Energy requirements of male academy soccer players from the English Premier League

Marcus Patrick Hannon

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“Success is no accident. It is hard work, perseverance, learning, studying, sacrifice and most of all, love of what you are doing or learning to do.”

Pele

Abstract

The goal of professional soccer academies is to develop players who can progress and represent their first team or that can be sold for financial gain. As an academy player transitions through the academy pathway (i.e. from under, U9 to U23), they undergo distinct phases of growth and maturation that result in anatomical (e.g. an increase in stature and body mass), physiological (e.g. an increase in growth hormone, insulin-like growth factor 1, testosterone and thyroid hormones) and metabolic changes (e.g. increased glycolytic capabilities). The collective result of such changes are likely to influence such daily energy requirements. However, unlike professional adult players, the body composition, physical loading patterns and associated daily energy expenditure have not yet been quantified in academy soccer players. A detailed understanding of such parameters is fundamental in order to promote growth and maturation whilst also maximising each players physical and technical development. With this in mind, the aim of this thesis was to determine the energy requirements of male academy soccer players from the English Premier League of different chronological and biological ages.

The aim of Study 1 (Chapter 4) was to assess body composition and resting metabolic rate in a cohort of academy soccer players. In a cross-sectional design, ninety-nine males from a Category One English Premier League academy (U12-U23 age-groups) underwent assessments of body composition (dual-energy X-ray absorptiometry, DXA) and resting metabolic rate (indirect calorimetry). Fat-free mass increased between the U12 (31.6 ± 4.2 kg) and U16 (56.3 ± 5.3 kg) age-groups after which no further increases occurred. Resting metabolic rate in the U12 (1655 ± 195 kcal·day^{-1}), U13 (1720 ± 205 kcal·day^{-1}) and U14 (1846 ± 218 kcal·day^{-1}) age-groups was significantly lower than the U15 (1957 ± 128 kcal·day^{-1}), U16 (2042 ± 155 kcal·day^{-1}), U18 (1875 ± 180 kcal·day^{-1}) and U23 (1941 ± 197 kcal·day^{-1}) age-groups. These data provide the first report of differences in body composition and resting metabolic rate in academy soccer players (as assessed via DXA and indirect calorimetry, respectively) and demonstrate that the growth and maturation occurring between U12-U16 significantly increases resting energy requirements.

Having quantified body composition and resting metabolic rate in Study 1 (Chapter 4), the aim of Study 2 (Chapter 5) was to determine the typical weekly training and match loading patterns of academy soccer players. Over the course of an entire competitive season, weekly training and match load was quantified using global positioning system technology in 76 soccer players from a Category One English Premier League academy (U12-U18 age-groups). Weekly training and match volume (i.e. duration and total distance) was similar in the U12 (329 ± 29 min; 19.9 ± 2.2 km), U13 (323 ± 29 min; 20.0 ± 2.0 km) and U14 (339 ± 25 min; 21.7 ± 2.0 km) age-groups, but was lower than the U15 (421 ± 15 min; 26.2 ± 2.1 km), U16 (427 ± 20 min; 25.9 ± 2.5 km) and U18 (398 ± 30 min; 26.1 ± 2.6 km) age-groups. Weekly high-speed running and sprint distance (i.e. intensity) were comparable in the U12 (220 ± 95 m and 6 ± 9 m respectively), U13 (331 ± 212 m and 6 ± 27 m) and U14 (448 ± 193 m and 21 ± 29 m) age-groups was similar, but less than the U15 (657 ± 242 m and 49 ± 98 m), U16 (749 ± 152 m and 95 ± 55 m) and U18 (979 ± 254 m and 123 ± 56 m) age-groups. These data provide the first

report to objectively assess accumulative training and match loads in academy soccer players and demonstrate that the absolute loads are progressive in nature throughout the academy pathway.

Given the progressive changes in body composition (Study 1, Chapter 4), resting metabolic rate (Study 1, Chapter 4) and physical loading patterns (Study 2, Chapter 5), the aim of Study 3 (Chapter 6) was to quantify the total daily energy expenditure of academy soccer players with different chronological and biological ages. Energy expenditure (doubly labelled water) and energy intake (remote food photographic method) was assessed over a 14-day in-season period in 24 soccer players from a Category One English Premier League academy (U12/13, n=8; U15, n=8; U18, n=8). U18 players presented with greater total energy expenditure (3586 ± 487 kcal·day^{-1}) than both the U15 (3029 ± 262 kcal·day^{-1}) and U12/13 players (2859 ± 265 kcal·day^{-1}), though no differences were evident between the U12/13 and U15 age-groups. Within age-groups, no differences were apparent between energy intake and total energy expenditure, whilst U18 players (3180 ± 279 kcal·day^{-1}) reported a higher energy intake than both the U15 (2821 ± 338 kcal·day^{-1}) and U12/13 (2659 ± 187 kcal·day^{-1}) players. In some individuals (evident in all age-groups) total energy expenditure was greater than that previously observed in adult English Premier League soccer players (3566 ± 585 kcal·day^{-1}).

In summary, the data presented in this thesis provides the first report to simultaneously quantify body composition, resting metabolic rate, physical loading patterns and total daily energy expenditure of academy soccer players. Importantly, these data demonstrate that players' absolute daily energy expenditure progressively increase as they become more biologically mature, likely a reflection of increased fat-free mass and physical loading patterns. From a practical perspective, these data will assist in developing population specific sport nutrition guidelines.

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Finally, I hope that this work has added value to our field and will ultimately influence applied practice.

Declaration

I declare that the work in this thesis, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own. Additionally, all attempts have been made to ensure that the work is original, does not, to the best of my knowledge, breach any copyright laws and has not been taken from the work of others, apart from the works that have been fully acknowledged within the text.

Publications & Presentations

Publications of the work listed within this thesis are as follows:

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Abbreviations

^{18}O	Heavy oxygen
^{2}H	Heavy hydrogen / deuterium
AEE	Activity energy expenditure
ANOVA	Analysis of variance
BM	Body mass
BMR	Basal metabolic rate
CO_2	Carbon dioxide
CV	Coefficient of variation
DIE	Desired initial enrichment
DLW	Doubly labelled water
DXA	Dual-energy X-ray absorptiometry
EA	Energy availability
EE	Energy expenditure
EI	Energy intake
EPL	English Premier League
EPPP	Elite player performance plan
FC	Football club
FFM	Fat-free mass
GPS	Global positioning system
HR	Heart rate
HSR	High speed running
IE	Initial enrichment
ISAK	International Society for the Advancement of Kinanthropometry
Kcal	Kilocalories
KJ	Kilojoules
MD	Match day
MEMS	Micro electrical mechanical systems
MJ	Megajoules
NEAT	Non-exercise activity thermogenesis
O_2	Oxygen
PAL	Physical activity level
PAS	Predicted adult stature
PHV	Peak height velocity
PI	Prediction interval
PWV	Peak weight velocity
RFPM	Remote food photographic method
RMR	Resting metabolic rate
RPE	Rating of perceived exertion
RQ	Respiratory quotient
SD	Standard deviation
SEE	Standard error of the estimate
SENr	Sport and Exercise Nutrition register
TD	Total distance
TEE	Total energy expenditure
TEF	Thermic effect of food
TML	Training and match load
TRB	Tom Reilly Building
U	Under
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}O_2$	Oxygen consumption

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Chapter 1

General Introduction

The aim of this General Introduction is to provide a brief overview and introduction to the area in order to provide the rationale for the aims and objectives of this thesis.

1.1 Background

The value of soccer (or football, as is it more commonly termed in the United Kingdom) players has increased exponentially over the last number of years (Foster, 2016). For example, Neymar Jr. was bought for a world record fee of €222 million in August 2017, by Paris Saint-Germain Football Club (FC) from FC Barcelona. Consequently, to obviate the need to spend on these types of transfer fees, many professional soccer clubs worldwide have put more emphasis on developing their own academy players who can progress and represent their first team or that can be sold for financial gain (Elferink-Gemser *et al.*, 2012). The development of academy soccer players is multi-faceted, with a significant emphasis placed on improving these players technically, tactically, physically and psychosocially as they transition through the academy pathway (Premier League, 2011). It is therefore no surprise that there has been an increase in research investigating these specific areas of development over the last decade (Wrigley *et al.*, 2012; Rowat, Fenner and Unnithan, 2017; Saward *et al.*, 2019).

Whilst academy soccer players in the same age-group may be of similar chronological ages (i.e. the number of years and days an individual is from their date of birth) they may be at different stages of biological maturation (sexual, skeletal or somatic maturation). As an academy player transitions through the academy pathway, they undergo rapid biological growth and maturation which results in many anatomical, physiological and metabolic changes (Malina, Bouchard and Bar-Or, 2004). These changes, most notably the increase in body size, subsequently influence the nutritional requirements of these players (Desbrow *et al.*, 2014). It is therefore of great importance for sports science and medicine practitioners working with academy soccer players to understand these anatomical, physiological and metabolic changes in addition to the specific nutritional requirements, in order to optimise growth, maturation and physical development in this population. Despite the importance, only several descriptive studies have investigated the nutritional practices within English Premier league (EPL) academy players (Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016).

