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Quantification of energy expenditure in elite youth soccer players: implications for population specific nutrition guidelines

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Contents Page

1. Executive summary

Despite published data on adult soccer players, the typical training loads and associated total daily energy expenditures (TEE) of academy soccer players are not yet documented. As such, it is currently difficult to prescribe population specific nutritional guidelines that simultaneously optimise growth, maturation and adaptation to training. Additionally, it is possible that players' energy requirements increase as they progress through the academy pathway owing to developments in anthropometrical profile and potentially, increased training load. Therefore, the aim of this study was to test the hypothesis that U18 players will present with higher TEE than U15 and U12/13 players in accordance with higher stature, body mass, fat-free mass, resting metabolic rate (RMR) and training loads. Twenty-four elite male youth soccer players from an English Premier League Academy (n = 8 U12/13s; n = 8 U15s; n = 8 U18s) underwent baseline assessments of stature, body mass, maturity (maturity offset and current percentage of predicted adult stature), body composition (assessed via DXA) and resting metabolic rate (RMR; assessed via indirect calorimetry). We also quantified TEE (via the gold standard doubly-labelled water technique), and training load over a 14-day in-season period via GPS technology (Statsports, Ireland). Energy intake was also quantified for the first 7-days, via the remote food photography method and 24-hour recall. Baseline characteristics including stature, body mass, maturity status, fat-free mass and RMR significantly increased in a stepwise manner between age-groups. There was no difference in training and match-play volume (duration and total distance) or intensity (average speed) between the three age-groups, with some markers of training loads comparable to those of professional adult players. Mean daily 14-day TEE of the U18 age group (approximately 3500-4000 kcal.day^{-1}) was comparable to that of professional adult players, though such expenditures were significantly higher compared to the U15 age-group (approximately 3000 kcal.day^{-1}). Energy expenditure data from U12/13 group is not yet available due to the late signing of the contract between UEFA and LJMU (such data will be available in the next 4-6 weeks). Energy and macronutrient intakes of players in the present study are higher than previously reported in elite youth soccer players, with differences between the three age-groups. There was a significant positive correlation between TEE and stature, body mass, fat-free mass and RMR however there was no significant relationship between TEE and training load measures. We report for the first time the daily TEE of academy soccer players, as quantified by the gold standard doubly labelled water technique. Despite no differences in training loads between the three age-groups, we conclude that the energy requirements of academy soccer players vary in accordance with changes in stature, body mass, fat-free mass and RMR. When considering the similarity in daily TEE of academy and adult players in combination with high individual expenditures of some academy players (e.g. in some cases >5000 kcal.day^{-1}), our data demonstrate that optimising energy availability should be the cornerstone of any soccer academy nutrition programme. Data from this research will now inform nutritional guidelines specific for elite youth soccer players worldwide.

2. Introduction

Despite the wealth of research conducted in elite adult soccer players, there is a distinct lack of data informing the delivery of research informed practice in elite youth soccer. This is especially the case for tailored sport nutrition guidelines where the advice is often similar to that provided to adult players (Naughton *et al.*, 2016). The implementation of population specific recommendations is of paramount importance considering that the goal of soccer academies is to promote technical, tactical and physical development throughout key phases of the growth and maturation. To date, no accurate data on the total daily energy expenditure (TEE) of elite youth soccer exists, thus preventing accurate prescription of specific nutritional guidelines for this population. Considering the detrimental effects of low energy availability on growth, health and performance (Loucks, Kiens and Wright, 2011), it is imperative to determine the energy expenditure of elite youth soccer players. To this end, it is proposed that the data produced from this research will have ***immediate translational impact on elite youth soccer players worldwide and sports science and medicine practitioners*** given that population specific nutritional guidelines can now be formulated. These data will therefore have practical implications for optimising growth and development of the elite youth soccer player.

3. Hypotheses & research questions

The aim of this study was to simultaneously quantify the energy expenditure, energy intake and training loads of elite youth soccer players over a 14-day in-season period. We tested the hypothesis that U18 players will present with higher TEE than U15 and U12/13 players in accordance with higher stature, body mass, fat-free mass, resting metabolic rate (RMR) and training loads. These data will have implications for the development of population specific nutritional guidelines.

4. Literature review

Whilst the training regimes of elite adult soccer players focus on optimising performance for competitive match play, the focus of youth soccer academies is long term player development. As youth players progress through a soccer academy and develop technically and tactically, they also undergo rapid biological growth and maturation (Malina, Figueiredo and Coelho-e-Silva, 2017). To maximise physical development but also minimise the risk of injury in elite youth soccer players, it is essential that a youth player's energy availability is appropriate during this rapid growth period. Despite such clear rationale, there is currently no accurate data available that quantifies the energy expenditure of elite youth soccer players in response to habitual in-season training and match loads.

The doubly labelled water (DLW) technique is the gold standard method of assessing energy expenditure *in vivo* (Westerterp, 2017). Importantly, this method is non-invasive and can provide information on energy expenditure over a prolonged period of time, such as a 7-14 day period. Although several studies have attempted to estimate energy expenditure of elite youth soccer players using methodologies such as activity diaries (Russell and Pennock, 2011) and accelerometry (Briggs *et al.*, 2015), no data exists in this population when assessed from the DLW method. Given the lack of direct measures of energy expenditure, prescription of nutritional guidelines for elite youth soccer players is currently difficult. Recent data using DLW from our laboratory has reported average daily energy expenditures of 3566 ± 585 kcal.day^{-1} in adult Premier League soccer players (~27 years old) (Anderson *et al.*, 2017). Nonetheless, it is unlikely that such data translate to elite youth soccer players undergoing rapid biological growth and maturation. Indeed, it is noteworthy that previous researchers using DLW have observed average daily energy expenditures of 4626 ± 682 and 3497 ± 242 $kcal.day^{-1}$ in elite youth (~17 years old) male and female basketball players who were training at least 10 hours per week (Silva *et al.,* 2013). In addition, average daily energy expenditures of ~4010 $kcal.day^{-1}$ have also been quantified via the DLW method in 15 year old English Academy rugby players (Smith *et al.*, 2018). When considering that elite youth soccer players train for a similar duration as the aforementioned youth team sport athletes, it is possible such energy expenditures are also experienced in these individuals. Nonetheless, we have also recently reported daily energy intakes of ~1900 $kcal.day^{-1}$ in elite youth soccer players aged 12-16 (Naughton *et al.*, 2016), thus suggesting that energy availability may be seriously compromised in this population. Chronic low energy availability may result in impaired growth and maturation of tissues and organs, reduced skeletal bone mineral accrual, increased risk of stress fractures, increased risk of osteoporosis later in life, delayed sexual maturation and a suppression of the immune system (Loucks, Kiens and Wright, 2011).

