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Abstract

Purpose: To inform the energy requirements of highly trained adolescent soccer players, total energy expenditure (TEE) was quantified in academy soccer players from the English Premier League (EPL). ***Methods:*** Twenty-four male adolescent soccer players from an EPL academy (n=8 U12/13; n=8 U15; n=8 U18) were assessed for baseline maturity (maturity offset), body composition (DXA) and resting metabolic rate (RMR; indirect calorimetry). Subsequently, TEE, energy intake (EI) and physical loading patterns were assessed over a 14-day in-season period using doubly labelled water, the remote food photographic method and global positioning system technology, respectively. ***Results:*** Under-18 players presented with greater RMR (2236±93 kcal·day^{-1}) and TEE (3586±487 kcal·day^{-1}; range: 2542-5172 kcal·day^{-1}) than both U15 (2023±162 and 3029±262 kcal·day^{-1}, respectively; TEE range: 2738-3726 kcal·day^{-1}) and U12/13 players (1892±211 and 2859±265 kcal·day^{-1}, respectively; TEE range: 2275-3903 kcal·day^{-1}) (all P<0.01), though no difference in TEE was apparent between the U12/13 and U15 age-groups. Fat-free mass was significantly different between all comparisons in a hierarchal manner (U18: 57.2±6.1 kg > U15: 42.9±5.8 kg > U12/13: 31.1±3.5 kg; all P<0.01). Within age-groups, no differences were apparent between EI and TEE (U12/13: -29±277 kcal·day^{-1}, P=0.78; U15: -134±327 kcal·day^{-1}, P=0.28; U18: -243±724 kcal·day^{-1}, P=0.37), whilst U18 players (3180±279 kcal·day^{-1}) reported higher EI than both U15 (2821±338 kcal·day^{-1}; P=0.05) and U12/13 players (2659±187 kcal·day^{-1}; P<0.01). ***Conclusion:*** The TEE of male academy soccer players progressively increase as players progress through the academy age-groups. In some individuals (evident in all age-groups), TEE was greater than that previously observed in adult EPL soccer players. **Key words:** doubly labelled water, energy expenditure, energy intake, training load

Introduction

Many professional soccer clubs worldwide have formalized talent development programs (often referred to as *academies*) that aim to produce players who can progress to represent their first team or that can be sold for financial gain (1). The development of academy soccer players is multi-faceted, where a significant emphasis is placed upon technical, tactical, physical and psychological development (2). In English Premier League (EPL) academies, formal registration of players commences at the under (U) nine age group (2) and so, as an academy player transitions through the academy pathway they will undergo biological growth and maturation (3), during which time sufficient energy is required to synthesize new tissues (4). From a nutritional perspective, changes in anatomical, physiological and metabolic parameters will likely influence players' daily energetic requirements in relation to both training and match days (5). It is therefore of paramount importance for sports science and medicine practitioners to better understand the energetic requirements of academy soccer players at relevant stages of the academy pathway, so as to simultaneously promote growth, maturation and physical development in addition to optimally fuelling for training and match play.

In this regard, we recently quantified changes in body composition and resting metabolic rate (RMR) in a cohort of male English Premier League academy soccer players from U12 – U23 age-groups (6). In accordance with progressive increases in physical characteristics (e.g. stature, body mass and fat free mass), we also observed an increase in RMR of approximately 400 $kcal \cdot day^{-1}$ between ages 12 and 16 (i.e. the period corresponding with peak height velocity, PHV), thus highlighting the requirement to adjust total energy intake accordingly (6). However, given that RMR only represents a proportion of total daily energy expenditure (TEE) (7), there is a definitive requirement to accurately quantify TEE, alongside assessments of training load, in order to prescribe specific energy requirements. Whilst previous studies have reported daily TEE in both U18 (8) and U15 (9) male academy players (3618 ± 61 and 2551 ± 245 kcal·day^{-1} respectively), it is noteworthy that TEE was estimated from indirect measures such as activity diaries and accelerometry. Additionally, both studies also estimated RMR (using common prediction equations), though recent observations from our laboratory demonstrates that such prediction equations significantly underestimate RMR in this population (6).

The doubly labelled water (DLW) method is the gold standard method of assessing energy expenditure in free-living conditions *in vivo* (10). Importantly, this non-invasive method can provide information on energy expenditure over a 7-14 day period (i.e. a typical in-season micro-cycle) without interfering in day-to-day activities such as soccer training or match play (10). Using the DLW method, we recently reported a mean daily TEE of 3566 ± 585 kcal·day^{-1} in adult (~27 years old) male Premier League soccer players, as assessed in a seven day in-season period comprising of two matches and five training sessions (11). Nonetheless, it is unlikely that such data can immediately translate to academy soccer players given they present with a different anthropometric profile, resting metabolic rate (6), daily schedule (e.g. schooling and training demands) and a higher (relative) energy cost of exercise (12).

In addition to quantifying TEE, there is also a requirement to simultaneously quantify energy intake, to determine whether or not academy soccer players are achieving their daily energy requirements in order to maximize growth, maturation and physical development. Studies investigating the dietary intakes of Premier League academy soccer players have reported energy intakes of ~1900-2899 kcal·day^{-1} in players aged 12-17 (8,9,13). Considering these values alongside the aforementioned estimated TEE values in academy soccer players (8,9), it is plausible to suggest that energy availability may be compromised in this population as previously highlighted by Briggs and colleagues (9). Chronic low energy availability (<30 kcal·kg FFM^{-1}·day^{-1}) may result in impaired growth and maturation of tissues and organs, reduced skeletal bone mineral accrual, thus increasing risk of stress fractures) and osteoporosis later in life, delayed sexual maturation and a suppression of the immune system (14). It is clear that these detrimental consequences of low energy availability would negatively affect both health and performance. Given the importance of at least matching energy intake to TEE in order to maximize growth, maturation and physical development, but also to minimize the risk of illness and injury, it is essential that a youth player's energy availability is appropriate during this period of rapid biological growth and maturation (14).

With this in mind, the aim of the present study was to therefore quantify energy expenditure (using the DLW method), energy intake and physical loading of male academy soccer players at different stages of maturation. To this end, we studied a cohort of U12/13 (n=8), U15 (n=8) and U18 (n=8) players from an EPL academy during a 14-day in-season period comprising a typical training and match schedule for each playing squad. We hypothesized that TEE would increase in an incremental manner between squads in accordance with progressive increases in fat-free mass (FFM), RMR and training and match load.

Methods

Participants

Twenty-four (n=24) male outfield soccer players from a Category One (i.e. top tier) English Premier League soccer academy volunteered to participate in this study. Players were of differing maturity status and categorized according to their age group (U12/13, U15, U18). Participant characteristics are presented in **Table 1**. One player from the U15 age group and one player form the U18 age-group (n=2) sustained an injury on day three and day four, respectively, and took no further part in training or match-play for the remainder of the study (both injuries sustained were unrelated to the present study). These players' data have been removed where deemed appropriate and is indicated accordingly. All experimental procedures and associated risks were explained to both the players and their parents/guardians. Written informed parental/guardian consent and player assent was obtained for participants ≤16 years old, and participants ≥17 years old provided their own consent. Ethical approval was granted by the Wales Research Ethics Committee, UK (REC approval number: 17/WA/0228).

Overview of study design

In a cross-sectional design, we assessed total energy expenditure, energy intake and physical loading (comprising of both training and matches) over a 14-day in-season period during the 2018/19 season (November 2018 – February 2019). During this period, players continued with their normal schooling, training and match schedules. An overview of the daily schedule for each age-group is displayed in **Table 2**. In the U12/13, U15 and U18 age-groups (excluding the two injured players), players completed 86 ± 9 % (range: 76-100 %), 88 ± 8 % (range: 75-100 %) and 94 ± 5 % (range: 86-100 %) of total training and match duration, respectively.