An academy soccer player's nutritional requirements, specifically their energy requirements, are dictated by their energy expenditure (Desbrow *et al.*, 2014; Naughton *et al.*, 2016). Total energy expenditure (TEE) is comprised of three separate components, (1) basal metabolism (typically 45-75% of energy expenditure depending on activity levels), (2) thermic effect of food (typically 10% of energy expenditure) and (3) activity energy expenditure (AEE; the most variable component of energy expenditure depending on activity levels) (Manore and Thompson, 2015). During growth there is also a small amount of energy required for tissue growth (~5 kcal per gram of weight gain), both to synthesise new tissue and also for deposition into this new tissue (Torun, 2005). In athletic populations, AEE is often the largest component of TEE (Silva *et al.*, 2013) due to high training and match loads. From a physical standpoint, it is first important to understand the training and match demands of academy soccer players, given that these factors influence the subsequent energy expenditure of a player (Westerterp, 2013; Anderson *et al.*, 2017). However, to date no study has quantified the typical accumulative training and match demands of academy soccer players in the different academy age-groups over the course of a season.

Several studies have attempted to quantify total energy expenditure and it's individual components in youth male soccer players (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Kim *et al.*, 2015; Cherian *et al.*, 2018). However, the usefulness of this information when applying it to male EPL academy players is questionable due to the populations the data was derived from (only recreationally active, combining both male and female participants) and the methodologies used to obtain the data (not gold standard methods, e.g. prediction equations, activity diaries etc) (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Kim *et al.*, 2015; Cherian *et al.*, 2018). To date, there is no accurate data quantifying energy expenditure in EPL academy soccer players using gold standard methods such as indirect calorimetry and/or the doubly labelled water technique. This makes energy (intake) prescription currently difficult in this population owing to this lack of data.

Whilst the exact energy requirements of EPL academy soccer players is currently unknown, reported energy intake in this population is ~1900-2899 kcal·day^{-1} in players aged 12-17 (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016). Briggs and colleagues have previously suggested that energy availability may be compromised in this population (Briggs, Cockburn, *et al.*, 2015), which may lead to negative consequences to both a player's health and performance (Loucks, Kiens and Wright, 2011). Energy availability (EA) is the amount of energy left for homeostatic physiological functions and growth once activity energy expenditure (AEE) has been from energy intake (EI) and is relative to fat-free mass (FFM) [EA = (EI – AEE) / FFM]. Chronic periods of low energy availability 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 (Loucks, Kiens and Wright, 2011). Given the importance of *at least* matching energy intake to TEE in order to maximise growth, maturation and physical development but also to minimise the risk of illness and injury, it is essential that an academy player's energy availability is appropriate during this period of rapid growth (Loucks, Kiens and Wright, 2011). Therefore, it is of utmost importance that we gain a greater understanding of the typical energy expenditures experienced by EPL academy soccer players in order to enable accurate energy prescription and help prevent any detrimental consequences of low energy availability in this population.

1.2 Aims and objectives of this thesis

The aim of this thesis is to determine the energy requirements of male EPL academy soccer players of different chronological and biological ages.

This will be achieved through the following objectives:

1. To assess body composition and resting metabolic rate in male EPL academy soccer players of different chronological and biological ages. This objective will be achieved through the completion of Study 1 (Chapter 4).

2. To quantify external training and match load over a competitive season in male EPL academy players of different chronological and biological ages. This objective will be achieved through the completion of Study 2 (Chapter 5).

3. To quantify total energy expenditure and energy intake in male EPL academy players of different chronological and biological ages during a typical 14-day in-season period. This objective will be achieved through completion of Study 3 (Chapter 6).

Chapter 2

Literature Review

The aim of this Literature Review is to introduce key theoretical concepts and provide a summary and critical appraisal of the relevant current literature.

2.1 Introduction to soccer academies

2.1.1 History and objectives of English Premier League academies

Many professional soccer clubs worldwide have talent development programmes (academies) that aim to produce players for their first team or to produce players that compete in the top tiers of the professional game (Elferink-Gemser *et al.*, 2012). In 2011, there were 12,067 male academy soccer players registered with professional clubs in the UK (Premier League, 2011). In 2012, the Elite Player Performance Plan (EPPP) was developed between the EPL, English Football League clubs and representatives, the Football Association and other key stakeholders within the game, with the aim of producing more and better homegrown senior players (Premier League, 2011). The EPPP is a long-term strategy that aims to develop academy players technically, tactically, physically and psychologically from U5 through to U21, via an evidence led and multi-disciplinary approach. Formal registration of players commences at U9, although a player can register with an academy at any stage of the pathway (Premier League, 2011).

2.1.2 EPPP category status

Whilst professional academies are encouraged to create their own bespoke development programmes, the EPPP have established minimum standards which clubs have to adhere to be awarded 'category status'. Academies are judged on a number of areas including their vision and strategy, leadership and management, coaching, education, games programme, sports science and medicine, player development and progression, talent identification and recruitment, facilities and corporate and financial stability. An academy can be classified as a 'Category One' (highest classification), 'Category Two', 'Category Three' or 'Category Four' (lowest classification). Academies are (re)classified every two years following an independent audit (Premier League, 2011).

2.1.3 Staffing structure

Professional academies in the UK, particularly at Category One clubs, have a large number of staff working in different departments including management, coaching, recruitment, operations, education and sports science and medicine. As part of the service provision, sports science and medicine teams within academies are required to provide nutrition support to players (Premier League, 2011). It is therefore no surprise that since the EPPP was implemented, there has been an increase in research investigating the nutritional habits of EPL academy players (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016, 2017) and a greater call for more specialist sports nutrition/dietician practitioners to be employed by EPL academies (Russell, 2018).

2.1.4 Typical schedule

In a Category One academy, a typical week for players from U12 upwards consists of four training days, a match day and two rest days. Initially, the EPPP advised ~12 hours of pitch-based training per week for an U12 player, subsequently increasing to ~16 hours per week for an U21 (Premier League, 2011). In addition to this, an academy player is also required to partake in a minimum of four hours per day of education a day, sports science activities (which may include gym work and yoga) and also video analysis of training or games (Premier League, 2011). This often amounts to a 12 hour 'working day' for most EPL academy soccer players. These demanding schedules are clearly a challenge for both the academies and their players. Given that a key role of sports science within an academy is to optimise the factors influencing growth, maturation and physical development of the players, it is vital to understand the energy requirements of this population.

2.2 Overview of growth and maturation

As a player progresses through the academy pathway from childhood through adolescence and into adulthood, they undergo many anatomical, physiological and metabolic changes as a result of biological growth and maturation. Growth is the increase in the size of the body or its parts, whereas maturation is the progress towards a biologically mature state, which varies between different organ systems and tissues (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al.*, 2014). Growth and maturation is a complex process that is influenced by the interaction of genes, hormones, nutrients and the environments in which the individual lives (Malina, Bouchard and Bar-Or, 2004).

2.2.1 Chronological versus biological age

Chronological age is the number of years and days (at a precise time-point) an individual is from their date of birth. In EPL and other worldwide soccer academies, players are usually classified by chronological age and compete within an age-group, i.e. under (U) 12, U13, U14, U15 etc, depending on the chronological age range they fit within (Wrigley *et al.*, 2012; Buchheit and Mendez-Villanueva, 2013; Deprez *et al.*, 2014; Lovell *et al.*, 2015). Biological growth and maturation however does not coincide with chronological age (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al.*, 2014, 2016). There can be large inter-individual variation in level (magnitude of change), timing (onset of change) and tempo (rate of change) of biological maturation throughout childhood and adolescence (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al.*, 2014, 2016).

Individuals may be biologically advanced compared to their chronological age (i.e. an early maturing player), similar to their chronological age (i.e. an on time or normal maturing player), or behind their chronological age (i.e. a late maturing player, Figure 1) (Malina, Bouchard and

Bar-Or, 2004; Lloyd *et al.*, 2014, 2016). It is well documented however, that the majority of players within professional soccer academies worldwide are classified as on time or early maturers (Malina *et al.*, 2000; Carling, Le Gall and Malina, 2012; Lovell *et al.*, 2015; Malina, Figueiredo and Coelho-e-Silva, 2017). This may be due to such players demonstrating superior physical attributes such as size, strength and speed, all of which are important attributes in the talent identification of academy soccer players (Malina *et al.*, 2004, 2005; Philippaerts *et al.*, 2006; Figueiredo *et al.*, 2009).