Since the introduction of the English Elite Player Performance Plan (EPPP) in 2011, accumulative training hours of elite youth soccer players (age 8 to 21) has increased from 3760 to 8500 hours (Read *et al.*, 2017). This has undoubtedly resulted in an increased energy expenditure and it is noteworthy that a recent injury audit of six English professional soccer academies reported that injury rates have also increased threefold since the EPPP has been introduced (Read et al 2017). Whilst it is impossible to attribute this increase in injuries to one individual factor, it is possible that a gross mismatch of energy requirements and energy intake may be a contributing factor in what appears to be a high risk population. In considering that youth soccer players are also subjected to a greater weekly training load than adult players (Bowen *et al.*, 2017), the accurate measurement of energy expenditure (using the gold standard doubly labelled water technique) is therefore required to better understand the energy requirements elite youth soccer players and thus devise specific nutritional guidelines for this population.

5. A review of the proposed research design and strategy

5.1. Justification of the design

Using a cross-sectional design, 24 elite youth soccer players of different age groups (U12/13, n=8; U15, n=8; U18, n=8) from a Premier League Academy were assessed for energy expenditure, energy intake and training load assessed over a 14 day in-season period. Such a cross-sectional design was utilised given that the three different age group squads presented with distinctly different characteristics: age, maturation status, stature, body mass and fat-free mass. Our chosen sample therefore allowed us to assess our outcome variables across representative ages of academy soccer players at different stages of growth and maturation.

5.2. Justification of the measurement approach and assumptions about the research topic

The doubly labelled water technique, the gold standard method of assessing energy expenditure in free-living conditions, was used to measure energy expenditure. The typical observation period using this method is 1-3 weeks in human subjects (Westerterp, 2017), so a 14 day timescale was selected as an appropriate amount of time to provide accurate information. The gold standard doubly labelled water technique was used to measure energy expenditure. The typical observation period using this method is 1-3 weeks in human subjects (Westerterp, 2017). This timeframe allows for the single bolus does of hydrogen (deuterium - ^{2}H) and oxygen (^{18}O) stable isotopes to reach equilibrium with the total body water and then clear from the body via CO_2 and H_2O (Westerterp, 2017). Considering the high cost of the doubly labelled water isotopes and their analysis (~£800 per player x 24 = £19,200), finances dictated the number of players that could be included in this study. To assess energy intake (and thus energy balance), players self-reported dietary intake via the remote food photographic method (prospective method), which has recently been validated for use with youth athletes (Costello *et al.*, 2017) and used previously by our group in professional adult soccer players (Anderson et al. 2017). After two pilot trials, each lasting four days each, it was decided that 14 days would be too long to assess energy intake accurately. It was therefore decided that a seven-day period (1st week) would be assessed to ensure full athlete compliance. Additionally, to complement this remote food photographic data, a 24 hour recall, using the triple pass method (retrospective method), was also performed on one of the seven days to allow for comparison of data (Capling *et al.*, 2017). Each player's pitch based training and match load was monitored throughout the 14 day data collection period using GPS technology (Apex, Stats Sports, Ireland). This is commonplace in professional soccer environments, and as such all players were familiarised with this aspect of data collection.

5.3. An outline of the key variables for quantitative work

Energy expenditure (kcal.day^{-1})

Energy intake (kcal.day^{-1})

Energy balance (difference between energy intake and expenditure)

Training and match load metrics: Duration (minutes), Total distance (km) and Average speed (meters per minute)

5.4. The sample frame and size

A convenience sample of 24 elite youth soccer players was selected. Eight players from three different age groups were chosen: U18 (n=8), U15 (n=8) and U12/13 (n=8). Players were only considered for selection if they: 1) were outfield players i.e. not a goalkeeper, 2) were free from injury and involved in full squad training 3) were regularly involved in match day team/squad. Considering the high cost of the doubly labelled water isotopes and their analysis (~£800 per player x 24 = £19,200), finances dictated the number of players that could be included in this study.

5.5. An outline of the hypothesis(-es) addressed, the analysis strategy and techniques used, and the strength and significance of the results

We tested the hypothesis that U18 players will present with higher TEE than U15 and U12/13 players in accordance with higher stature, body mass, fat-free mass, resting metabolic rate (RMR) and training loads. To determine energy expenditure, participants provided a ~20ml urine sample (second pass of the day) on days 0, 2, 4, 6, 7, 8, 10, 12, 14 in a sealable container. Analysis entailed the measurement of Isotopic abundance via continuous-flow isotope ratio using mass spectrometry following gaseous exchange, for both isotopes. Isotopic enrichments were calculated by subtraction of the pre-dose abundance in each case. ^{2}H and ^{18}O elimination rates were estimated from the gradient of the log transformed data and combined with total body water from the intercept of these plots, to estimate CO_2 production rate. Isotope enrichments were converted to EE using a two-pool model equation (Schoeller *et al.*, 1986), assuming a food quotient of 0.85. Energy expenditure is expressed as a daily average from the 14-day data collection period and also separated into analysis of week 1 and 2, i.e. kcal.day^{-1}. Due to late signing of the contract, TEE of the U12/U13 group are not yet completed though all samples are collected. To quantify energy intake (and thus infer energy balance), data from the remote food photographic and the 24 hour recall were analysed using dietary analysis software (Nutritics, Ireland). Players were familiarised with both of these methods and were given clear written and verbal instructions of how to accurately report their dietary intake prior to commencement of the data collection. Each player's training and match load were recorded throughout the 14 day data collection period. Pitch based training and match loads were monitored via GPS technology (Apex, Stats Sports, Ireland) and analysed using the technologies software.

5.6. The validity and reliability of the instruments and variables applied

Doubly labelled water validation studies, comparing doubly labelled water-assessed energy expenditure with simultaneously measured energy expenditure in a respiration chamber, have shown that this method is accurate and has a precision of 2–8% (Schoeller, 1988). Reported dietary intake were analysed using dietary analysis software (Nutritics, Ireland). To ensure accuracy/reliability of the analysis, two different Sport and Exercise Nutrition register (SENr) practitioners both analysed the dietary intake data on Nutritics. Additionally, one 24 hour recall was performed to allow for comparison of energy intake data from the same day (using two different methods). Training and match load data were collected via GPS technology (Apex, Stats Sports, Ireland) and analysed on the technology's software. The GPS units used in the current study have a measurement error of 1-2% in total distance and different speed thresholds (Beato *et al.*, 2018).