Baseline measures

On the morning of day one (07:00–11:00) and after providing a urine sample, players were assessed for body composition, maturity status and RMR under standardized conditions (≥8 hours overnight fast and ≥12 hours after exercise) as previously described (6). Body mass (SECA, model-875, Hamburg, Germany), stature and sitting height (SECA, model-217, Hamburg, Germany) were measured followed by assessment of body composition via a whole-body fan-beam DXA scan (Hologic QDR Series, Discovery A, Bedford, MA, USA) (6). The resulting level of radiation exposure from this scan was very low (~0.4 μSv) and is considered a safe and ethical radiation dose (15). Somatic maturity (timing) was estimated for each participant by calculating maturity-offset (the time in years from PHV) (16). Predicted adult stature (PAS) was calculated according to the Sherar equation (17), with current percent of PAS (maturity status) then calculated using the following equation: *(Current Stature ÷ Predicted Adult Stature) x 100* (6).

Following all anthropometric measures, RMR was measured via open-circuit indirect calorimetry (GEM Nutrition Ltd, UK) previously used in EPL academy soccer players (6). The calorimeter was calibrated against known gas concentrations: 'zero' (0.0% O_2 and 0.0% CO_2) and 'span' (20.0% O_2 and 1.0% CO_2) gases (BOC, Guildford, UK), prior to each RMR assessment. Following calibration and before starting data collection, participants relaxed for ten minutes under a transparent ventilated hood in a supine position in a dark, quiet, thermoneutral room. Subsequently, data was collected over a 20-minute period (2 x 10-minute duplicates), in which data for the second 10 minutes was used to determine RMR. $\dot{V}O_2$ and $\dot{V}CO_2$ were measured continuously and mean one-minute values were provided throughout. $\dot{V}O_2$ and $\dot{V}CO_2$

were determined using the Haldane transformation (18) and energy expenditure (kcal·day^{-1}) calculated using the Weir equation (19).

Body mass and hydration status

In addition to baseline measures (day one), fasted body mass was also collected from all players on days seven and fourteen (SECA, model-875, Hamburg, Germany). Prior to each body mass assessment (days one, seven and fourteen), all players provided a urine sample to establish hydration status (PAL-1 refractometer, Atago, Japan).

Quantification of training and match loads

Pitch based training and match load was measured using global positioning system (GPS) technology (Apex, STATSports, Newry, Northern Ireland). Each portable GPS unit (30 x 80 mm, 48 grams) sampled positioning and time, thus velocity and distance, at 10 Hz and have been shown to provide valid and reliable estimates of distance and velocity during typical team sport movement activities (20,21). The GPS unit was placed inside a custom-made manufacturer provided vest (Apex, STATSports, Newry, Northern Ireland) that held the unit on the upper back between both scapulae, allowing clear exposure of the GPS antennae to acquire a clear satellite connection. The GPS units were turned on around 30 minutes before use and left outside to obtain a satellite lock as per the manufacturer's instructions. At the end of each session, data was downloaded and then cropped from the start of the warm-up to the end of the last organized drill (for training) or full-time (for match play) on the manufacture's software (Apex 10 Hz version 2.0.2.4, STATSports, Newry, Northern Ireland). The external load variables selected for analysis were duration (min) and total distance covered (km) as indicators of training and match volume, and average speed ($m \cdot min^{-1}$) as an indicator of training and match intensity. Duration of gym-based training (min) was also quantified and added to pitch based training and match play duration. No training and match load data was included for the two players that sustained an injury during the study.

Measurement of total energy expenditure using the doubly labelled water method

Measurement of TEE ($kcal \cdot day^{-1}$) was quantified using the DLW method (22,23) over a 14-day period. This method has been previously validated on multiple occasions by comparison to simultaneous indirect calorimetry in humans (23). On the evening of day 0, players provided a background urine sample. A single oral bolus dose of DLW ($^2H_2{}^{18}O$) was then consumed by each player. Doses were calculated according to each individual player's body mass, with a desired enrichment of 10% ^{18}O and 5% $^2H_2$, using the calculation:

Dose (mL) = 0.65 (body mass, grams) x DIE / IE

Where 0.65 is the approximate proportion of the body comprised of water, DIE = desired initial enrichment (DIE = 618.923 x body mass, $kg^{-0.305}$) and IE = initial enrichment (10%) 100,000 parts per million (23).

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 one (07:00–11:00) players provided another urine sample, allowing for isotope enrichment to be determined following total body water equilibrium (23). Additional urine samples were provided every other morning (second pass of the day) for the duration of the study, to determine elimination rates of both isotopes via the multi-point method (10). 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. Body mass was recorded at the start and end of the protocol and times of all urine sample collections were also recorded. Analysis of the isotopic enrichment of urine was performed blind using a Liquid Isotope Water Analyser (Los Gatos Research, USA) (24) at the University of Aberdeen, Scotland, UK. Initially the urine was encapsulated in capillaries, then vacuum distilled (25), and the resulting distillate was used. Samples were run alongside three lab standards for each isotope and International standards to adjust for day to day variation and allow correction from delta values to ppm. After adjustment for background levels, daily isotope enrichments were log converted and the elimination constants (ko and kd) were calculated by fitting a least squares regression model to the log converted data. The back extrapolated intercept was used to calculate the isotope dilution spaces (No and Nd). A two-pool model, specifically equation A6 from Schoeller and colleagues (26) as modified by Schoeller (27), was used to calculate rates of CO_2 production as recommended for use in humans (28), using a respiratory quotient of 0.85 given all players consumed a mixed diet. Results of TEE are expressed as a daily mean for weeks 1 and 2 and a 14-day mean. Physical activity level (PAL) was also calculated for each player by dividing TEE by RMR.

Dietary intake

Self-reported energy and macronutrient intakes were assessed during the first seven days via the remote food photographic method (RFPM), which has been previously validated in adolescent team-sport athletes (29) and previously used by our laboratory when assessing adult soccer players (11). In short, players provided a photograph of their food and drink before and after consumption. Photographs were timestamped alongside a description of the food/drink (including information on quantities, brands, preparation and cooking methods) and then sent to the principal investigator on a smart phone via WhatsApp messaging service (29). Seven-days was chosen as it is was considered an appropriate duration to assess habitual dietary intake (30), with the research team also deeming fourteen days too long a timeframe to obtain good quality dietary information (31).

Prior to data collection, all players and their parents/guardians attended a workshop during which the RFPM method was explained in detail. Live examples of how to record dietary intake were demonstrated, with all players and parents provided with the opportunity to ask questions. Each player completed at least one four-day pilot RFPM assessment prior to the study commencing, with individual feedback on data collection provided accordingly. Additionally, all players provided the lead researcher with at least one 24-hour recall during the seven-day assessment period (using the triple pass method) in an attempt to ensure players did not omit any foods/drinks and to cross-check the two sources of dietary intake information (32). Throughout the duration of the study, most meals and snacks (excluding breakfast and late evening meal/snack) were consumed at school or the club's training ground, during which the principal investigator was always present at both locations.

Dietary intake was analyzed by a Sport and Exercise Nutrition register (SENr) accredited nutritionist using dietary analysis software (Nutritics, v5, Ireland), which calculated energy and macronutrient intake for each player. To ensure reliability of energy and macronutrient intake data, a second SENr accredited nutritionist individually analyzed half (n=12, i.e. 84 days in total) of the players dietary intake (Nutritics, v5, Ireland). Estimated energy intake (EI) was reported in kilocalories per day ($kcal \cdot day^{-1}$) and macronutrient intakes were reported in grams (g) and grams per kilogram of body mass ($g \cdot kg^{-1}$). Energy and macronutrient intake analyzed by the two different researchers was compared for systematic bias via an independent t-test. No significant difference was observed between researchers for energy (P=0.91; 95% CI = -179 to 199 $kcal \cdot day^{-1}$), CHO (P=0.28; 95% CI = -41 to 12 $g \cdot day^{-1}$), fat (P=0.10; 95% CI = -1 to 17 $g \cdot day^{-1}$) or protein (P=0.97 ; 95% CI = -12 to 11 $g \cdot day^{-1}$) intake. The thermic effect of food (TEF) was assumed to be 10% of EI for each individual (33), subsequently enabling estimations of activity energy expenditure (AEE; TEE – (RMR + TEF)) and energy availability (EA = EI – AEE / FFM).