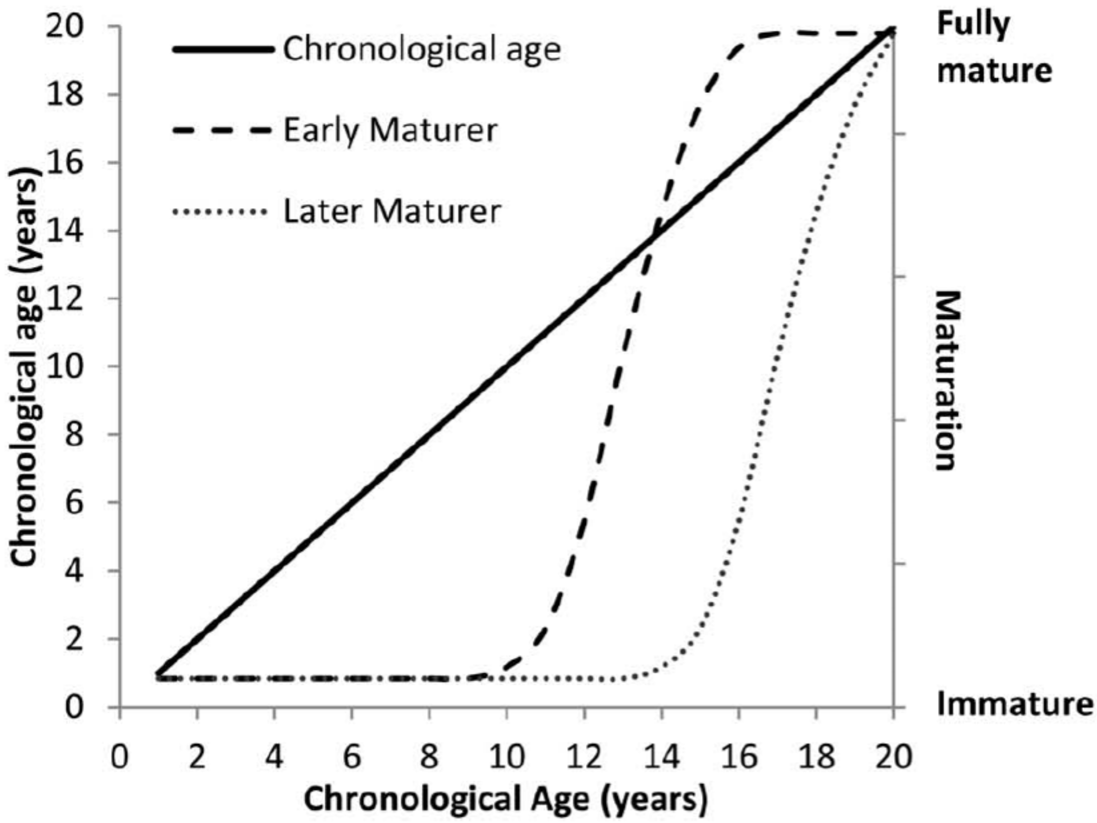

Figure 1. Differences in advancement of chronological age and biological maturation based on theoretical data (adopted from Lloyd et al., 2014).

2.2.2 Methods to assess biological age and maturation

Given the differences in biological age amongst academy soccer players of the same chronological age (and the resulting implications of this), it is important to assess biological age and maturation using valid and reliable measures. There are numerous different methods to assess both maturity status, namely, the level of maturation at a specific chronological age, and timing i.e. the chronological age at which certain maturational events occur.

2.2.2.1 Invasive measures

Sexual maturation, leading up to and through puberty, is the progress towards fully functional reproductive capability (Tanner, 1962). Assessment of sexual age is through ratings of secondary sexual characteristics (via observation or self-assessment) including pubic hair development in both sexes, age at menarche and breast development in females and genitalia development in males (Lloyd *et al.*, 2014; Malina *et al.*, 2015). These secondary sexual characteristics are compared to five separate stages known as 'Tanner Stages' (T1, T2, T3, T4 & T5; Tanner, 1962). Given the obvious intrusive nature of this method (both legally and ethically), it is not commonly used to assess biological maturation in youth athletes (Lloyd *et al.*, 2014).

Assessment of skeletal age provides an indication of the maturity status of the skeleton (specifically of the hand and wrist) and is considered the gold standard method of assessing biological maturation as it spans through childhood into adolescence (Tanner, 1962; Malina, Bouchard and Bar-Or, 2004). This method involves taking a hand/wrist radiograph (i.e. x-ray image) and as such, is considered an invasive method as it exposes the individual to low-level radiation (Lloyd *et al.*, 2014; Malina *et al.*, 2015). From childhood through to adulthood, skeletal tissues ossify throughout the maturation process until the skeleton reaches a fully mature state in early adulthood (Lloyd *et al.*, 2014; Malina *et al.*, 2015). There are three commonly used methods to analyse and assess skeletal age including the Greulich-Pyle method (Greulich and Pyle, 1999), Tanner-Whitehouse methods (TW1, TW2 and TW3) (Tanner *et al.*, 1975, 1983, 2001) and the Fels method (Roche, Chumlea and Thissen, 1988). These different methods were developed on different populations and also differ slightly in their classification of skeletal age, often leading to discrepancies in skeletal age between youth soccer players (Malina *et al.*, 2007; Malina *et al.*, 2017). Skeletal age assessments require specialist equipment, a trained medical practitioner to perform the radiograph and analyse and interpret the results which can be costly (Lloyd *et al.*, 2014; Malina *et al.*, 2015). For these reasons, non-invasive measures to assess biological maturation are more common within soccer academies worldwide.

2.2.2.2 Non-invasive measures

Due to the ease of assessment and lack of invasiveness, assessments of somatic maturation are more commonly used within soccer academies (Buchheit and Mendez-Villanueva, 2013; Lovell *et al.*, 2015; Towlson *et al.*, 2017). Somatic age refers to the amount of growth in stature or other specific body part (Lloyd *et al.*, 2014). The two most common methods of somatic maturation include predicting age at peak height velocity (PHV) i.e. the maximum rate of growth in stature during adolescence (maturity timing) and predicting adult stature (maturity status). One advantage of these methods is that they do not require longitudinal tracking of stature (or body mass) and can therefore be used in cross-sectional study designs (Lloyd *et al.*, 2014). The development of the maturity offset equation enables prediction of age at PHV in both males and females (Mirwald *et al.*, 2002). This equation is based on the fact that the bones in the leg experience peak growth before bones in the trunk. It incorporates chronological age, body mass, stature, sitting height and estimated leg length [calculated by subtracting sitting height from stature] (Mirwald *et al.*, 2002). The value calculated from the Mirwald equation provides information on time before/after PHV (i.e. maturity offset), with the difference between chronological age and maturity offset giving you predicted age at PHV. This equation was developed for individuals +/- four years from PHV (~10-18 years) and has a standard error of ± 0.24 years (Mirwald *et al.*, 2002). There have been questions raised over its use particularly within different ethnicities (Malina *et al.*, 2012), although Buchheit and Mendez-Villanueva (2013) discovered a strong correlation (r = 0.7) between maturity offset and skeletal age in academy soccer players.

A second commonly used assessment of somatic age and maturity status is predicted adult stature (PAS), which also enables the calculation of current percentage of PAS [current stature expressed as a percentage of PAS] (Lloyd *et al.*, 2014; Malina *et al.*, 2015). Thus whilst two players may be of the same chronological age and stature, one may be closer to their PAS than the other, and is therefore more biologically mature than the other player (see Figure 2). There are a number of different equations that can be used to predict PAS. Khamis and Roche (1994) developed an equation to predict PAS that incorporates body mass, stature and mid-parent stature (the mean stature of an individual's mother and father). The Khamis and Roche equation was developed in white Americans aged 4-18 years and has an error of ± 2.2 cm. Given the inclusion of mid-parent stature into the equation, the use of this equation is not always feasible and there can often be error associated with reporting of mid-parent stature (Malina *et al.*, 2007). Beunen *et al.* (1997) also developed an equation to predict PAS that incorporates chronological age, stature, sitting height, subscapular skinfold and triceps skinfold. The Beunen-Malina equation was originally developed in 13-16 year old Belgian (Flemish) males (Beunen *et al.*, 1997) and was later cross-validated in Portuguese children and adolescents aged 8-16 (Beunen *et al.*, 2010). This method has an error of ± 4.2 cm (Beunen *et al.*, 1997, 2010).

Another equation to predict PAS was developed by Sherar *et al.* (2005) using collated data from three longitudinal growth studies. Unlike other equations which predict PAS, the Sherar equation also accounts for maturity timing (maturity offset), in addition to chronological age, body mass, stature and sitting height. One advantage of the Sherar equation is that (unlike other equations that predict PAS) it does not require parental mid-height which is not always available for numerous reasons (Sherar *et al.*, 2005).

2.2.3 Anthropometric changes during growth and maturation in academy soccer players

2.2.3.1 Stature and body mass

In academy soccer players worldwide, both stature and body mass increase with age and maturity status (Malina *et al.*, 2000; Deprez *et al.*, 2013; Lovell *et al.*, 2015; Malina, Figueiredo and Coelho-e-Silva, 2017). Mean age at PHV in male soccer players is between 13-14 years (Philippaerts *et al.*, 2006; Deprez *et al.*, 2013; Lovell *et al.*, 2015), with PHV preceding peak weight velocity (PWV; i.e. the maximum rate of growth in body mass during adolescence) (Malina *et al.*, 2000). During PHV and PWV, growth velocities in stature in male academy soccer players can reach ~10 cm per year and in body mass can reach ~8 kg per year (Philippaerts *et al.*, 2006), although this is highly individualised. Earlier maturing players, between 12-16 years old, are generally taller and heavier compared to later maturing players of a similar chronological age. This may lead to selection bias (favouring earlier maturing players), particularly when players are grouped according to chronological age (Malina *et al.*, 2000). Selection bias may also have implications for player's individual nutritional requirements, e.g. a larger, more mature player may have greater energy requirements compared to a smaller, less mature player of the same age. In academy soccer players, PHV coincides with increases in parameters of physical performance including strength, power and aerobic and anaerobic endurance (Philippaerts *et al.*, 2006). Adult stature appears to be achieved at approximately ~16-17 years old in academy soccer players, although increases in body mass continue beyond this (Milsom *et al.*, 2015; Patel *et al.*, 2019). Milsom *et al.* (2015) observed no differences in stature between the U18 (16.6 ± 0.6 years; 179.4 ± 6.0 cm), U21 (18.4 ± 1.0 years; 181.8 ± 6.9 cm) and first team (24.1 ± 3.9 years; 182.5 ± 7.1 cm) squads from a EPL club, however the U18's (75.1 ± 8.3 kg) were considerably lighter than the U21 (80.2 ± 6.9 kg) and first team (81.4 ± 8.2 kg) squads. A recent study by Malina, Figueiredo and Coelho-e-Silva (2017) also observed secular increases in both stature and body mass (between 1978-2015), potentially due to improved nutrition and enhanced training programmes.