5.7. An overview of any ethical issues and how they are addressed

Ethical approval was granted by the Wales Research Ethics Committee, UK (REC approval number: 17/WA/0228) and by the Ethics Committee of Liverpool John Moores University (ethics number: M18SPS037).

Use of human participants: Following ethical approval, participation was sought on a voluntary basis. Participants were fully informed of the procedures and associated risks of such procedures and if they agreed to proceed, they provided signed informed consent. Our exclusion criteria ensured participants immediately at risk were excluded i.e. those with any previous diagnosis of; ischaemic heart disease, myopathy or any neuromuscular disorder.

Research on minors (11-18 year olds): This research involved data collection from minors. All researchers have up to date CRB/DBS checks. Parents were fully informed of the study and invited to provide informed consent for their child if they so desired. The research team worked closely with the parents and safeguarding team at the soccer club throughout the study.

DXA scans: The use of DXA scans are common in physiological investigations with athletes and the associated risks are negligible to the participants as ionizing radiation levels are very small at 0.4 µSv per scan, which is less than a chest xray and/or the levels exposed to a passenger on a transatlantic flight. However, this risk was explained to all participants before giving consent and in the case of minors was explained to their parents/guardians. The chief investigator and all co-investigators have undergone dual-energy X-ray absorptiometry (DXA) training and are IR(ME)R certificated.

Human Tissue Act (HTA): Storage of urine samples requires a human tissue act (HTA) licence. Liverpool John Moores University (LJMU) currently has an approved Human Tissue Act licence (licence no: 12528) to obtain and store human tissue. LJMU has detailed risk assessments, adverse events procedures, and participant complaint procedures for taking blood and urine samples. LJMU also maintains a strict storage and disposal policy that complies with the HTA and uses a Procuro database to log and store the tissue. The same approach to procedures, storage and disposal was used for the human tissue derived from these studies to maintain a level of best practice.

Consent: Signed informed consent was taken by one of the research team, after the procedures were fully explained verbally. For minors, informed parental consent was obtained alongside child assent. Sufficient time was allowed for the participant to consider their decision and ask any questions about the trial.

Confidentiality: The confidentiality and privacy of the volunteers has been maintained at all times by coding all information and locking identifying information in filing cabinets and password protected computers in the School of Sport & Exercise Sciences.

6. An overview of the main research findings, with a clear focus on the research question(s)

Full data sets are presented for the U18 and U15 age-groups. Energy intake and training load data are presented for the U12/13 age-group. Upon payment of the last installment from UEFA, we will be able to pay the for the analysis of DLW for the U12/13 age-group. It should be noted that one player from the U15 age group and one player form the U18 age-group (n=2) sustained an injury on day 1 and day 5 respectively. These players data have been removed where deemed appropriate (indicated accordingly).

6.1. Players characteristics

Player characteristics including age, maturity offset, percent of predicted adult stature (PAS), stature, body mass, fat-free mass, fat mass, percent body fat and resting metabolic (RMR) rate are presented in Table 1.

Table 1. 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, percent body fat and resting metabolic rate.

	U12/13	**U15**	**U18**
n	8	8	8
Age (years)*	12.2 ± 0.4 ^{bc}	15.0 ± 0.2 ^{ac}	17.5 ± 0.4 ^{ab}
Maturity offset (years)*	-1.3 ± 0.6 ^{bc}	1.2 ± 0.7 ^{ac}	3.5 ± 0.6 ^{ab}
Current percent of PAS (%)*	85.5 ± 2.0 ^{bc}	95.5 ± 2.2 ^{ac}	99.7 ± 0.3 ^{ab}
Stature (cm)*	157.1 ± 4.1 ^{bc}	173.9 ± 5.6 ^{ac}	181.2 ± 5.2 ^{ab}
Body mass (kg)*	43.0 ± 4.8 ^{bc}	56.8 ± 6.2 ^{ac}	73.1 ± 8.1 ^{ab}

Fat-free mass (kg)*	31.1 ± 3.5 [bc]	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
Resting metabolic rate (kcal.day^{-1})*	1904 ± 226 [c]	2023 ± 162	2235 ± 93 [a]

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

6.2. Between age-group differences

6.2.1. TEE

Mean daily (14-day) TEE of the U15 age group (n = 8; 3029 ± 265 kcal.day-1) was lower than U18 (n = 8; 3586 ± 388 kcal.day-1) age-group (95% CI = 126 to 990 kcal.day-1; P = 0.02; Figure 1). TEE data for the U12 age group is not yet available.

6.2.2. Duration

Accumulative 14-day training and match-play duration (Figure 1) did not differ between the U12 (n = 8; 659 ± 81 min), U15 (n = 8; 766 ± 299 min) and U18 (n = 8; 783 ± 180 min) age-groups (P = 0.44).

6.2.3. Total distance

Accumulative 14-day total distance (Figure 1) did not differ between the U12 (n = 8; 38.3 ± 5.1 km), U15 (n = 8; 47.6 ± 17.9 km) and U18 (n = 8; 49.0 ± 16.8 km) age-groups (P = 0.30).

6.2.3. Average speed

Mean average speed (Figure 1) did not differ between the U12 (n = 8; 63 ± 4 m.min^{-1}), U15 (n = 8; 72 ± 13 m.min^{-1}) and U18 (n = 8; 73 ± 2 m.min^{-1}) age-groups (P = 0.06).