Statistical Analyses

All data were initially assessed for normality of distribution using the Shapiro–Wilk's test. Statistical comparisons between squads were performed using a one-way between-groups analysis of variance (ANOVA). Differences in body mass and hydration status were analyzed using a one-way repeated measures ANOVA. Where significant main effects were present, Tukey post-hoc analysis was conducted to locate specific differences. Within age groups, comparisons between week one and week two and between energy intake and expenditure were analyzed using a paired t-test. Ninety-five percent confidence intervals (95% CI) for the differences are also presented. Relationships between TEE and body mass, fat-free mass, stature, RMR, training and match-play duration, total distance and average speed were assessed using Pearson's correlation. All statistical analyses were completed using SPSS (version 26, SPSS, Chicago, IL) where $P<0.05$ is indicative of statistical significance. Post-hoc statistical power analyses were performed (G*Power, version 3.1.9.6), revealing the sample size used provided sufficient statistical power (0.85) to detect differences in energy expenditure between groups. Data are presented as mean ± SD.

Results

Baseline characteristics (n=24)

Player characteristics including age, maturity offset, percent of predicted adult stature (PAS), stature, body mass, fat-free mass, fat mass and percent body fat are presented in Table 1. With the exception of fat mass ($P=0.07$) and percent body fat ($P=0.13$), all of the aforementioned parameters were significantly different between squads ($P<0.01$ for all comparisons).

Training and match load (n=22)

Accumulative 14-day training and match duration (Figure 1A) was lower in the U12/13 players (659 ± 81 min) compared with the U15 (869 ± 72 min; 95% CI = -301 to -118 min; $P<0.01$) and U18 (846 ± 39 min; 95% CI = -278 to -95 min; $P<0.01$) age-groups. In contrast, no difference was apparent between U15 and U18 age-groups ($P>0.99$). Duration of activity did not differ ($P=0.12$) between week one (284 ± 45 min) and two (375 ± 107 min) in the U12/13 players. In the U15 and U18 age-groups, training and match duration was lower in week one (U15: 380 ± 51; U18: 369 ± 13 min) compared with week two (U15: 489 ± 33; U18: 477 ± 44 min) in both the U15 (95% CI = -154 to -64 min; P<0.01) and U18 (95% CI = -155 ± -60 min; P<0.01) age-groups.

In accordance with exercise duration, accumulative 14-day total distance (Figure 1B) was lower in the U12/13 players (38.3 ± 5.1 km) compared with the U15 (53.7 ± 4.5 km; 95% CI = -23.1 to -8.0 km; P<0.01) and U18 (54.4 ± 7.1 km; 95% CI = -23.8 to -8.4 km; P<0.01) age-groups, though no difference was apparent between the U15 and U18 age-groups (P>0.99). In relation to week by week comparisons, total distance was similar in weeks one and two in both the U12/13 (18.6 ± 2.7 and 19.7 ± 6.0 km, respectively: P=0.70) and U15 players (25.6 ± 2.9 and 28.1 ± 3.0 km, respectively: P=0.13). In contrast, the U18 players completed less distance in week one (23.2 ± 1.5 km) compared with week two (31.2 ± 6.6 km) (95% CI = -13.9 to -2.0 km; P=0.02).

Average speed in the U18 players was significantly higher (74 ± 4 $m \cdot min^{-1}$) than both U15 (67 ± 2 $m \cdot min^{-1}$; 95% CI = 2 to 12 $m \cdot min^{-1}$; P<0.01) and U12/13 players (63 ± 4 $m \cdot min^{-1}$; 95% CI = 6 to 16 $m \cdot min^{-1}$; P<0.01), though no difference (P=0.10) was apparent between the U12/13 and U15 age-groups (Figure 1C). Average speed was higher in week one compared with week two in both the U12/13 (71 ± 6 and 55 ± 5 $m \cdot min^{-1}$, respectively: 95% CI = 10 to 22 $m \cdot min^{-1}$; P<0.01) and U15 (73 ± 5 and 61 ± 3 $m \cdot min^{-1}$, respectively: 95% CI = 6 to 18 $m \cdot min^{-1}$; P<0.01) age-groups, though no weekly differences (P=0.58) existed in the U18 players (75 ± 6 and 73 ± 7 $m \cdot min^{-1}$, respectively).

Energy expenditure (n=24)

U18 players presented with a higher RMR (2236 ± 93 kcal·day^{-1}) than both U15 (2023 ± 162 kcal·day^{-1}; 95% CI = 8 to 418 kcal·day^{-1}; P=0.04) and U12/13 players (1892 ± 211 kcal·day^{-1}; 95% CI = 139 to 549 kcal·day^{-1}; P<0.01). In contrast, RMR was not different (P=0.26) between the U15 and U12/13 squads (see Figure 2A).

In accordance with RMR, the U18 players (3586 ± 487 kcal·day^{-1}; range: 2542-5172 kcal·day^{-1}) also presented with a higher mean (14 day) TEE than both the U15 (3029 ± 262 kcal·day^{-1}; range: 2738-3726 kcal·day^{-1}; 95% CI = 111 to 1004 kcal·day^{-1}; P=0.01) and U12/13 players (2859 ± 265 kcal·day^{-1}; range: 2275-3903 kcal·day^{-1}; 95% CI = 281 to 1174 kcal·day^{-1}; P<0.01), whereas no differences (P=0.61) were apparent between the U12/13 and U15 age-groups (Figure 2B). In the U12/13 players, TEE was lower in week one (2702 ± 255 kcal·day^{-1}) compared with week two (3122 ± 364 kcal·day^{-1}; 95% CI = -688 to -152 kcal·day^{-1}; P<0.01). In contrast, no weekly differences were apparent in either the U15 (2955 ± 197 and 3093 ± 352 kcal·day^{-1}, respectively) or U18 players (3419 ± 560 and 3845 ± 826 kcal·day^{-1}, respectively). TEE for weeks one, two and 14-day mean in the two injured players respectively, was 2806, 2542 and 2771 kcal·day^{-1} in the U18 player and 2798, 2742 and 2797 kcal·day^{-1} in the U15 player.

Mean daily AEE (Figure 2C) was similar between the U18 (1033 ± 456 kcal·day^{-1}), U15 (724 ± 172 kcal·day^{-1}) and U12/13 (700 ± 184 kcal·day^{-1}) age-groups (P=0.07). In the U12/13 players, mean daily AEE was lower in week 1 (543 ± 151 kcal·day^{-1}) compared with week 2 (963 ± 329 kcal·day^{-1}; 95% CI = -688 to -152 kcal·day^{-1}; P<0.01). However, there were no weekly differences in the U15 (650 ± 126 and 788 ± 252 kcal·day^{-1}; P=0.09) and U18 (866 ± 530 and 1292 ± 808 kcal·day^{-1}; P=0.21) age-groups, respectively. AEE for weeks one, two and 14-day mean in the two injured players respectively, was 415, 151 and 380 kcal·day^{-1} in the U18 player and 636, 580 and 635 kcal·day^{-1} in the U15 player.

Mean PAL values (Figure 2D) did not differ between the U12/13 (1.5 ± 0.1), U15 (1.5 ± 0.1) or U18 age-groups (1.6 ± 0.2; P=0.29). In U12/13 players, PAL values were lower in week 1 (1.4 ± 0.1) compared with week 2 (1.7 ± 0.2; 95% CI = -0.4 to -0.1; P<0.01) though no weekly differences were evident in U15 (1.5 ± 0.1 and 1.5 ± 0.1, respectively) or U18 players (1.5 ± 0.2 and 1.7 ± 0.4, respectively).