Figure 2. Players from an U15 age-group from a Category One English Premier League soccer academy. It is clear to see significant differences in in both stature and body mass despite players being of a similar chronological age.

2.2.3.2 Body composition

Body mass can be separated in different compartments (based on each compartments composition of different tissues), including fat mass, fat-free mass and bone mineral content

(Malina and Geithner, 2011). Most studies assessing body composition in academy soccer players use the sum of skinfold thickness (a two compartmental method, i.e. fat mass and fat-free mass) measured via skinfold callipers, to estimate adiposity (i.e. body fat) (Buchheit and Mendez-Villanueva, 2013; Figueiredo *et al.*, 2009). The amount of body fat does not appear to differ between different age-groups (11-18 years) in male soccer players, irrespective of maturity status, suggesting that changes in body fat are not affected by growth and maturation (Figueiredo *et al.*, 2009; Nikolaidis and Vassilios Karydis, 2011; Buchheit and Mendez-Villanueva, 2013; Hammami *et al.*, 2013). However, differing methodologies between studies (different location of measurement sites and number of sites measured) make comparisons difficult (Figueiredo *et al.*, 2009; Nikolaidis and Vassilios Karydis, 2011; Buchheit and Mendez-Villanueva, 2013; Hammami *et al.*, 2013). Certain studies also use skinfold thickness to estimate percent body fat using different available prediction equations (Nikolaidis and Vassilios Karydis, 2011; Hammami *et al.*, 2013). These equations are developed on specific populations and when applied to different populations from which they were developed (e.g. academy soccer players), often have a high degree of error (Reilly *et al.*, 2009). Therefore, the use of these different equations between studies again makes body composition comparisons difficult.

Dual-energy X-ray absorptiometry (DXA) is considered the reference method for assessing body composition and is a three compartmental method, i.e. fat mass, fat-free mass (FFM) and bone mineral content (Reilly *et al.*, 2009; Nana *et al.*, 2015). A recent study which used DXA to assess body composition in soccer players from an EPL club showed that whilst U18, U21 and first team players have similar amounts of absolute fat mass (~8 kg), there is an approximate difference in FFM of ~7 kg between U18 players (16.6 ± 0.6 years) and their adult counterparts (first team; 24.1 ± 3.9 years) (Milsom *et al.*, 2015). This suggests that increases in body mass derive primarily from increases in FFM, however there is currently no DXA derived data from EPL academy soccer players throughout the academy age ranges (U12-U18) or at differing stages of growth and maturation. This information may be useful for practitioners working with this population and may have implications for training or nutrition advice, thus further research is warranted.

2.2.4 Physiological and metabolic changes during growth and maturation

At the onset of PHV, activation of the hypothalamic-pituitary-gonadal axis, particularly an increase in growth hormone, insulin-like growth factor 1, testosterone and thyroid hormones, promote accumulation of muscle mass (Malina, Bouchard and Bar-Or, 2004), which may have implications for energy and protein requirements. During exercise, youth athletes have a higher (relative) energy cost of movement compared to their adult counterparts. This may be due to increased stride frequency, a greater surface area:volume ratio, a more distal distribution of mass in the legs or because of greater levels of contraction of the antagonist leg muscles whilst moving (Morgan, 2008).

It is also well documented that higher rates of aerobic metabolism exist in children during exercise (Malina, Bouchard and Bar-Or, 2004; Ford *et al.*, 2011). Fat oxidation rates during sub-maximal exercise (of the same relative intensity) are greater in male and female children and adolescents compared to adults. Less mature children have a greater reliance on fat as a fuel compared to more mature adolescents and adults (Timmons, Bar-Or and Riddell, 2003). These higher fat oxidation rates (during exercise) may be the result of lower endogenous carbohydrate stores and reduced glycolytic capabilities. Pre-pubertal children have a lower endogenous glycogen storage capacity compared to compared to older, more mature adolescents (Eriksson and Saltin, 1974). This coincides with reduced glycolytic capabilities, with full anaerobic capabilities developing towards the end of puberty (Stephens, Cole and Mahon, 2006). Consequently, children and adolescents have lower levels of lactate production than adults during high intensity exercise of the same relative intensity (Eriksson, Gollnick and Saltin, 1973; Eriksson and Saltin, 1974). Youth athletes also have a greater reliance on exogenous carbohydrate as a fuel source. During exercise, exogenous carbohydrate is a greater contributor to total energy supply in children and adolescents compared to adults (Timmons, Bar-Or and Riddell, 2003). Exogenous carbohydrate oxidation rates are higher in less mature boys compared to more mature boys of the same chronological age (Timmons, Bar-Or and Riddell, 2007b). Given these differences in physiology and metabolism (see Table 1), the subsequent nutritional requirements of an academy soccer players may differ compared to adult player.

Table 1. The main anatomical, physiological and metabolic differences between youth and adult athletes.

Summary of main anatomical, physiological and metabolic differences between youth and adult athletes
Growth and increase in body size Macronutrient requirements are often prescribed relative to body mass (i.e. grams per kilo, $g.kg^{-1}$) to account for individual differences in size amongst youth athletes. Whilst fat mass does not appear to significantly change throughout growth and maturation in youth soccer players, increases in body mass are primarily derived from an increase in fat-free mass (Milsom *et al.*, 2015). An increase in stature is the result of skeletal growth and the laying down of bone mineral content (i.e. skeletal tissue). Around 95% of adult bone mineral content is achieved by the end of adolescence, with ~26% of this accruing during peak bone mineral content velocity (~12.5 and ~14 years old in girls and boys respectively) (Bailey *et al.*, 1999). Changes in fat-free mass and stature are significantly influenced by the energy and macronutrient intake of a young athlete during childhood and adolescence (Desbrow *et al.*, 2014).
Greater energy cost of movement Young athletes have a higher (relative) energy cost of movement compared to adults. This may be due to increased stride frequency, a greater surface area:volume ratio, a more distal distribution of mass in the legs, or because of greater levels of contraction of the antagonist leg muscles whilst moving (Morgan, 2008).
Higher rates of aerobic metabolism It is well documented that higher rates of aerobic metabolism exist in youth athletes during exercise. Fat oxidation rates during sub-maximal exercise (of the same relative intensity) are greater in children and adolescents compared to adults. Less mature children have a greater reliance on fat as a fuel compared to more mature adolescents. It has been suggested that these higher fat oxidation rates in children compared to adults are the results of lower endogenous carbohydrate stores and reduced glycolytic capabilities (Timmons, Bar-Or and Riddell, 2003).
Reduced glycogen storage capacity Youth athletes, particularly those that are pre-pubertal have lower endogenous glycogen storage capacity compared to older, more mature youth athletes and adult athletes (Eriksson and Saltin, 1974).

Reduced glycolytic capabilities Youth athletes have reduced glycolytic capabilities, with full anaerobic capabilities developing towards the end of puberty (Stephens, Cole and Mahon, 2006). Consequently, youth athletes have lower levels of lactate production than their adult counterparts during high intensity exercise of the same relative intensity (Eriksson, Gollnick and Saltin, 1973; Eriksson and Saltin, 1974).
Greater reliance on exogenous carbohydrate When exogenous carbohydrate is consumed during exercise, the oxidation rate of exogenous carbohydrate, relative to body mass, is higher in children and adolescents compared to adults (Timmons, Bar-Or and Riddell, 2003). Relative exogenous carbohydrate oxidation rates are higher in less mature boys compared to more mature boys of the same chronological age (Timmons, Bar-Or and Riddell, 2007b); although this is not the case in girls (Timmons, Bar-Or and Riddell, 2007a).

2.3 Training demands, match demands and energy expenditure in academy soccer players

2.3.1 Rationale to monitor training and match demands

Considering the purpose of a soccer academy is to develop players who can progress and represent the club's first team (Wrigley *et al.*, 2012), these long-term development programmes aim to improve technical, tactical, physical and psychological capabilities of players as they progress through the academy pathway (Brownlee *et al.*, 2018). From a physical standpoint, it is important to understand the training and match demands of academy soccer players, given that these factors influence the subsequent energy expenditure of a player (Westerterp, 2013; Anderson *et al.*, 2017). It is also important to ensure that the training and match demands are progressive in nature (towards those experienced by adult players) in order to minimise the risk of injury (Bowen *et al.*, 2017), and prevent academy players missing days so they can maximise their development (Wrigley *et al.*, 2012; Bourdon *et al.*, 2017).

The physical development of academy soccer players requires exposure to appropriate levels of training volume, intensity and frequency, commonly referred to as 'load' in soccer (Foster *et al.*, 2001; Impellizzeri, Rampinini and Marcora, 2005). Load can be subdivided into external and internal load. External load is an objective measure of work performed by a player during training/match-play, whereas internal load is the physiological response (or stress) to the external load (Impellizzeri, Rampinini and Marcora, 2005). It is widely accepted that external load (particularly exercise volume and intensity) is closely linked with energy expenditure (Westerterp, 2013; Hills, Mokhtar and Byrne, 2014). Quantification of training and match load (TML) provides practitioners with objective data which may inform subsequent energy prescription, assist with decisions around training and match play, as well general player development. Despite over 40 years of research investigating the training and match demands of adult soccer players (Thomas and Reilly, 1979), less consideration has been given to the TML of academy players. Given the influence of TML on energy expenditure and subsequent physical development of academy soccer players, further research within this population is warranted.