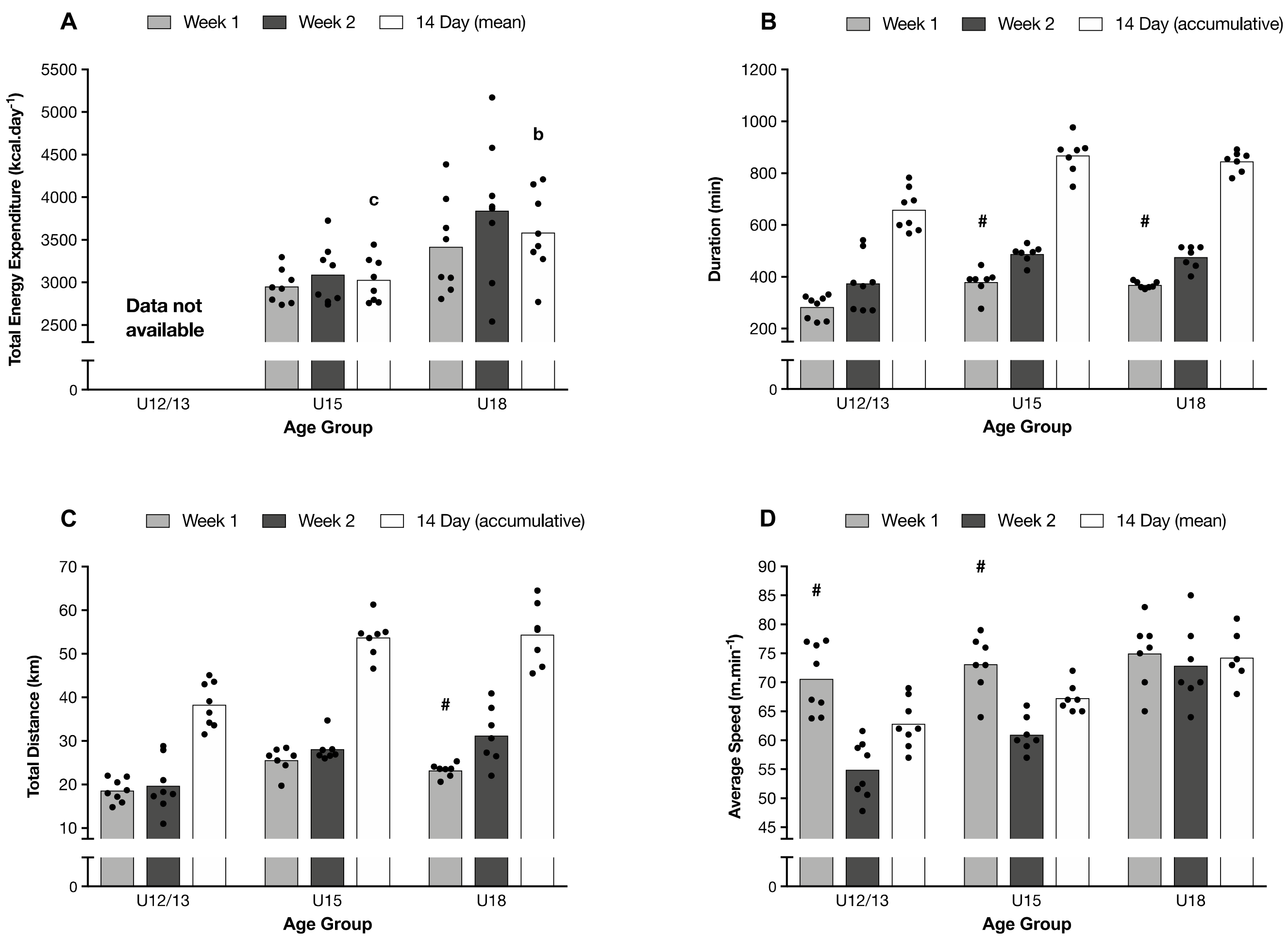

Figure 1. (A) Mean daily total energy expenditure, **(B)** training and match-play duration, **(C)** total distance and **(D)** average speed in the U12/13, U15 and U18 age-groups over the 14-day data collection period (n = 24). [a] denotes significant difference from U12/13 squad, P<0.05. [b] denotes significant difference from U15 squad, P<0.05. [c] denotes significant difference from U18 squad, P<0.05. [#] denotes significant difference from week 2. Black circles represent individual players.

6.2.4. Energy and macronutrient intake (n = 24)

There was a significant main effect of age-group on both absolute (P < 0.01) and relative (P < 0.01) mean energy intake (Figure 2). The U12's (2673 ± 203 kcal.day^{-1}) consumed a similar absolute amount of energy compared to the U15's (2821 ± 338 kcal.day^{-1}; P = 0.76), however less than the U18 age-group (3180 ± 279 kcal.day^{-1}; 95% CI = -878 to -162 kcal.day^{-1}; P<0.01). Absolute energy intake between the U15 and U18 age-groups was not statistically different (P = 0.06). Relatively, the U12's (63 ± 8 kcal.kg^{-1}) had a higher energy intake compared to both the U15 (50 ± 7 kcal.kg^{-1}; 95% CI = 3 to 22 kcal.kg^{-1}; P = 0.01) and U18 (44 ± 7 kcal.kg^{-1}; 95% CI = 9 to 28 kcal.kg^{-1}; P <0.01) age-groups, however there was no difference in relative energy intake between the U15's and U18's (P = 0.39).

Mean absolute carbohydrate intake was similar between the U12 (311 ± 28 g.day^{-1}), U15 (325 ± 44 g.day^{-1}) and U18 (346 ± 29 g.day^{-1}) age-groups (P = 0.12; Figure 2). There was however a significant main effect of age-group on mean relative carbohydrate intake (P <0.01), with the U12 (7.3 ± 1.0 g.kg^{-1}.day^{-1}) consuming more carbohydrate 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 (Figure 2). There was no difference in mean relative carbohydrate intake between the U15 and U18 age-groups (P = 0.07).

There was a significant main effect of age-group on both absolute (P = 0.04) and relative (P <0.01) mean fat intake (Figure 2). The U12's (110 ± 13 g.day^{-1}) absolute fat intake was similar to the U15's (117 ± 18 g.day^{-1}), however was less than the U18 (117 ± 18 g.day^{-1}; 95% CI = -42 to -1 g.day^{-1}; P = 0.04). Absolute fat intake between the U15 and

U18 age-groups was similar ($P = 0.23$). Relatively, the U12's (2.6 ± 0.4 g.kg^{-1}) had a higher fat intake compared to both the U15 (2.1 ± 0.4 g.kg^{-1}; 95% CI = 0.0 to 1.0 g.kg^{-1}; $P = 0.04$) and U18 (1.8 ± 0.4 g.kg^{-1}; 95% CI = 0.3 to 1.3 g.kg^{-1}; $P <0.01$) age-groups, however there was no difference in relative fat intake between the U15's and U18's ($P = 0.70$).

There was a significant main effect of age-group on mean absolute protein intake ($P <0.01$; Figure 2). The U12's (107 ± 10 g.day^{-1}) absolute protein intake did not differ from the U15's (117 ± 12 g.day^{-1}; $P = 0.75$), however was less than the U18 age-group (152 ± 28 g.day^{-1}; 95% CI = -70 to -21 g.day^{-1}; $P <0.01$). The U15's absolute protein intake was also less than the U18's (95% CI = -58 to -10 g.day^{-1}; $P <0.01$). However, there was no difference in mean relative protein intake between the U12 (2.5 ± 0.4 g.kg^{-1}), U15 (2.1 ± 0.3 g.kg^{-1}) and U18 (2.1 ± 0.6 g.kg^{-1}) age-groups ($P = 0.13$; Figure 2).