Self-reported energy and macronutrient intake (n=24)

Both absolute (P<0.01) and relative (P<0.01) mean energy intake (Figures 3C & 3D) was significantly different between playing squads. In absolute terms, the U18 players consumed more energy (3180 ± 279 kcal·day^{-1}) than the U15 players (2821 ± 338 kcal·day^{-1}; 95% CI = 0 to 717 kcal·day^{-1}; P=0.05) and U12/13 players (2659 ± 187 kcal·day^{-1}; 95% CI = 162 to 878 kcal·day^{-1}; P<0.01). In contrast, no difference was apparent between the U12/13 players and U15 players (P=0.76). Relative to body mass, the U12/13 players (63 ± 8 kcal·kg^{-1}.day^{-1}) consumed more energy than the U15 (50 ± 7 kcal·kg^{-1}·day^{-1}; 95% CI = 3 to 22 kcal·kg^{-1}·day^{-1}; P=0.01) and U18 players (44 ± 7 kcal·kg^{-1}·day^{-1}; 95% CI = 9 to 28 kcal·kg^{-1}·day^{-1}; P<0.01) age-groups, though there was no difference between the U15 and U18 age-groups (P=0.39).

Mean absolute CHO intake (Figure 3E) was similar between the U12/13 (309 ± 27 g·day^{-1}), U15 (325 ± 44 g·day^{-1}) and U18 (346 ± 28 g·day^{-1}) age-groups (P=0.12). When expressed in relative terms (Figure 3F), the U12/13 players (7.3 ± 1.0 g·kg^{-1}·day^{-1}) consumed more than the U15 (5.8 ± 0.8 g·kg^{-1}·day^{-1}; 95% CI = 0.5 to 2.5 g·kg^{-1}·day^{-1}; P<0.01) and U18 (4.8 ± 0.6 g·kg^{-1}·day^{-1}; 95% CI = 1.4 to 3.5 g·kg^{-1}·day^{-1}; P<0.01) age-groups, whereas no difference was evident between the U15 and U18 age-groups (P=0.07).

Both absolute (P=0.04) and relative (P<0.01) mean fat intake (Figures 3G & 3H) was significantly different between squads. In absolute terms, the U18 players consumed more fat (131 ± 17 g·day^{-1}; 95% CI = 1 to 42 g·day^{-1}; P=0.04) than the U12/13 players (110 ± 12 g·day^{-1}) whereas no differences existed between U18 and U15 players (117 ± 18 g·day^{-1}, P=0.23). When expressed relatively, the U12/13 players consumed more fat (2.6 ± 0.4 g·kg^{-1}·day^{-1}) than the U15 (2.1 ± 0.4 g·kg^{-1}·day^{-1}; 95% CI = 0.0 to 1.0 g·kg^{-1}·day^{-1}; P=0.04) and U18 (1.8 ± 0.4 g·kg^{-1}·day^{-1}; 95% CI = 0.3 to 1.3 g·kg^{-1}·day^{-1}; P<0.01) age-groups, whereas no differences were evident between the U15 and U18 age-groups (P=0.70).

Absolute protein intake was significantly different (P<0.01; Figure 3I) between squads such that U18 players (152 ± 28 g·day^{-1}) consumed more than both U15 (117 ± 12 g·day^{-1}; 95% CI = 10 to 58 g·day^{-1}; P<0.01) and U12/13 players (107 ± 11 g·day^{-1}; 95% CI = 21 to 69 g·day^{-1}; P<0.01). No difference was apparent between the U12/13 and U15 age-groups (P=0.75). There was no difference (P=0.13) in mean relative protein intake between the U12/13 (2.5 ± 0.4 g·kg^{-1}·day^{-1}), U15 (2.1 ± 0.3 g·kg^{-1}·day^{-1}) and U18 players (2.1 ± 0.5 g·kg^{-1}·day^{-1}; Figure 3J).

Energy intake versus energy expenditure and energy availability (n=24)

There was no difference between EI and TEE in the U12/13 (-29 ± 277 $kcal\cdot day^{-1}$; P=0.78), U15 (-134 ± 327 $kcal\cdot day^{-1}$; P = 0.28) or U18 (-243 ± 724 $kcal\cdot day^{-1}$; P = 0.37) age-groups (Figure 3A). Similarly, body mass (Figure 3B) did not significantly change from baseline after seven and fourteen days in all age-groups (P>0.05 for all comparisons). There was also no change in hydration status from days one (804 ± 211 $mOsmol\cdot kg^{-1}$) to seven (775 ± 206 $mOsmol\cdot kg^{-1}$) and fourteen (867 ± 177 $mOsmol\cdot kg^{-1}$), respectively (P=0.08).

Mean daily estimated energy availability in the U12/13 age-group (69 ± 10 $kcal\cdot kg\ FFM^{-1}\cdot day^{-1}$) was greater than the U15 (51 ± 9 $kcal\cdot kg\ FFM^{-1}\cdot day^{-1}$; 95% CI = 3 to 33 $kcal\cdot kg\ FFM^{-1}\cdot day^{-1}$; P=0.02) and U18 age-groups (41 ± 15 $kcal\cdot kg\ FFM^{-1}\cdot day^{-1}$; 95% CI = 13 to 43 $kcal\cdot kg\ FFM^{-1}\cdot day^{-1}$; P<0.01), with no differences between the U15 and U18 age-groups (P=0.23).

Factors affecting TEE and AEE

There was a significant positive relationship between TEE and stature (r^2 = 0.41; P<0.01), body mass (r^2 = 0.65; P<0.01), fat-free mass (r^2 = 0.65; P<0.01), RMR (r^2 = 0.56; P<0.01) and AEE (r^2 = 0.79; P<0.01) (Figure 4). There was also a significant positive relationship between AEE and training and match-play duration (r^2 = 0.20; P<0.01) and total distance (r^2 = 0.24; P<0.01), though no relationship was evident between AEE and average speed (r^2 = 0.01; P=0.49) (Figure 4).

Discussion

In using the doubly labelled water method, we provide the first direct measurement of total daily energy expenditure of highly trained male academy soccer players from the English Premier League. Confirming our hypothesis, our data demonstrate that TEE progressively increases as players transition through the academy pathway, likely due to the influence of growth and maturation on key anthropometrical parameters in addition to increased physical loading. Within the present sample, players from each age-group also reported consuming a habitual energy intake that was comparable to TEE. It was noteworthy, however, that in some individuals (as evident in all age groups), TEE was greater than that previously observed in adult players from the EPL.

The present data may provide an initial starting point for which to formulate energy requirements of academy soccer players. Indeed, the U18 players presented with a TEE (3586 ± 487 kcal·day^{-1}; range: 2542-5172 kcal·day^{-1}) that was approximately 600 and 700 kcal·day^{-1} higher than both the U15 (3029 ± 262 kcal·day^{-1}; range: 2738-3726 kcal·day^{-1}) and U12/13 players (2859 ± 265 kcal·day^{-1}; range: 2275-3903 kcal·day^{-1}) respectively. Such differences in TEE is likely due to a combination of differences in anthropometric profile, RMR and physical loading between squads. For example, stature, body mass and FFM was different between all pair-wise comparisons, such that U18 > U15 > U12/13 players, whilst U18 players also presented with a higher RMR than their younger counterparts. It is therefore unsurprising that stature, body mass, FFM and RMR were all positively correlated with TEE. In considering the role of physical loading, it is noteworthy that both U18 and U15 players also completed more distance and minutes of activity than U12/ U13 players. In accordance, there was also a strong correlation between TEE and AEE. When subsequently examining factors affecting AEE, we observed that markers of volume (i.e. duration and distance completed) had a greater influence (as evidenced from correlation data, Figure 4) than crude markers of exercise intensity (i.e. average speed). As such, it would appear prudent to collectively consider FFM, RMR and measures of training volume when formulating age-specific guidelines for energy intake.