2.3.2 Methods to monitor training and match load in academy soccer players

There are a number of commonly used methods to quantify both internal and external TML in soccer players. These methods may be used in isolation or collectively to provide an overall assessment of TML. Global positioning systems (GPS), heart rate telemetry and subjective rating of perceived exertion (RPE) are the most routinely used methods to monitor TML in academy soccer players (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015; Bowen *et al.*, 2017), each with their own advantages and disadvantages.

2.3.2.1 Global positioning systems

Originally developed in the United States for military purposes, GPS is a satellite-based navigational technology which provides precise information on geolocation (both latitude and longitude) and time (Larsson, 2003). GPS devices continually communicate (at the speed of light) with up to 27 orbiting satellites with atomic clocks. Once turned on, the clock within the GPS device is set by synchronising it with the atomic clock in the satellite. The time delay between the GPS device and the orbiting satellites, enable calculation of the signal travel time and subsequent calculation of distance between GPS device and satellites (Larsson, 2003). A connection to at least four different satellites is required to trigonometrically determine the exact position of the GPS device, however the higher the number of connected satellites, the higher the quality of the signal (Larsson, 2003; Malone *et al.*, 2017).

The rate at which a GPS device collects data depends on its sampling frequency. GPS devices originally used in sport had a sampling frequency of 1 Hz (i.e. one sample per second), however due to technological improvements, devices of 10 Hz and 15 Hz are now commercially available and widely used within sport (Cummins *et al.*, 2013; Malone *et al.*, 2017). Further developments of GPS devices include the integration of triaxial accelerometers and gyroscopes; collectively termed as micro electrical mechanical systems (MEMS; Cummins *et al.*, 2013; Malone *et al.*, 2017). These MEMS work independently to the GPS, quantifying the rate of change in acceleration/deceleration in the three different planes of motion (anterior-posterior, mediolateral and longitudinal planes; Malone *et al.*, 2017). This permits quantification of metrics associated with mechanical loading, enabling a more holistic quantification of external workload (Hennessy and Jeffreys, 2018). However, it should be noted that differences in running motion between players and device positioning in loose garments can result in erroneous data, and should be considered by both researchers and practitioners using this technology (Malone *et al.*, 2017).

The first study that used GPS to monitor locomotion during exercise was in 1997 (Schutz and Chambaz, 1997). Since then there has been an exponential increase in its use within sport, particularly in soccer (Cummins *et al.*, 2013; Malone *et al.*, 2017). In recent years, GPS has been routinely used to monitor the external loads of both adult (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016) and academy (Coutinho *et al.*, 2015) soccer players. Commonly used GPS derived metrics used within soccer include training/match play duration, total distance (TD) covered and distance covered and/or time spent in in different speed thresholds (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016).

Whilst TD is considered a stable metric, speed thresholds may be customised in commercially available GPS devices. Speed thresholds may be individualised, according to a player's maximum running speed or in relation to a specific physiological parameter (Hunter *et al.*, 2014; Malone *et al.*, 2017). This method, however, requires individual testing of players to assess a specific parameter (e.g. maximum speed, maximum aerobic speed, anaerobic threshold etc) and when used in academy soccer players may result in erroneous data, particularly in higher speed thresholds (Hunter *et al.*, 2014). Additionally, given that academy players improve in parameters of physical performance (speed, repeated sprint ability and endurance capacity) as they progress through the academy pathway (Wrigley *et al.*, 2014), regular testing of these parameters would be required which may not always be practically viable in the applied setting. This is of particular relevance if longitudinally monitoring load in youth soccer players. Consequently, arbitrary or absolute speed thresholds may be more appropriate in youth soccer players. Absolute speed thresholds are commonly used in both adult (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016) and academy soccer monitoring (Buchheit *et al.*, 2010; Hunter *et al.*, 2014). Whilst it is acknowledged that younger players may not be physically capable of reaching the higher absolute speed thresholds, it does enable direct comparison within and between different age-groups and also between studies. Given that one of the purposes of a soccer academy is to physically develop players to play for the club's first team, it could be suggested that load monitoring should be consistent throughout the first team and academy to enable tracking of progression.

Given its widespread use as a monitoring tool in soccer, it is important that GPS devices are both valid and reliable. Several studies have assessed the validity and reliability of different GPS devices in the context of team sport movement demands. Whilst there is an agreement that all GPS devices (irrespective of sampling frequency) are able to accurately quantify TD, 1 and 5 Hz devices are unable to accurately quantify distance covered at higher speed thresholds, particularly during multi-directional team sport movements (Coutts and Duffield, 2010; Portas *et al.*, 2010; Scott, Scott and Kelly, 2016). Devices that sample at 10 Hz are considered the most accurate and reliable (when compared with 1, 5 and 15 Hz devices) in quantifying locomotion at higher speed thresholds (Johnston *et al.*, 2014; Rampinini *et al.*, 2014) during team sport movements. Whilst inter-unit reliability for most GPS derived metrics from the same manufacturer (including TD and different speed thresholds) is considered good (CV: 0.2-1.5 %; Thornton *et al.*, 2019), where possible the same unit should be worn by a player, particularly throughout longitudinal monitoring (Malone *et al.*, 2017). Reliability between different GPS devices (brands and models) and associated software (and different versions) is questionable and should be interpreted with caution (Thornton *et al.*, 2019).

2.3.2.2 Heart rate telemetry

The physiological response to soccer training and match play is commonly monitored through measurement heart rate (HR) via radio telemetry. This non-invasive method provides information on a player's internal response to an external load, which can often differ between players (Drust, Atkinson and Reilly, 2007). Practitioners in soccer academies often use HR data in combination with external load data (combined on GPS software) to provide a more global representation of TML (Mendez-Villanueva *et al.*, 2012). HR data can be expressed in absolute terms (beats.min^{-1}) or expressed relatively (according to the percentage of maximum HR; HR_{max}) and subsequently reported as time spent in different heat rate thresholds (e.g. <60% HR_{max}, 61-70% HR_{max}; 71-80% HR_{max}; 81-90% HR_{max} and >91% HR_{max}).

Whilst relative HR data is used to monitor internal load in academy soccer players (Mendez-Villanueva *et al.*, 2012; Wrigley *et al.*, 2012; Aşçı, 2016), the thresholds used may need to be regularly adjusted, particularly if monitoring longitudinally, due to the improvement in cardiovascular fitness as players progress through the academy pathway (Wrigley *et al.*, 2014). Again, this may not always be practically viable in the applied setting. Additionally, HR response to training and match play in academy soccer players may be affected by normal day-to-day variation in HR, i.e. circadian rhythm (Hammouda *et al.*, 2013), external environment e.g. temperature (No and Kwak, 2016), level of dehydration (Sawka, Cheuvront and Kenefick, 2015) and level of fatigue or over-reaching (Brink *et al.*, 2012). Consequently, all of these aforementioned factors should be considered when monitoring and interpreting HR data in academy soccer players.

2.3.2.3 Rating of perceived exertion

Subjective RPE is considered one of the simplest tools to monitor internal TML. In 1970, Borg developed the original RPE scale, which required individuals to subjectively rate their perception of effort on a scale of 6-20 (Borg, 1970). More recently, Foster *et al.* (2001) developed a 10 point scale. Using this method, an individual's RPE score (0-10) is multiplied by session duration to provide session-RPE, a global indication of internal load (Foster *et al.*, 2001). To ensure accurate data is collected it must be collected following specific procedures

(Foster *et al.*, 2001). Both players and athletes should be familiarised with the method prior to its use and scores should be collected individually 30 minutes after exercise, however the latter is not always feasible in the applied setting. This method is quick to collect, inexpensive and does not require any specific training, making it a popular tool routinely used within soccer academies (Wrigley *et al.*, 2012; Gjaka *et al.*, 2016). However, Rodríguez-Marroyo and Antoñan (2015) reported a poor relationship between RPE and HR (r = 0.17) for soccer training in youth players, questioning the appropriateness of its use within this population. Given the subjective nature of this method, it is not possible to quantify energy expenditure from it.

2.3.3 Training and match demands of academy soccer players

2.3.3.1 Training load

To date few studies have investigated the typical training loads experienced by academy soccer players. Wrigley *et al.* (2012) quantified the typical training loads in U14, U16 and U18 age-groups from an EPL academy over a 14 day in-season period. Accumulative weekly training load (assessed via HR and RPE) increased in accordance with age in a hierarchical fashion, U18 (3948 ± 222 AU) > U16 (2919 ± 136) AU > U14 (2524 ± 128 AU), however no measures of external load were quantified in this study. Brownlee *et al.* (2018) investigated the typical duration of pitch-based soccer training, gym-based resistance training and match-play in a cohort of soccer players (U9-U21 age-groups) from a Category One EPL academy. Total weekly duration increased from 268 ± 25 $min \cdot week^{-1}$ in the U9 age-group to 477 ± 19 $min \cdot week^{-1}$ in the U14 age-group, after which there was a decrease in total weekly duration in the U15 to U21 age-groups (~260-300 $min \cdot week^{-1}$). These higher total durations in the younger age-groups were due to an increased amount of time spent on pitch-based technical development compared to the older age-groups. However, it should be noted that whilst the younger age-groups spent no time performing gym-based resistance training, there was a greater emphasis on this in the U15-U21 age-groups (~45 min·week^{-1}).