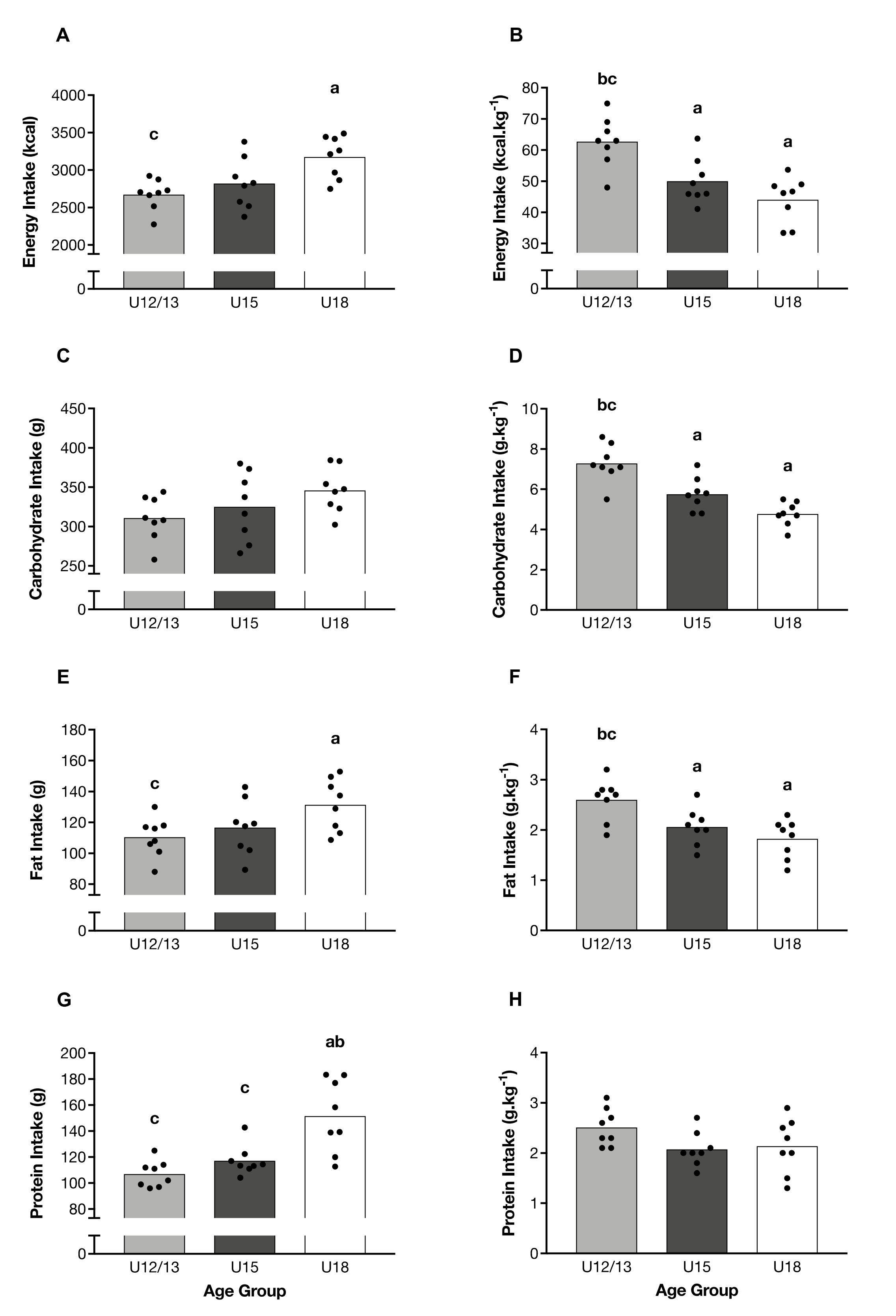

Figure 2. Absolute and relative energy and macronutrient intake over the 7-day data collection period. **(A)** Absolute and **(B)** relative energy intake; **(C)** absolute and **(D)** relative carbohydrate intake; **(E)** absolute and **(F)** relative fat intake; and (G) absolute and (H) relative protein intake in the U12/13, U15 and U18 age-groups (n = 24). [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. Black circles represent individual players.

6.3. Energy intake versus energy expenditure

There was no difference between energy intake and energy expenditure in either the U15 (n = 8; P = 0.40) or U18 (n = 8; P = 0.31) age-groups (Figure 3).

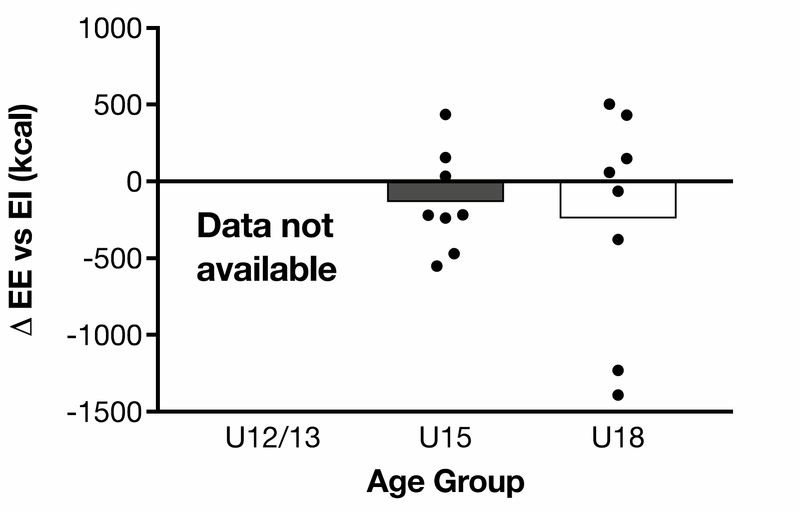

Figure 3. Difference between energy intake and expenditure in the U15 and U18 age-groups (n = 16). Black circles represent individual players.

6.4. Weekly differences: week one versus week two

6.4.1. TEE

Mean daily TEE was similar in weeks one (U15: 2955 ± 197; U18: 3507 ± 543 kcal.day^{-1}) and two (U15: 2980 ± 248; U18: 4031 ± 688 kcal.day^{-1}) in the both the U15 (n=8; P=0.09) and U18 (n = 8; P = 0.17) age-groups (Figure 1).