The weekly loading for the U18 players (i.e. total weekly distance of 25-35 km) and their mean daily TEE was comparable to previously published data from adult English Premier League (3566 ± 585 kcal·day^{-1}) and Dutch Eredivisie (3285 ± 354 kcal·day^{-1}) players, also assessed using DLW (9,34). Additionally, TEE was similar to that reported in U18 Championship (i.e. second tier) academy soccer players (3618 ± 61 kcal·day^{-1}) (8), despite the latter authors using indirect assessment methods. In relation to the U15 players, the TEE reported here is ~500 kcal·day^{-1} higher than that previously reported in U15 Premier League academy players (2551 ± 245 kcal·day^{-1}), though it is acknowledged that the latter authors estimated TEE from accelerometry (9). In addition to squad mean data, it is noteworthy that all age-groups displayed marked individual variation in TEE. For example, within the same week we observed individual variation of approximately 1600, 1000 and 2600 kcal·day^{-1} in the U12/13, U15 and U18 squads, respectively. Whilst it is currently difficult to ascertain the exact reasons why such large individual variation in TEE was observed, it is noted that the two injured players presented with some of the lowest values within their age groups (14-day mean TEE; U18 player: 2771 kcal·day^{-1}; U15 player: 2797 kcal·day^{-1}). Similar to previous research in youth team-sport athletes (34,35), we also observed a strong correlation between TEE and AEE (thus suggesting that training load has a clear role). However, we do acknowledge that we were not able to differentiate (AEE) between soccer and non-soccer related activity. Notwithstanding this limitation, such data demonstrate that in certain individuals in the U12/13 and U15 age-groups, TEE was comparable to that of adult Premier League players, whilst several of the U18 players displayed TEE values that exceeded adult players, despite presenting with approximately 7 kg less FFM (11). In addition to individual variation, our data also demonstrate large differences from adolescent athletes from other team sports where both age matched basketball (34) and rugby players (35) present with an absolute TEE ~1000 kcal·day^{-1} greater than that observed here, likely due to these athletes being significantly taller and heavier. Indeed, when comparing relative TEE in the U18 (~49 kcal·kg^{-1}·day^{-1}) and U15 (~54 kcal·kg^{-1}·day^{-1}) age-groups with age-matched basketball (~57 kcal·kg^{-1}·day^{-1}; 35) and rugby (~50 kcal·kg^{-1}·day^{-1}; 35) players, such differences are no longer apparent. When taken together, the importance of adopting an individualized and sport-specific approach to energy prescription (i.e. energy intake based on energy expenditure) in adolescent team sport athletes therefore becomes clearly evident. Such individual approaches should also account for different positional demands (e.g. goalkeepers) and players with reduced training and match loads (e.g. substitutes).

In relation to estimation of energy intake, U18 players reported higher intakes (3180 ± 279 kcal·day^{-1}) than both U15 (2821 ± 338 kcal·day^{-1}) and U12/13 players (2659 ± 187 kcal·day^{-1}). Such data contrast from our previous observations on academy soccer players where we observed similar values (~2000 kcal·day^{-1}) in U13/14, U15/16 and U18 players (13). Additionally, our data are also ~500 kcal·day^{-1} greater than previous observations on U18 (7) and U15 (8) academy soccer players. Differences between studies are most likely due to variations in dietary assessment methods, where in the previous studies, energy intake was estimated from food diaries as opposed to the remote food photographic method and 24-hour recalls adopted here. Indeed, the latter methods appear to be more sensitive to assess total daily CHO and fat intake, given that the absolute intake of both macronutrients was approximately 100 g more than our previous observations (13). When making inferences of energy balance, we observed no differences between self-reported energy intake and energy expenditure within squads, nor did we detect any significant differences in mean body mass. However, such data also displayed large individual variation, particularly evident in two U18 players who self-reported a mean energy deficit >1000 kcal$\cdot$day^{-1}. Whilst we acknowledge acute day-to-day fluctuations in body mass, it is noteworthy that in one of these players the energy deficit coincided with a reduction in body mass of 2 kg over the 14-day study period thus potentially suggesting that the apparent energy deficit may be of physiological relevance. In contrast, body mass in the other player showed no appreciable change, which may therefore be reflective of the under-reporting of dietary intake that is commonly observed in adolescent athletes (8,9,34). On the basis of our estimation of total energy requirements, it is suggested that relative intakes of CHO, fat and protein corresponding to 6-8, 1.5-2.5 and 2 g$\cdot$kg$^{-1}\cdot$day^{-1} body mass would provide a reasonable starting point for which to meet the daily energy requirements of academy soccer players. To this end, it is important that all key stakeholders associated within Premier League academies (and other professional academies worldwide), i.e. players, parents/guardians, academy/school staff and policy makers, are aware of such energy requirements so that appropriate nutrition education and provision can be put in place. Indeed, whilst the present players appeared capable of consuming appropriate energy intake for the require TEE, it should be noted that the academy in which this research was conducted had a full-time nutrition practitioner and also provided numerous meals and snacks to their players on a daily basis. In those clubs where such a service provision is not available, practitioners should therefore make a concerted effort to engage and educate all stakeholders to ensure that players achieve their daily energy requirements.

One limitation of the DLW method is that it only permits quantification of mean TEE over a period of time. As such, this method cannot provide information on the AEE of a specific exercise bout (e.g. a training session) or identify day-to-day differences in TEE (36,37). However, day-to-day differences in TEE and subsequent periodisation of daily EI is not likely relevant in academy soccer players (and other youth athletes) compared to their adult counterparts, given that a slight energy surplus is beneficial (through to adulthood i.e. when a fully mature state is reached), in order to optimise growth, maturation and physical development (particularly of FFM) (4,38).

In summary, we report for the first time the direct assessment of TEE of male academy soccer players from the English Premier League. Whilst we demonstrate that TEE progressively increases in accordance with anthropometrical parameters, RMR and physical loading, our data also demonstrate marked individual variation within age groups. Importantly, such data demonstrate that in some individuals, TEE is comparable to or exceeds that previously reported in adult Premier League soccer players.

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Conflict of interest

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

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Figure 1. (**A**) Training and match-play duration, (**B**) total distance, and (**C**) average speed in the U12/13, U15 and U18 age-groups from a Category One English Premier League academy (n=22). [a] denotes significant difference from U12/13 squad, $P<0.05$. [b] denotes significant difference from U15 squad, $P<0.05$. [#] denotes significant difference from week 2, $P<0.05$. Black circles represent individual players. Data not included for the two injured players.

Figure 2. (**A**) Resting metabolic rate, (**B**) mean daily total energy expenditure, (**C**) mean daily activity energy expenditure, and (**D**) physical activity level (PAL) in the U12/13, U15 and U18 age-groups (n=24) from a Category One English Premier League academy. [a] denotes significant difference from U12/13 squad, $P<0.05$. [b] denotes significant difference from U15 squad, $P<0.05$. [#] denotes significant difference from week 2. Black circles represent individual players. TEE and AEE data are included for one injured player in the U15 age-group and one injured player in the U18 age-group. TEE for weeks one, two and 14-day mean in the two injured players respectively, was 2806, 2542 and 2771 $kcal \cdot day^{-1}$ in the U18 player and 2798, 2742 and 2797 $kcal \cdot day^{-1}$ in the U15 player. AEE for weeks one, two and 14-day mean in the two injured players respectively, was 415, 151 and 380 $kcal \cdot day^{-1}$ in the U18 player and 636, 580 and 635 $kcal \cdot day^{-1}$ in the U15 player.