There also appears to be evidence of periodisation of physical loading throughout the week in academy soccer players at different stages of the academy pathway, particularly in the older age-groups compared to younger age-groups, likely due to the shift in focus from development to competition (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015). Coutinho *et al.* (2015) examined the periodisation of physical loading throughout a single weekly (training only) micro-cycle in U15, U17 and U19 soccer players from a professional Portuguese academy. There was no evidence of weekly load periodisation in the U15 players, with technical development being the focus of training throughout the week in this age-group. In the U17 age-group, the mid-week training sessions elicited the highest number of sprints (18.5 ± 7.1 sprints) and highest average speed (81 ± 7 m·min^{-1}) compared to the start of the week (16.2 ± 7.7 sprints and 77 ± 12 m·min^{-1}) and match day (MD)-1 (15.0 ± 8.7 sprints and 64 ± 14 m·min^{-1}). In the U19 age-group, the greatest physical load occurred at the start of the weekly micro-cycle and this was reduced throughout the week towards MD. For example, the number of sprints, mean distance per sprint and average speed respectively decreased from 14.5 ± 5.8 sprints, 14.7 ± 2.5 m and 70.3 ± 15.4 m·min^{-1} at the start of the week, to 13.7 ± 4.2 sprints, 11.2 ± 2.1 m and 65.1 ± 15.7 m·min^{-1} mid-week, to 1.1 ± 1.7 sprints, 6.7 ± 8.6 m and 41.1 ± 5.3 m·min^{-1} MD-1. However, it should be noted that this study was only conducted over one single weekly (training only) micro-cycle which may not be representative of a typical in-season week (Coutinho *et al.*, 2015). Additionally, during training, differences in training area (i.e. pitch size), number of players involved, and differences in technical/tactical content of training can all influence HR response in academy soccer players (Aşçı, 2016), making comparison between specific training sessions and days difficult.

2.3.3.2 Match load

Total distance covered during a match ranges from ~4 km in U9 players (Goto, Morris and Nevill, 2015a) to ~9 km in U18 players (Buchheit *et al.*, 2010), with older players generally covering greater distances than younger players (Harley *et al.*, 2010; Saward *et al.*, 2016). Given differences in methodologies (absolute vs. relative thresholds and different speed thresholds being used), comparison of running intensities is difficult, however higher running speeds are generally associated with increases in age during match play in academy soccer players (Goto, Morris and Nevill, 2015b; Brito *et al.*, 2018). Mendez-Villanueva *et al.* (2012) found no difference in relative HR response (% HR_{max}) between U13-U18 players during match-play. Whilst these players spent time in various different HR thresholds, the majority (~75%) of time was spent >80% HR_{max}. Wrigley *et al.* (2012) reported that the mean intensity (% HR_{max}) of match-play was significantly higher compared to pitch-based training in U14 (83 ± 2 and 74 ± 2 %), U16 (84 ± 2 and 74 ± 1 %) and U18 (81 ± 3 and 69 ± 2 %) EPL academy soccer players, respectively.

Differences in match duration, pitch dimensions and the number of players on each team (which can differ between age-groups and leagues), result in varying physical demands being placed on academy soccer players (Goto, Morris and Nevill, 2015a, 2015b; Brito *et al.*, 2018). Additionally, playing position (particularly in older age-groups) and specific tactics can influence match demands in academy soccer players (Mendez-Villanueva *et al.*, 2012). Given the focus of soccer academies is on player development and not always on match play (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015), it may be more appropriate to consider accumulative weekly training and match load in academy soccer players across the academy age-range. A comparison of accumulative weekly training and match loads between academy and adult players quantified using established GPS metrics is provided in Table 2.

Table 2. Accumulative weekly training and match loads of male soccer players (adult and academy players). – represents no data available.

Reference	Population (Status & Age)	Duration (min)	Total Distance (km)	Average Speed ($m \cdot min^{-1}$)	High Speed Running Distance (m)	Sprint Distance (m)	Time >90% HR_{max} (min or %)
Adult Data							
(Anderson, Orme, Di Michele, *et al.*, 2016)	12 English Premier League players 25 ± 5	1 game week: 352 ± 14 2 game week: 408 ± 8 3 game week: 364 ± 22	1 game week: 26 ± 2 2 game week: 33 ± 4 3 game week: 36 ± 2	1 game week: ~66 2 game week: ~89 3 game week: ~83	1 game week: 862 ± 309 2 game week: 1467 ± 494 3 game week: 2332 ± 612	1 game week: 298 ± 123 2 game week: 520 ± 318 3 game week: 981 ± 374	-
(Stevens *et al.*, 2017)	28 Dutch Eredivisie players 22 ± 3	~396	~33	-	~1549	-	~50 min
(Oliveira *et al.*, 2019)	19 UEFA Champions League players 26 ± 4	~407	~33	~83	~1124	-	-
Academy Data							
(Wrigley *et al.*, 2012)	English Premier League academy players 8 U14 8 U16 8 U18	U18: ~700 U16: ~560 U14: ~500	-	-	-	-	U14 training: 3 ± 1% U14 match: 11 ± 6% U16 training: 5 ± 1% U16 match: 18 ± 9% U18 training: 6 ± 3% U18 match: 16 ± 8%
(Bowen *et al.*, 2017)	32 EPL academy players U18	-	Low: ~9 Mod-Low: 9-20 Mod-High: 20-31 High: 31-39 Very High: 39+	-	Low: ~261 Mod-Low: 261-855 Mod-High: 856-1448 High: 1449-2047 Very High: 2048	-	-

(Brownlee *et al.*, 2018)	184 EPL academy players U9-U21	U9: 268 ± 25 U10: 387 ± 20 U11: 386 ± 17 U12: 469 ± 34 U13: 461 ± 35 U14: 477 ± 19 U15: 266 ± 77 U16: 321 ± 98 U18: 313 ± 92 U21: 281 ± 77	-	-	-	-	-

In addition to quantifying the TML experienced by academy soccer players, understanding the subsequent energy expenditure (and thus energy requirements) is vital in order to formulate population specific nutritional guidelines for academy soccer players that optimise growth, maturation and physical development. This data would be extremely valuable not only for the players, their parents/guardians and academy staff (notably sports science, medical and coaching staff), but also for governing bodies such as the EPL, given their objective for the EPPP is that it is evidence led (Premier League, 2011).

2.3.4 Energy expenditure

All metabolic processes within the body ultimately result in heat production. Thus, the rate of heat production defines the rate of energy metabolism. Energy expenditure is a process of energy production from the combustion of energy containing substrates carbohydrate, fat, protein and alcohol (FAO/WHO/UNU, 2001). This process requires oxygen and results in carbon dioxide production and was originally discovered by Lavoisier in the late 18th century:

$$(\text{substrate} + O_2 \Rightarrow CO_2 + H_2O + \text{heat})$$

Whilst energy expenditure (and energy intake) is quantified in kilojoules (KJ) or megajoules (MJ), kilocalories (kcal; 1000 calories) is the most commonly understood unit of energy (British Nutrition Foundation, 2020). One calorie is the amount of energy required to increase the temperature of one gram of water by one degree Celsius (Jeukendrup and Gleeson, 2019). Energy expenditure is comprised of three components, (1) basal metabolism; (2) thermic effect of food (TEF; also known as diet induced thermogenesis); and (3) activity energy expenditure (AEE).

2.3.4.1 Basal metabolism

Basal metabolism is the amount of heat produced over a period of time in a rested, fasted and thermoneutral state. It represents the amount of energy required to maintain normal homeostatic physiological functions (cellular, central nervous system and organ homeostasis) at rest (Manore and Thompson, 2015). The measurement of basal metabolic rate (BMR) is completed in the bed that the individual being assessed slept in. Because of this, the assessment of resting metabolic rate (RMR) is more common in both research and practice (Manore and Thompson, 2015). Resting metabolic rate (RMR) is measured under the same conditions as BMR (i.e. rested, fasted and thermoneutral state), however the individual being assessed does not have to remain in the bed they slept in, but do require a period of rest prior to the measurement. Therefore, RMR includes basal metabolism plus the energy cost of arousal (Manore and Thompson, 2015). Food/drink intake (specifically energy and macronutrient content), caffeine, alcohol and exercise all have an influence on RMR and consequently, assessments of RMR should be conducted under standardised conditions (Compher *et al.*, 2006; Bone and Burke, 2018).

RMR is generally the largest component of energy expenditure in the general population (Speakman and Selman, 2003; Pinheiro Volp *et al.*, 2011), although this is often not the case in athletic populations (Silva *et al.*, 2013; Morehen *et al.*, 2016). RMR has been studied in humans for over 100 years, with early studies identifying that both stature and body mass significantly correlated with RMR (Harris and Benedict, 1918). Therefore, as a player progresses through the academy pathway and increases in both stature and body mass (Malina *et al.*, 2000; Deprez *et al.*, 2013; Lovell *et al.*, 2015; Malina, Figueiredo and Coelho-e-Silva, 2017) their RMR will likely increase. However, there is currently a lack of data quantifying RMR (alongside stature, body mass and FFM) across the age-range (and maturity states) of soccer players from an EPL academy. Data from Indian soccer players demonstrates that RMR increases by ~400 kcal·day^{-1} from the (chronological) ages of 10 to 13, in accordance with increases in stature, body and FFM (Cherian *et al.*, 2018). It should be noted however that in this study, participants were only recreationally active and the sample included both male and female participants (Cherian *et al.*, 2018).