6.4.2. Duration

Training and match-play duration was similar in weeks one (284 ± 45 min) and two (375 ± 107 min) in the U12's (n = 8; P = 0.12; Figure 1). However, training and match-play duration was lower in week one (U15: 380 ± 51; U18: 369 ± 13 min) than week two (U15: 489 ± 33; U18: 477 ± 44 min) in the U15 (n = 7; 95% CI = -154 to -64 min; P <0.01) and U18 (n = 7; 95% CI = -155 ± -60 min; P <0.01) age-groups (Figure 1).

6.4.3. Total distance

Total distance was similar in weeks one (U12: 18.6 ± 2.7 ; U15: 25.6 ± 2.9 km) and two (U12: 19.7 ± 6.0 ; U15: 28.1 ± 3.0 km) in both the U12's (n=8; P=0.70) and U15's (n = 7; P = 0.13), however was lower in week one (23.2 ± 1.5 km) compared with week two (31.2 ± 6.6 km) in the U18 age-group (n = 7; 95% CI = -13.9 to -2.0 km; P = 0.02; Figure 1).

6.4.4. Average speed

Average speed was higher in week one (U12: 71 ± 6; U15: 73 ± 5 m.min^{-1}) compared to week two (U12: 55 ± 5; U15: 61 ± 3 m.min^{-1}) in both the U12 (n = 8; 95% CI = 10 to 22 m.min^{-1}; P<0.01) and U15 (n = 7; 95% CI = 6 to 18 m.min^{-1}; P<0.01) age-groups, however was similar in weeks one (75 ± 6 m.min^{-1}) and two (73 ± 7 m.min^{-1}) in the U18's (n = 7; P = 0.12; Figure 1).

6.5. Correlations

6.5.1. TEE versus participant characteristics

There was a significant positive relationship between TEE and stature (r^2 = 0.29; P = 0.03), body mass (r^2 = 0.64; P<0.01), fat-free mass (r^2 = 0.69; P <0.01) and RMR (r^2 = 0.50; P <0.01) (Figure 4).

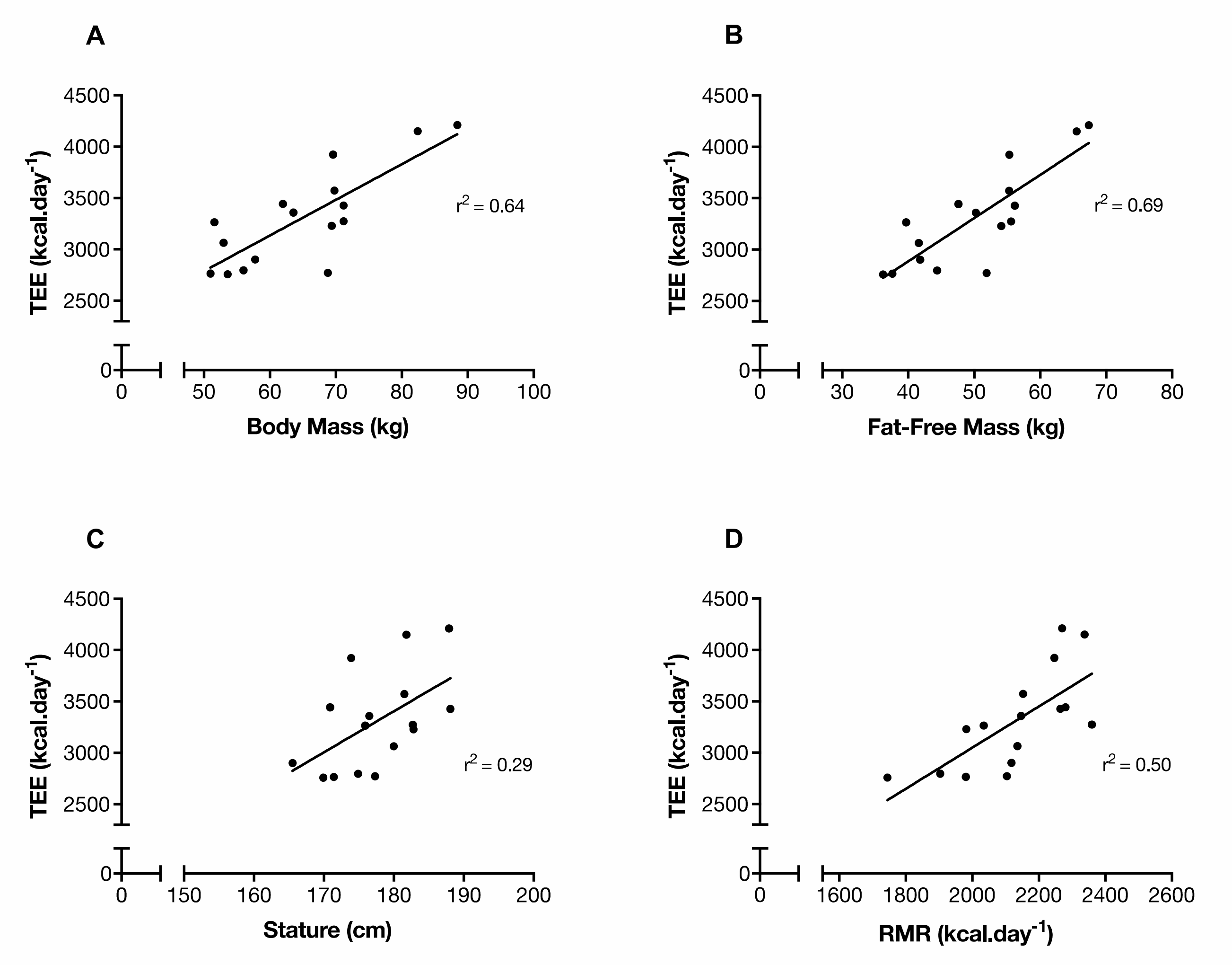

Figure 4. The relationship between mean daily total energy expenditure (TEE) and: **(A)** body mass; **(B)** fat-free mass; **(C)** stature and **(D)** resting metabolic rate (RMR) for the U15 and U18 age-groups (n = 16). Black circles represent individual players.

6.5.2. TEE versus training load measures

There was no significant relationship between TEE and training and match-play duration (r^2 = 0.12; P = 0.22), total distance (r^2 = 0.10; P = 0.27), average speed (r^2 = 0.11; P = 0.25) in the U15 age-group. In the U18 age-group, however, there was a significant positive relationship between TEE and training and match-play duration (r^2 = 0.33; P = 0.03) and total distance (r^2 = 0.41; P = 0.01, though there was no significant relationship between TEE and average speed (r^2 = 0.06; P = 0.40) (Figure 5).