Figure 3. (**A**) Difference between mean energy intake and expenditure; (**B**) body mass change (Δ) from baseline, on days 7 and 14; (**C**) absolute and (**D**) relative energy intake; (**E**) absolute and (**F**) relative carbohydrate intake; (**G**) absolute and (**H**) relative fat intake; and (**I**) absolute and (**J**) relative protein intake in the U12/13, U15 and U18 age-groups from a Category One English Premier League academy over 7-days (n = 24). [a] denotes significant difference from

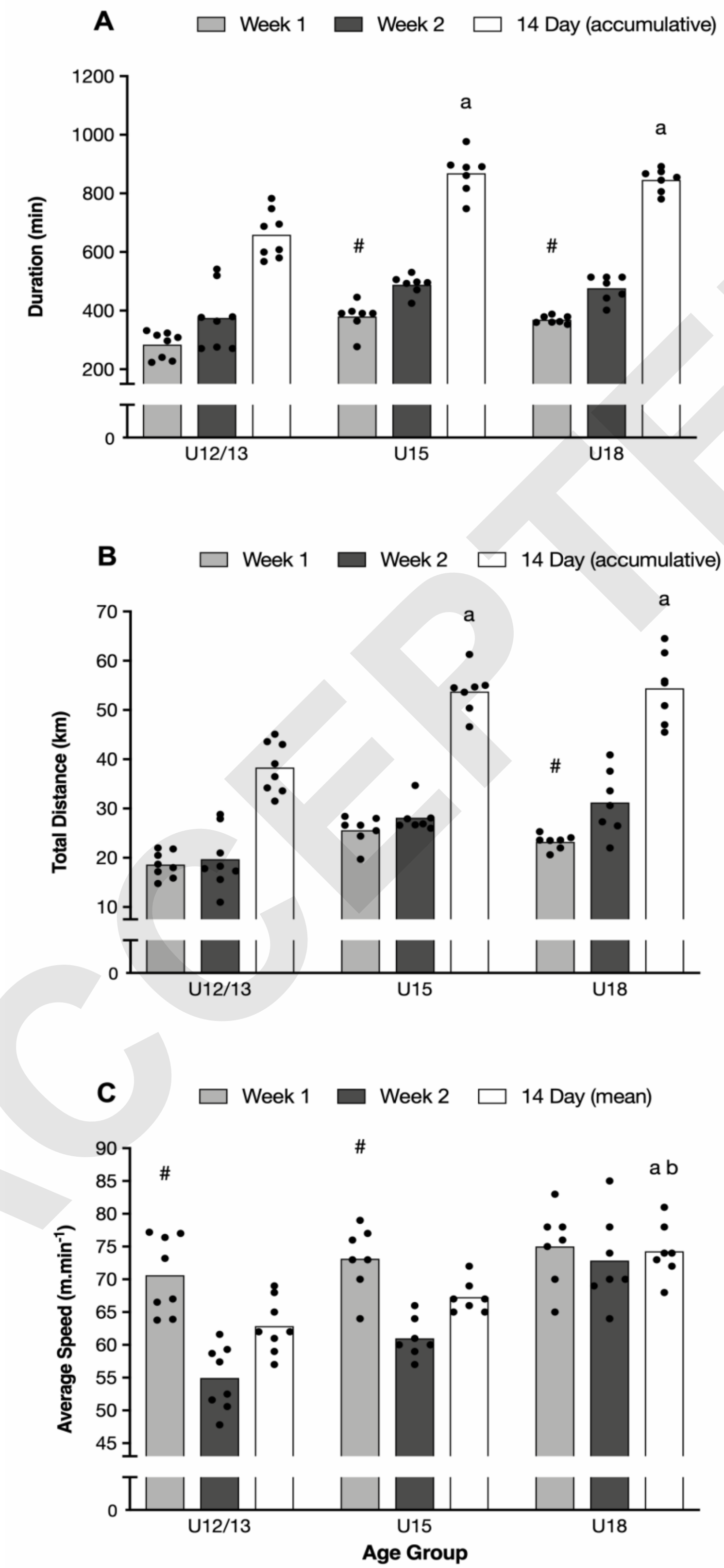
U12/13 squad, P<0.05. [b] denotes significant difference from U15 squad, P<0.05. Black circles represent individual players.

Figure 4. The relationship between mean daily total energy expenditure (TEE) and (**A**) body mass (P<0.01), (**B**) fat-free mass (P<0.01), (**C**) stature (P<0.01), (**D**) resting metabolic rate (RMR; P<0.01) and (**E**) activity energy expenditure (AEE; P<0.01) in youth soccer players from a Category One English Premier League academy (n=24). Additionally, the relationship between mean daily AEE and (**F**) training and match-play duration (P<0.01), (**G**) total distance (P<0.01) and (**H**) average speed (P=0.49) in youth soccer players from a Category One English Premier League academy (n=22). In Figures **F**, **G** and **H** there are two data points per player, representing values from two different weeks.

Table 1. Baseline player characteristics from the U12/13, U15 and U18 age-groups from a Category One English Premier League academy. A comparison of age, maturity offset, current percent of predicted adult stature (PAS), stature, body mass, fat-free mass, fat mass and percent body fat.

Table 2. An overview of the training and match schedule for the U12/13, U15 and U18 age-groups from a Category One English Premier League academy over the 14-day in-season study period.

Figure 1



A
Week 1
Week 2
14 Day (accumulative)
Duration (min)
1200
1000
800
600
400
200
0
a
a
#
#
U12/13
U15
U18
B
Week 1
Week 2
14 Day (accumulative)
Total Distance (km)
70
60
50
40
30
20
10
0
a
a
#
U12/13
U15
U18
C
Week 1
Week 2
14 Day (mean)
Average Speed (m.min-1)
90
85
80
75
70
65
60
55
50
45
0
#
#
a b
U12/13
U15
U18
Age Group