Whilst it is accepted that FFM is the most metabolically active compartment, the heterogenous tissues contained within FFM (skeletal muscle and different organs) do not equally contribute to RMR (Gallagher *et al.*, 1998; Javed *et al.*, 2010; Müller *et al.*, 2013). For example, despite only accumulating to ~6% of body mass, the brain, heart, liver and kidneys contribute to ~60-70% of RMR in adults. Skeletal muscle however, accumulates to ~40-50% of body mass but only contributes to ~20-30% of RMR (Gallagher *et al.*, 1998). Therefore, as body size increases during adolescent growth, there is also a change in the relative proportion of these highly metabolic organs to FFM (Müller *et al.*, 2018). Because the contribution of FFM to RMR is not linear, when comparing the relative RMR (i.e. adjusted for FFM) of individuals, standard ratio scaling (i.e. RMR/FFM) should not be used. Appropriate scaling techniques should be applied when comparing RMR in individuals of different sizes (Weinsier, Schutz and Bracco, 1992).

2.3.4.2 Thermic effect of food

The TEF is the increase in metabolism (above RMR) following the consumption of food/drink (i.e. energy). It represents the amount of energy required to digest, absorb, transport, metabolise and store nutrients following their consumption (Manore and Thompson, 2015). The TEF peaks ~60-180 minutes after food/drink consumption (Compher *et al.*, 2006) and fully subsides by ~8 hours (D'Alessio *et al.*, 1988). The TEF varies according to the energy content and also the macronutrient profile of the ingested food/drink: for carbohydrates the TEF is 5-10% of the total energy content of the consumed carbohydrate, for fat 0-3% of the total energy content of the consumed fat, for protein 20-30% of the total energy content of the consumed protein and for alcohol 10-30% of the total energy content of the consumed alcohol (Westerterp, 2004). In individuals consuming a mixed diet (i.e. a diet containing carbohydrates, fat and protein), which is typical in academy soccer players (Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016), the TEF is ~10% of the total energy intake (Westerterp, 2004).

2.3.4.3 Activity energy expenditure

AEE is the amount of energy expended above RMR and TEF as the result of physical activity (Poehlman, 1989). It is the most variable component of TEE and is influenced by both anthropometric profile (i.e. body size) and locomotion (Westerterp, 2013). AEE can be divided into non-exercise activity thermogenesis (NEAT), which is the energy cost maintaining posture, daily living activities, fidgeting and spontaneous muscle contraction e.g. shivering; and (planned) exercise-related energy expenditure (Levine, 2002). In athletic populations, AEE can often be the largest component of TEE in both adult (Morehen *et al.*, 2016) and youth athletes (Silva *et al.*, 2013). Whilst there is currently no data quantifying AEE in academy soccer players, several studies have attempted to estimated TEE in this population (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015).

2.3.4.4 Total energy expenditure

Total energy expenditure (TEE) is the sum of the three aforementioned components and it dictates an individual's energy requirements (i.e. their energy intake) (Manore and Thompson, 2015). The first study investigating the energy expenditures of top tier English soccer players (adults) was conducted in the late 1970s (Reilly and Thomas, 1979). More recently, a series of studies by Anderson and colleagues quantified the TEE of adult EPL soccer players, using the gold standard doubly labelled water method. Observed mean daily TEE was 3566 ± 585 kcal·day^{-1} (range: 3047 – 4400 kcal·day^{-1}) in outfield players (Anderson *et al.*, 2017) and 2894 kcal·day^{-1} in a goalkeeper (Anderson, Close, Morgans, *et al.*, 2019) assessed over a seven day in-season period comprising of two matches and five training sessions and 3178 kcal·day^{-1} in a player returning from an anterior cruciate ligament injury (Anderson, Close, Konopinski, *et al.*, 2019). Anderson speculated that the variation in mean daily TEE was the result of individual differences in anthropometric profiles and TML between players (Anderson *et al.*, 2017; Anderson, Close, Morgans, *et al.*, 2019). A summary of the aforementioned studies can be seen in Table 3.

Several studies have attempted to estimate mean daily TEE in academy soccer players using a variety of different methods (Table 3). Mean daily TEE of 3618 ± 61 kcal·day^{-1} (Russell and Pennock, 2011) and 2551 ± 245 kcal·day^{-1} (Briggs *et al.*, 2015) were observed in U18 English Championship and U15 EPL academy players respectively. Despite differences in the methodologies used to estimate TEE between these studies, the data shows clear differences in TEE between these two different age-groups, in accordance with differences in body mass (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015). Considering the differences in anthropometric profiles (Malina *et al.*, 2000; Deprez *et al.*, 2013; Lovell *et al.*, 2015; Malina, Figueiredo and Coelho-e-Silva, 2017) and TML (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015) between academy soccer players of different ages (and maturity status), it is likely that TEE will vary significantly between different age-groups. However, to date there is a lack of data quantifying TEE in EPL academy soccer players across the academy age-range using gold standard methods.

Table 3. Reported total energy expenditures of male soccer players of different ages.

Reference	**Population (age and status)**	**Anthropometric Profile (stature and body mass)**	**Training & Match Load**	**Assessment Method & Duration**	**TEE (kcal·day^{-1})**
(Reilly and Thomas, 1979)	English First Division players 22.6 ± 3.2 years	73.0 ± 7.0 kg	Mean training duration: 75 min Mean match TD: 8.7 ± 1.0 km	23 weeks Training activity: heart rate Match play: motion analysis Habitual activity: activity diary	3449 (range: 3025 – 4133)
(Anderson *et al.*, 2017)	English Premier League outfield players 27 ± 3 years	180 ± 7 cm 80.5 ± 8.7 kg	**Weekly total:** Duration: 321 ± 33 min TD: 26.4 ± 5.4 km HSR distance: 1322 ± 717 m Sprint distance: 430 ± 274 m	DLW 7 days (in-season)	3566 ± 585 (range: 3047 – 4400)
(Anderson, Close, Morgans, *et al.*, 2019)	27 year old English Premier League goalkeeper	191 cm 85.6 kg	**Weekly total:** Duration: 484 min TD: 20.9 km HSR distance: 26 m	DLW 7 days (in-season)	2894
(Anderson, Close, Konopinski, *et al.*, 2019)	23 year old English Premier League player returning from an ACL injury	179 cm 77.0 kg	**Weekly total:** 5 lower body weights sessions (uninjured limb only – endurance and maintenance focus) 3 upper body weights sessions (strength focus)	DLW 7 days (individual rehab)	3178

Reference	Population (age and status)	Anthropometric Profile (stature and body mass)	Training & Match Load	Assessment Method & Duration	TEE ($kcal \cdot day^{-1}$)
(Russell and Pennock, 2011)	English Championship academy players 17 ± 1 years	172 ± 1 cm 67.5 ± 1.8 kg	Weekly total: ~540 min	RMR: prediction equation AEE: activity diary 7 days (in-season)	3618 ± 61
(Briggs *et al.*, 2015)	English Premier League academy players 15.4 ± 0.3 years	170 ± 6 cm 57.8 ± 7.8 kg	Typical weekly mean: ~1200 min (estimated, not measured)	RMR: prediction equation AEE: accelerometery 7 days (in-season)	2552 ± 245
(Boisseau *et al.*, 2007)	French academy players 13.8 ± 0.1 years	164 ± 2 cm 54.2 ± 3.5 kg	Daily mean: 95 ± 7 $min.day^{-1}$	RMR: prediction equation AEE: activity diary 3 x 4 days (in-season)	1st 4 days: 2895 ± 88 2nd 4 days: 2837 ± 79 3rd 4 days: 2823 ± 131
(Caccialanza, Cameletti and Cavallaro, 2007)	Italian academy players 16 ± 1 years	179 ± 5 cm 69.8 ± 7.4 kg	4 day total: ~340 min	RMR: prediction equation TEE: PAL 4 days (in-season)	3450 ± 260

TEE = total energy expenditure. TD = total distance. HSR = high speed running. DLW = doubly labelled water. ACL = anterior cruciate ligament. RMR = resting metabolic rate. PAL = physical activity level.

2.3.5 Methods to assess energy expenditure

Considering energy prescription for an academy soccer player (i.e. their energy requirements) is based upon their energy expenditure, it is important to be able to accurately quantify (or estimate) energy expenditure. There are a variety of methods that can be used to measure energy expenditure, which vary in terms of their validity, reliability and practicality within the applied setting (Donahoo, Levine and Melanson, 2004; Levine, 2005). These methods are classified as:

- Calorimetric (direct and indirect calorimetry)
- Non-calorimetric (estimation methods)

2.3.5.1 Direct calorimetry

Direct calorimetry measures heat that is lost from the body via convection, evaporation and radiation, and is the gold standard method of quantifying energy expenditure in humans (Ainslie, Reilly and Westerterp, 2003; Levine, 2005). Direct calorimetry requires a highly sophisticated metabolic chamber which are extremely expensive to set-up and maintain and require a highly skilled technician to operate. Individuals being assessed are also confined to the chamber for the duration of the measurement, limiting the type of activities that can occur within the chamber (Levine, 2005). Due to these limitations, this method is seldomly used in either research or applied practice, particularly in assessments of energy expenditure in soccer players (Ainslie, Reilly and Westerterp, 2003).