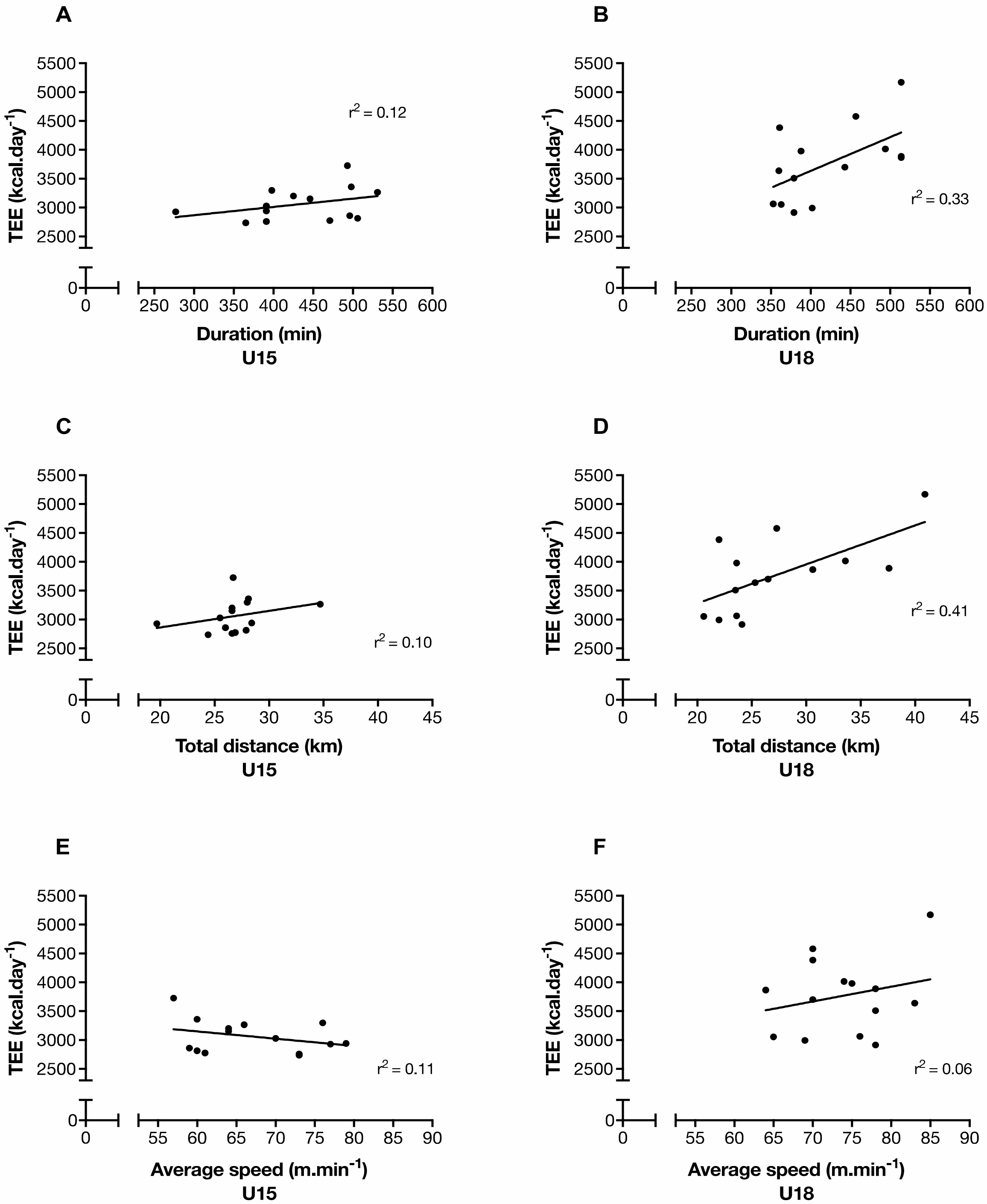

Figure 5. The relationship between mean daily total energy expenditure (TEE) and: duration in the **(A)** U15's and U18's **(B)**; total distance in the **(C)** U15's and **(D)** U18's; and average speed in the **(E)** U15's and **(F)** U18's (n = 14; two data points per player - one data point for week one and one data point for week two per player). Black circles represent individual players.

6.6. Individual player data

Individual player data for the U18, U15 and U12/13 age groups are presented in Tables 2a, 2b and 2c respectively.

Table 2a. An overview of individual player data from the U18 age group including: baseline characteristics (body mass and resting metabolic rate) and training (inclusive of pitch and gym based training) and competitive match-play duration, total distance, average speed, total energy expenditure and physical activity level for weeks one and two.

			Week 1					Week 2				
Player	**Body mass (kg)**	**RMR (kcal.day^{-1})**	**Duration (min)**	**TD (km)**	**Average speed (m.min^{-1})**	**TEE (kcal.day^{-1})**	**PAL (AU)**	**Duration (min)**	**TD (km)**	**Average speed (m.min^{-1})**	**TEE (kcal.day^{-1})**	**PAL (AU)**
1	69.6	2247	353	23.6	76	3063	1.4	514	40.9	85	5172	2.3
2	63.6	2147	379	24.1	78	2915	1.4	514	37.6	78	3890	1.8
3	82.4	2338	388	23.6	75	3980	1.7	457	27.3	70	4579	2.0
4	71.2	2265	363	20.6	65	3055	1.3	443	26.5	70	3699	1.6
5	88.4	2270	361	22.0	70	4386	1.9	494	33.6	74	4016	1.8
6	71.2	2360	379	23.5	78	3508	1.5	402	22.0	69	2992	1.3
7 *	68.8	2104	270	10.8	61	2806	1.3	76	0.0	0	2542	1.2
8	69.8	2153	360	25.3	83	3640	1.7	514	30.6	64	3867	1.8
Mean ± SD	**73.1 ± 8.1**	**2235 ± 93**	**357 ± 37**	**21.7 ± 4.6**	**73 ± 7**	**3507 ± 542**	**1.6 ± 0.2**	**427 ± 147**	**27.0 ± 12.6**	**64 ± 27**	**4031 ± 688**	**1.8 ± 0.3**

RMR: resting metabolic rate. TD: total distance. TEE: total energy expenditure. PAL: Physical activity level. * denotes injured player.

Table 2b. An overview of individual player data from the U15 age group including: baseline characteristics (body mass and resting metabolic rate) and training (inclusive of pitch and gym based training) and competitive match-play duration, total distance, average speed, total energy expenditure and physical activity level for weeks one and two.