Figure 2

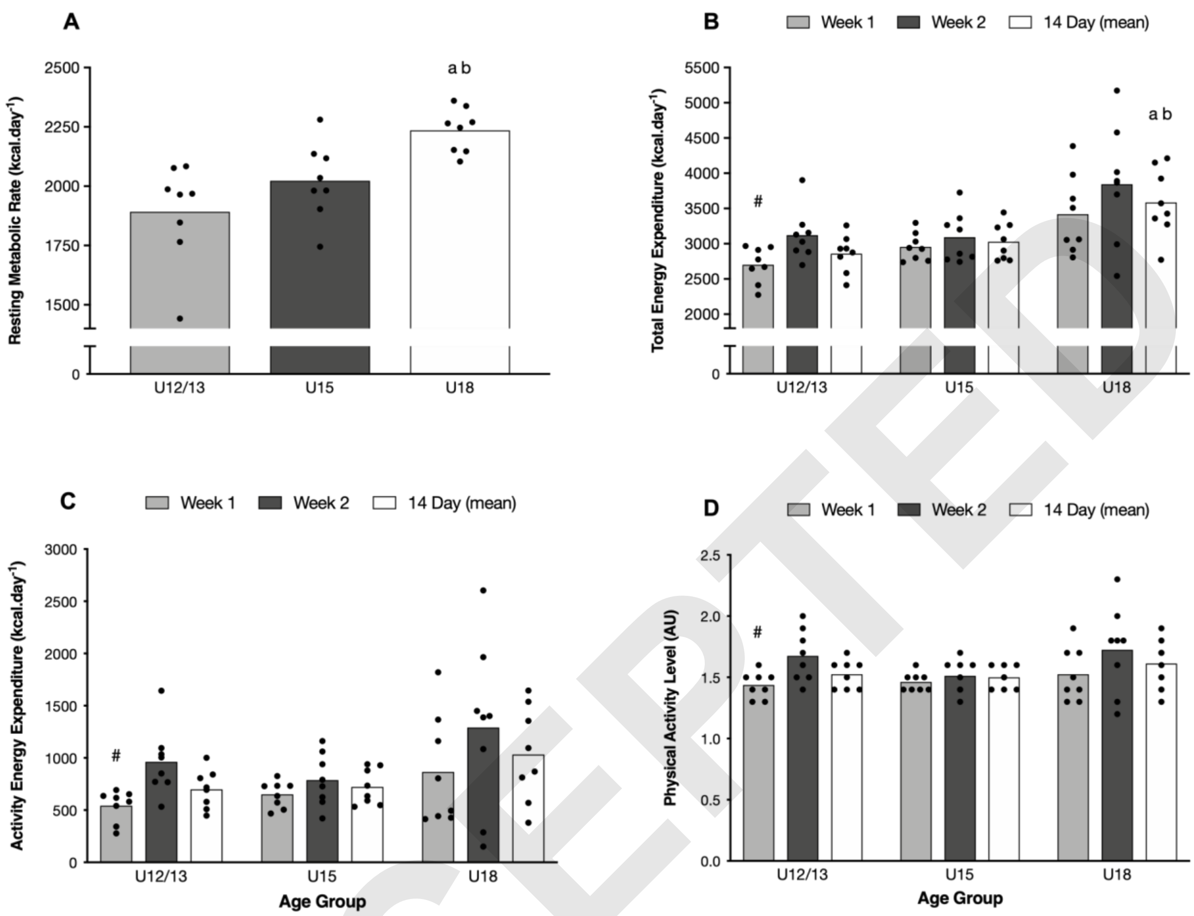
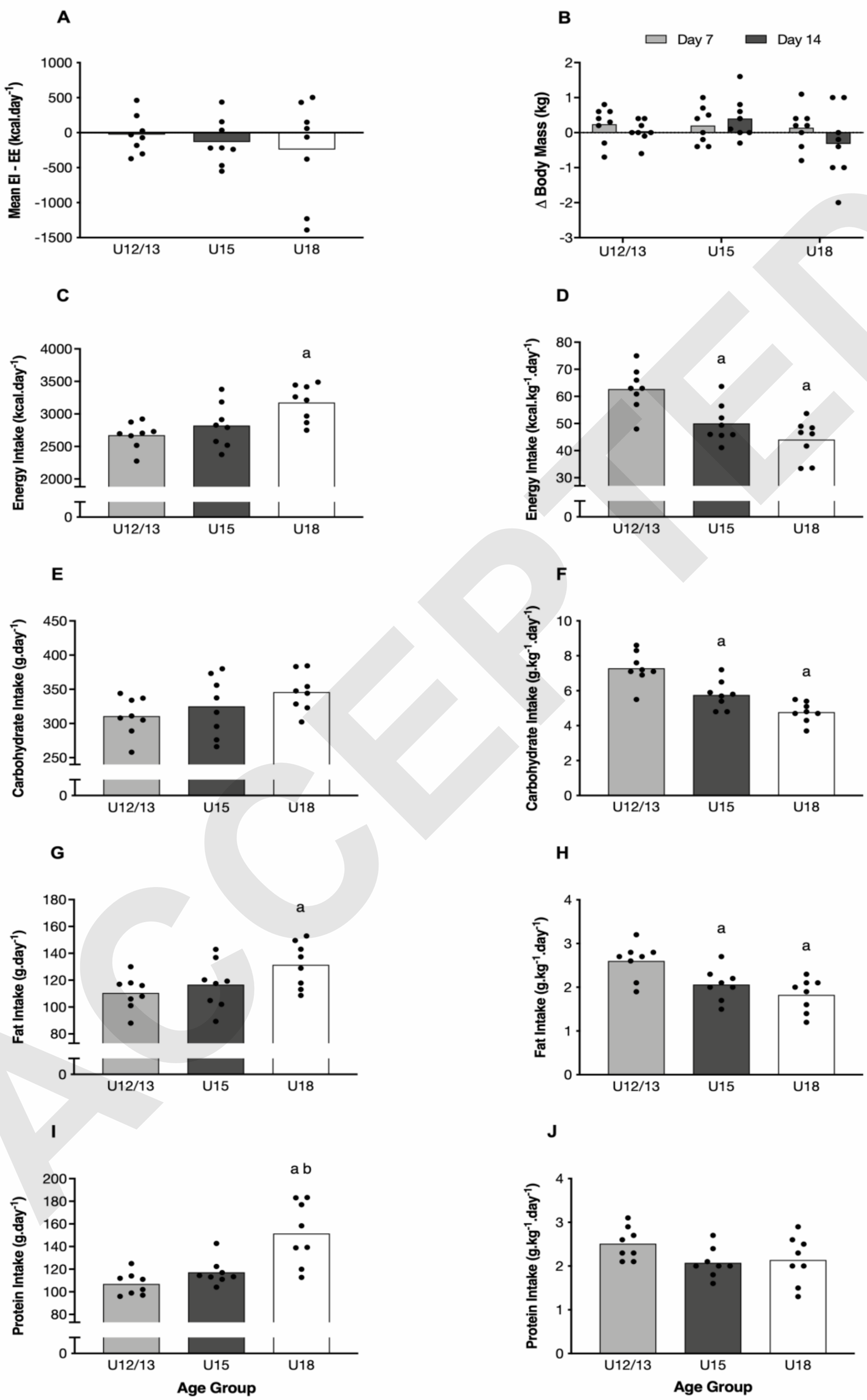

A
Resting Metabolic Rate (kcal.day^{-1})
2500
2250
2000
1750
1500
0
a b
U12/13
U15
U18
B
Week 1
Week 2
14 Day (mean)
Total Energy Expenditure (kcal.day^{-1})
5500
5000
4500
4000
3500
3000
2500
2000
0
#
a b
U12/13
U15
U18
C
Week 1
Week 2
14 Day (mean)
Activity Energy Expenditure (kcal.day^{-1})
3000
2500
2000
1500
1000
500
0
#
U12/13
U15
U18
Age Group
D
Week 1
Week 2
14 Day (mean)
Physical Activity Level (AU)
2.5
2.0
1.5
1.0
0.5
0.0
#
U12/13
U15
U18
Age Group

Figure 3



A
Mean EI - EE (kcal.day-1)
1000
500
0
-500
-1000
-1500
U12/13
U15
U18
B
Day 7
Day 14
Δ Body Mass (kg)
2
1
0
-1
-2
-3
U12/13
U15
U18
C
Energy Intake (kcal.day-1)
a
4000
3500
3000
2500
2000
0
U12/13
U15
U18
D
Energy Intake (kcal.kg-1.day-1)
a
a
80
70
60
50
40
30
0
U12/13
U15
U18
E
Carbohydrate Intake (g.day-1)
450
400
350
300
250
0
U12/13
U15
U18
F
Carbohydrate Intake (g.kg-1.day-1)
a
a
10
8
6
4
2
0
U12/13
U15
U18
G
Fat Intake (g.day-1)
a
180
160
140
120
100
80
0
U12/13
U15
U18
H
Fat Intake (g.kg-1.day-1)
a
a
4
3
2
1
0
U12/13
U15
U18
I
Protein Intake (g.day-1)
a b
200
180
160
140
120
100
80
0
U12/13
U15
U18
Age Group
J
Protein Intake (g.kg-1.day-1)
4
3
2
1
0
U12/13
U15
U18
Age Group

