing to consume sufficient totality of energy and carbohydrate intake within appropriate timing for preparation and in recovery from academy training sessions (Stables et al., 2022). Furthermore, we also reported that the most prevalent injury occurring in academy players from England, Europe and South America was growth-related injuries in the anatomical location of the knee, lower back, sacrum and pelvis, the prevalence of which was most evident during periods of peak height velocity (Hall et al., 2020). Collectively, these data further demonstrate the requirement for specific education and behaviour change strategies that ensure sufficient CHO availability and intake is promoted in what is clearly an "at risk" population.

In relation to self-reported energy intake, we also observed a significantly greater energy intake in academy players versus non-academy players (see Figure 3). Notwithstanding the errors associated with dietary assessment (Stables et al., 2021) and difficulties when comparing methodologies between studies, the academy players studied here reported less absolute energy intake (2178 ± 319 kcal $\cdot$ d^{-1}) than our previous assessments of U12/13 players (2659 ± 187 kcal $\cdot$ d^{-1}) from another Category One academy cohort (Hannon et al., 2021). Whilst we accept the principal investigator being on-site for the academy group will have strengthened the quality of energy and macronutrient intake data versus the non-academy group, possibly leading to greater reporting, only three players reported a daily CHO intake >6 g $\cdot$ kg^{-1} per day, an intake that is recommended to support the typical volume of exercise that is completed by these players (Collins et al., 2021). Interestingly, approximately 125 g $\cdot$ d^{-1} of CHO intake that was self-reported by academy players was attributable to food and drink provision provided by the host club as opposed to sources that were purchased by the player or related stakeholders (e.g., parents and guardians). Indeed, in accordance with a designated "Category One" status, the host club studied here provided on-site food provision and players and staff were also exposed to a full-time nutritionist to ensure both education and service provision. In contrast, however, our recent audit of nutrition provision across soccer academies in England demonstrated that the extent of nutrition service provision differs considerably between clubs in relation to whether they are deemed as Category One, Two or Three status (Carney et al., 2023). As such, it is possible that players enrolled at a "lower category academy" may present with an increased risk and prevalence of under-fuelling despite the fact that they are likely completing significantly greater training volumes than non-academy players.

In summary, we report for the first time that the daily energy expenditure of male academy soccer players is significantly greater than age-matched soccer players who are not enrolled on a formalised academy coaching programme. Additionally, our data demonstrate that the typical weekly training volumes (e.g., total distance covered) and daily energy expenditure of adolescent academy players are comparable to adult professional players, albeit at a time when they are not yet physically mature. Given the injury risk associated with high training loads completed during periods of growth and maturation, our data clearly demonstrate the requirement for academy players to consume a sufficient totality and timing of energy (and CHO) intake to support the enhanced energy cost associated with formalised academy coaching programmes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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