			Week 1					**Week 2**				
Player	**Body mass (kg)**	**RMR ($kcal.day^{-1}$)**	**Duration (min)**	**TD (km)**	**Average speed ($m.min^{-1}$)**	**TEE ($kcal.day^{-1}$)**	**PAL (AU)**	**Duration (min)**	**TD (km)**	**Average speed ($m.min^{-1}$)**	**TEE ($kcal.day^{-1}$)**	**PAL (AU)**
9	53.0	2136	391	28.4	79	2942	1.4	425	26.6	64	3202	1.5
10	62.0	2281	398	28.0	76	3297	1.4	493	26.7	57	3726	1.6
11	57.8	2118	277	19.7	77	2927	1.4	471	26.9	61	2776	1.3
12	69.4	1982	391	25.5	70	3030	1.5	498	28.1	60	3361	1.7
13	53.6	1745	391	26.6	73	2758	1.6	506	27.9	60	2816	1.6
14	51.6	2035	446	26.6	64	3152	1.5	531	34.7	66	3265	1.6
15	51.0	1981	365	24.4	73	2738	1.4	496	26.0	59	2859	1.4
16 *	56.0	1904	45	4.6	103	2798	1.5	0	0.0	0	2742	1.4
Mean ± SD	**56.8 ± 6.2**	**2023 ± 162**	**338 ± 128**	**23.0 ± 7.9**	**77 ± 12**	**2955 ± 197**	**1.5 ± 0.1**	**427 ± 175**	**25.0 ± 10.3**	**53 ± 22**	**2980 ± 248**	**1.6 ± 0.1**

RMR: resting metabolic rate. TD: total distance. TEE: total energy expenditure. PAL: Physical activity level. * denotes injured player.

Table 2c. An overview of individual player data from the U12 age group including: baseline characteristics (body mass and resting metabolic rate) and training (inclusive of pitch and gym based training) and competitive match-play duration, total distance, average speed, total energy expenditure and physical activity level for weeks one and two.

			Week 1					Week 2				
Player	Body mass (kg)	RMR (kcal.day^{-1})	Duration (min)	TD (km)	Average speed (m.min^{-1})	TEE (kcal.day^{-1})	PAL (AU)	Duration (min)	TD (km)	Average speed (m.min^{-1})	TEE (kcal.day^{-1})	PAL (AU)
17	43.2	1987	316	22.0	76.4	-	-	379	21.0	58.7	-	-
18	33.4	1442	332	20.5	67.0	-	-	276	11.0	47.8	-	-
19	48.0	1968	309	18.0	63.9	-	-	271	15.6	57.4	-	-
20	40.8	1765	224	15.9	77.0	-	-	377	18.3	52.5	-	-
21	42.6	2184	297	18.7	66.5	-	-	271	17.8	50.6	-	-
22	41.6	1847	324	21.8	73.2	-	-	364	17.3	51.6	-	-
23	47.0	2077	241	14.8	63.8	-	-	542	28.8	59.3	-	-
24	47.6	1965	228	17.2	77.2	-	-	520	27.9	61.6	-	-
Mean ± SD	**43.0 ± 4.8**	**1904 ± 226**	**284 ± 45**	**18.6 ± 2.7**	**71 ± 6**	**-**	**-**	**375 ± 107**	**19.7 ± 6.0**	**55 ± 5**	**-**	**-**

RMR: resting metabolic rate. TD: total distance. TEE: total energy expenditure. PAL: Physical activity level.

7. The limitations of the current study, including any issues of inherent partiality and any operational issues, such as data access

Limitations of the current study include:

- This study is only reflective of players from one English Premier League Academy, and hence, may not be representative of the customary training and match demands of other Academy players from other professional clubs around the world.
- Due to the high cost of the doubly labelled water technique, only eight players from three different age groups were assessed, n=24. Whilst this study will provide novel data on the energy expenditures of these players, it is acknowledged that the sample size may be considered small.
- Measurement of energy intake is often subject to under-reporting (Livingstone *et al.*, 1992). To try to address this issue, participants were educated on how to accurately report their dietary intake prior to data collection. Additionally, one 24-hour recall was performed to cross-check the dietary intake data.

8. The impact of the research in terms of current theory, state of knowledge and/or practices, and the consequences for UEFA and soccer

The aim of this study was to simultaneously quantify, for the first time, the energy expenditure, energy intake and training loads of elite youth soccer players over a 14-day in-season period. Specifically, we tested the hypothesis that U18 players will present with higher TEE than U15 and U12/13 players in accordance with higher stature, body mass, fat-free mass, resting metabolic rate (RMR) and training loads.

In accordance with our hypothesis, our data demonstrate that mean daily 14-day TEE of the U18 age group (i.e. 3500-400 kcal.d^{-1}) was comparable to that of professional adult players and was significantly higher than that of the U15 age-group (i.e. 3000- kcal.d^{-1}, data from U12/13 group is not yet available). When data from both age groups were pooled, we also observed that TEE was significantly correlated with changes in stature, body mass, fat free mass and resting metabolic rate. Importantly, we also observed large inter-individual differences in TEE, thus highlighting the need to adopt an individualised approach to player development programmes. Energy and macronutrient intakes were also higher than previously reported in elite youth soccer players (Briggs *et al.*, 2015; Naughton *et al.*, 2016) and are closer to that reported in elite adult soccer players (Anderson *et al.*, 2017). This is a likely a reflection of the more accurate methodology utilised to assess energy intake here.

In relation to training loads, we also observed no differences in training and match play load (duration and total distance) or intensity (average speed) between the U12/13, U15 and U18 age groups. Interestingly, some parameters of training loads (particularly of the U15 and U18 age groups) were also similar to that of adult Premier League players (Anderson *et al.*, 2016). Whilst measures of training load did not correlate with TEE in the U15 players, it is noteworthy that in the U18 players, TEE was significantly increased in accordance with increased training distances and duration.

When taken together, our data clearly demonstrate that the transition across the academy pathway is associated with progressive increases in stature, body mass and fat free mass, the result of which increasing both resting energy requirements (i.e. resting metabolic rate) and total daily energy requirements. From a practical perspective, our data highlight the necessity to adjust daily energy intake according to each player's phase of growth and maturation and underscore the importance of adopting an individualised approach to player development. Once the TEE data from the U12/U13 group has been analysed, we will have provided an assessment of the TEE of the representative age groups of pre-, circa and post peak height velocity. It is hoped that these data can therefore be used to provide a framework for nutritional guidelines that is specific to the key transitional phases of the academy pathway. Ultimately, these data may help to optimise player technical and physical development whilst reducing injury risk.

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