Figure 4

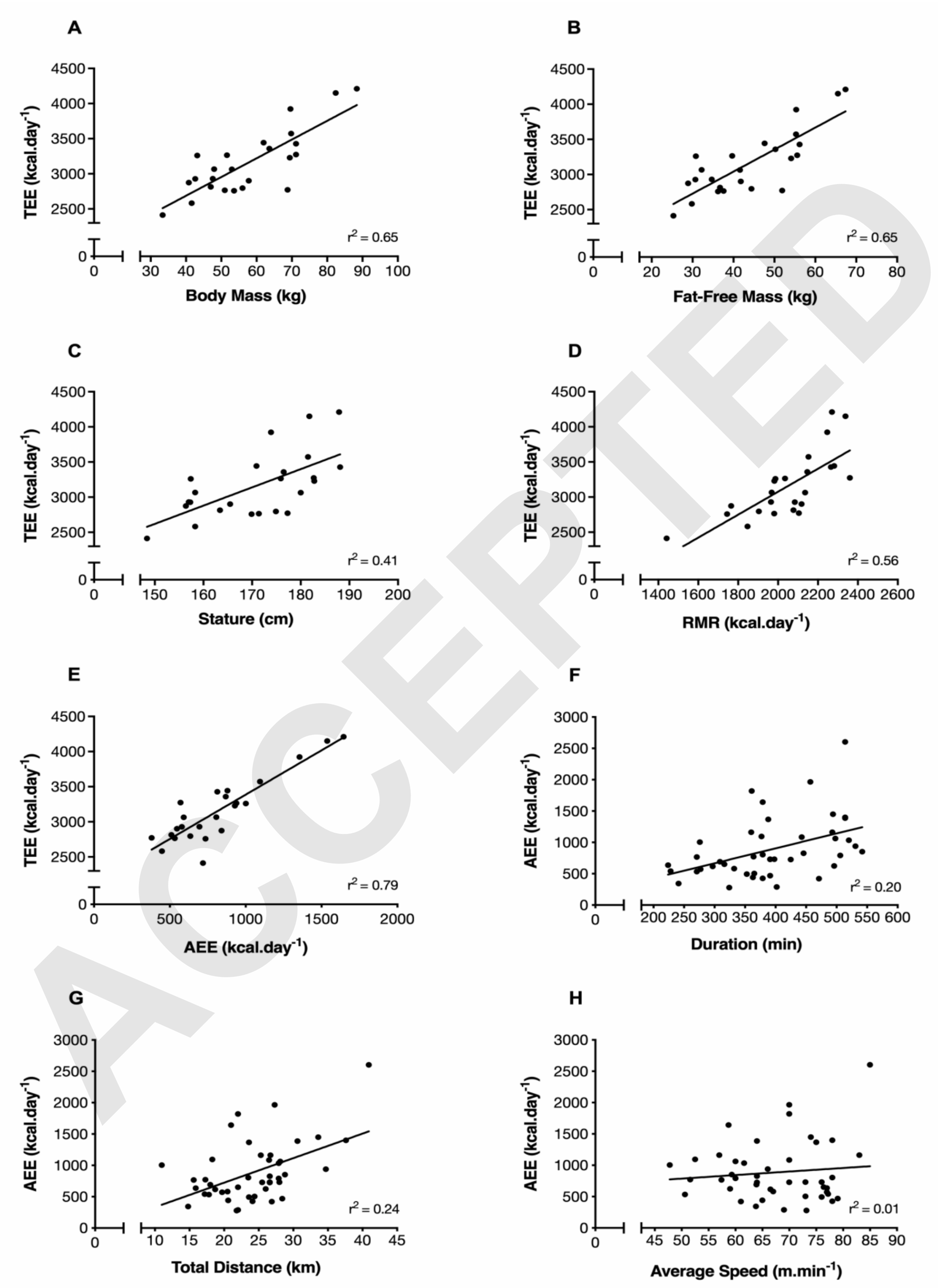

A
TEE (kcal.day⁻¹)
Body Mass (kg)
r² = 0.65
B
TEE (kcal.day⁻¹)
Fat-Free Mass (kg)
r² = 0.65
C
TEE (kcal.day⁻¹)
Stature (cm)
r² = 0.41
D
TEE (kcal.day⁻¹)
RMR (kcal.day⁻¹)
r² = 0.56
E
TEE (kcal.day⁻¹)
AEE (kcal.day⁻¹)
r² = 0.79
F
AEE (kcal.day⁻¹)
Duration (min)
r² = 0.20
G
AEE (kcal.day⁻¹)
Total Distance (km)
r² = 0.24
H
AEE (kcal.day⁻¹)
Average Speed (m.min⁻¹)
r² = 0.01

Table 1. Baseline player characteristics from the U12/13, U15 and U18 age-groups from a Category One English Premier League academy. A comparison of age, maturity offset, current percent of predicted adult stature (PAS), stature, body mass, fat-free mass, fat mass and percent body fat.

	U12/13	U15	U18
n	8	8	8
Age (years)*	12.2 ± 0.4	15.0 ± 0.2 [ac]	17.5 ± 0.4 [ab]
Maturity offset (years)*	-1.3 ± 0.6	1.2 ± 0.7 [ac]	3.5 ± 0.6 [ab]
Current percent of PAS (%)*	85.5 ± 2.0	95.5 ± 2.2 [ac]	99.7 ± 0.3 [ab]
Stature (cm)*	157.1 ± 4.1	173.9 ± 5.6 [ac]	181.2 ± 5.2 [ab]
Body mass (kg)*	43.0 ± 4.8	56.8 ± 6.2 [ac]	73.1 ± 8.1 [ab]
Fat-free mass (kg)*	31.1 ± 3.5	42.9 ± 5.8 [ac]	57.2 ± 6.1 [ab]
Fat mass (kg)	7.5 ± 2.1	8.9 ± 2.4	10.3 ± 2.4
Percent body fat (%)	18.5 ± 4.0	16.6 ± 4.6	14.6 ± 2.1

* denotes significant main effect. [a] denotes significant difference from U12/13 squad, $P<0.05$. [b] denotes significant difference from U15 squad, $P<0.05$. [c] denotes significant difference from U18 squad, $P<0.05$.

Table 2. An overview of the training and match schedule for the U12/13, U15 and U18 age-groups from a Category One English Premier League academy over the 14-day in-season study period.

	Week 1						
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
U12/13	**Saturday**	**Sunday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
	Rest (8)	Match (8) ~11:00-12:20	Rest (8)	Training (8) ~15:30-17:30	Rest (8)	Rest (1) Training (7) ~15:30-17:30	Rest (8)
U15	**Sunday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
	Rest (8)	Rest (8)	Match (8) * ~19:00-20:20	Rest (8)	Rest (2) Training (6) ~15:30-17:30	Rest (1) Training (7) ~15:30-17:00	Rest (1) Match (7) ~11:00-12:20
U18	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**	**Monday**	**Tuesday**
	Rest (8)	Training (8) ~10:00-12:00	Training (8) ~10:00-11:30	Match (8) * ~11:00-12:30	Rest (8)	Rest (1) Training (7) ~10:00-12:00	Rest (5) Match (3) ~15:00-16:30
	Week 2						
	Day 8	**Day 9**	**Day 10**	**Day 11**	**Day 12**	**Day 13**	**Day 14**
U12/13	**Saturday**	**Sunday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
	Rest (8)	Rest (6) Match (2) ~11:00-12:10	Rest (8)	Training (8) ~15:30-17:30	Training (8) ~15:30-17:30	Rest (1) Training (7) ~15:30-17:30	Rest (1) Training (7) ~15:30-17:30

U15	**Sunday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
	Rest (8)	Rest (2)	Rest (1)	Rest (8)	Rest (1)	Rest (1)	Rest (1)
		Training (6)	Training (7)		Training (7)	Training (7)	Match (7)
		~15:30-17:30	~15:30-17:30		~15:30-17:30	~15:30-17:00	~11:30-12:50
U18	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**	**Monday**	**Tuesday**
	Rest (8)	Rest (1)	Rest (1)	Rest (1)	Rest (8)	Rest (1)	Rest (1)
		Training (7)	Training (7)	Match (7)		Training (7)	Match (7)
		~10:00-12:00	~10:00-11:30	~11:00-12:30		~10:00-11:30	~15:00-16:30

Numbers in parentheses represents the number of players in each respective age-group that partook in the relevant day. *Injuries were sustained on day three in an U15 player and day four in an U18 player. They did not take part in any further training or match play following their respective injuries and therefore had ‘rest’ days for the remainder of the study. Day one for the U12/13 age-group was a Saturday. Day one for the U15 age-group was a Sunday. Day one for the U18 age-group was a Wednesday. Baseline measures were collected on the morning of day one for all players.