2.3.5.2 Indirect calorimetry

Indirect calorimetry involves the measurement of oxygen (O_2) consumption ($\dot{V}O_2$) and carbon dioxide (CO_2) production ($\dot{V}CO_2$) from pulmonary ventilation, rather than the direct measurement of heat. $\dot{V}O_2$ and $\dot{V}CO_2$ corresponds to the amount of O_2 required for substrate oxidation and the amount of CO_2 produced respectively. In quantifying $\dot{V}O_2$ and $\dot{V}CO_2$, the respiratory quotient (RQ) can be calculated ($\dot{V}CO_2$ / $\dot{V}O_2$) to determine which substrate(s) are being oxidised (McArdle, Katch and Katch, 2013). Oxidation of different substrates is associated with different $\dot{V}O_2$ and $\dot{V}CO_2$ resulting in different RQ values (see Table 4). Subsequently a calculation of energy expenditure can be made using the modified Weir equation (Weir, 1949) which is commonly used in athletic populations (Schofield, Thorpe and Sims, 2019):

$$\textit{Energy expenditure (kcal·day}^{-1}\textit{)} = [(\dot{V}O_2 \times 3.941) + (\dot{V}CO_2 \times 1.11)] \times 1440$$

Table 4. Comparison of oxygen uptake, carbon dioxide released, respiratory quotient, and heat generation during oxidation of 3 main biological substrates. Adopted from Haugen, Chan and Li (2007).

Substrate	**$\dot{V}O_2$ (L.min^{-1})**	**$\dot{V}CO_2$ (L.min^{-1})**	**RQ**	**Heat produced per gram oxidized (kcal)**
Glucose	0.746	0.746	1.00	3.75
Lipid	2.029	1.430	0.69	9.30
Protein	0.966	0.782	0.81	4.30

Indirect calorimetry, specifically ventilated metabolic carts, is the most commonly used method to quantify RMR in both research and applied practice (Levine, 2005; Pinheiro Volp *et al.*, 2011) and has been previously used to determine RMR in recreationally active youth soccer players, aged ~10-13 (male and female) (Cherian *et al.*, 2018). This method has an accuracy of 0.5-2.0 % (Levine, 2005), with a typical coefficient of variation (CV) of ~2-3 % (Donahoo, Levine and Melanson, 2004). Accurate measurements of RMR can be determined in ~10 minutes (following a period of rest) under steady-state conditions (CV <10% for $\dot{V}O_2$ and $\dot{V}CO_2$) via indirect calorimetry (Compher *et al.*, 2006). Prior food, alcohol, caffeine consumption and also exercise can influence $\dot{V}O_2$ and $\dot{V}CO_2$ (and consequently energy expenditure values) during an RMR assessment so best practice, standardised conditions should be adhered to for an RMR assessment (Compher *et al.,* 2006).

2.3.5.3 Prediction equations

In the absence of specialist equipment (direct / in-direct calorimetry), technical expertise or opportunity (due to cost or time), an array of prediction equations have been developed to estimate RMR. For practitioners working with athletes these prediction equations permit a time-efficient and more practical alternative to direct measurements. After directly assessing RMR (either via direct / in-direct calorimetry) in a specific population, regression analysis can determine the best predictor variable(s), enabling development of a novel prediction equation. Commonly used predictor variables include sex, stature, body mass and FFM (Harris and Benedict, 1918; Cunningham, 1980; De Lorenzo *et al.*, 1999; Wong *et al.*, 2012).

These equations are often derived from non-athletic populations (Harris and Benedict, 1918; Cunningham, 1980; Henry, 2005) and therefore may not be suitable for use in athletes. Several studies have reported that prediction equations that were developed in non-athletic populations underestimate RMR in athletes (Carlsohn *et al.*, 2011; Morehen *et al.*, 2016), likely because they do not include FFM in the equation (Schofield, Thorpe and Sims, 2019). A number of prediction equations including the De Lorenzo (De Lorenzo *et al.,* 1999) and the Wong (Wong *et al.,* 2012) equations have been developed using athletic populations, however neither include FFM a as predictor variable. The Kim equation (Kim *et al.,* 2015) however, which was developed using ~16 year old recreational soccer players of Korean origin, does include FFM. It should be noted though that these subjects were non-elite and the equation did not differentiate between males and females (Kim *et al.,* 2015), so its application to male soccer players in a EPL academy is questionable.

2.3.5.4 Doubly labelled water

The doubly labelled water (DLW) technique is considered the gold standard method of assessing TEE in free-living conditions (FAO/WHO/UNU, 2001; Ainslie, Reilly and Westerterp, 2003). DLW was first used to assess TEE in humans almost 40 years ago (Schoeller and van Santen, 1982) and has since been used to quantify TEE in EPL soccer players (Anderson *et al.*, 2017) and youth athletes in various team sports, including basketball (Silva *et al.*, 2013) and rugby (Smith *et al.*, 2018). However, to date this method has not been used to quantify TEE in academy soccer players. This method enables the quantification of TEE over a 4-20 day period (Ainslie, Reilly and Westerterp, 2003) and has a precision of 2-8% when compared to direct calorimetry (Schoeller, 1988).

The principle of the DLW is based on oxygen and hydrogen turnover in the body. This method involves enriching the body water pool with two stable (non-radioactive) isotopes, heavy oxygen (^{18}O) and heavy hydrogen (^{2}H, also known as deuterium), which are ingested via an oral bolus dose of 'doubly labelled water' ($^{2}H_2{}^{18}O$) (Speakman, 1998; Ainslie, Reilly and Westerterp, 2003). The amount of $^{2}H_2{}^{18}O$ consumed is based on the subject's body mass using the following calculation:

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

Where 0.65 is the approximate proportion of the body comprised of water, DIE = desired initial enrichment (DIE = 618.923 × body mass, $kg^{-0.305}$) and IE = initial enrichment (10%) 100,000 parts per million (Speakman, 1997). Once ingested the isotopes mix with the total body water pool and reach an equilibrium with the total body water pool after several hours (Speakman, 1998).

Oxygen turnover within the body is determined by respiration (i.e. oxygen consumption and carbon dioxide production) and the flow of water through the body (lost via urine, sweat, saliva or breath). Hydrogen turnover however is solely determined by the flow of water through the body (Speakman, 1998). Therefore, the elimination rate of ^{18}O is faster than the elimination rate of ^{2}H, as demonstrated in Figure 3. The difference in the elimination rates between these two isotopes reflects the rate at which carbon dioxide is produced (Ainslie, Reilly and Westerterp, 2003). This enables subsequent estimation of TEE if an RQ of 0.85 is assumed for a mixed diet (Ainslie, Reilly and Westerterp, 2003), which is representative of EPL academy soccer players (Naughton *et al.*, 2016).

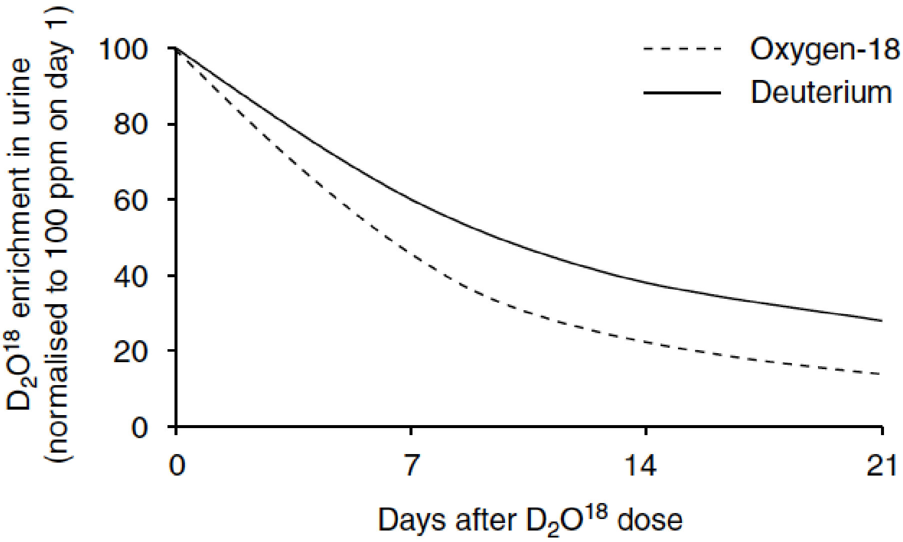

Figure 3. Decline of ^{2}H (deuterium) and ^{18}O (oxygen-18) in body fluids (urine, plasma or saliva) during a hypothetical doubly labelled water experiment (adopted from Ainslie, Reilly and Westerterp, 2003).

The DLW technique enables quantification of mean daily TEE over a period of time. Therefore, this method cannot provide information on the AEE of a specific exercise bout (e.g. a training session) or TEE for a specific day (FAO/WHO/UNU, 2001; Ainslie, Reilly and Westerterp, 2003). Due to the high costs of the isotopes and the highly technical analysis required to determine isotope concentrations (using isotope ratio mass spectrometry) this method is expensive (~£1,000 per subject) (Westerterp, 2017). Despite these limitations, it is still considered the gold standard method, and is particularly useful in quantifying TEE in athletes as it is non-invasive and does not interfere with day-to-day activities such as soccer training or match play (Westerterp, 2017). Additionally, given the timeframe of measurement this is an ideal method to quantify TEE in academy soccer players as it can capture one or two typical in-season weeks (including training and match play).

Whilst this method has been used to quantify TEE in adult soccer players (Anderson *et al.*, 2017; Brinkmans *et al.*, 2019), no data in academy soccer players exists. Accurately determining TEE in academy soccer players of different ages and maturation statuses, would enable nutrition guidelines to be developed for this population that are age/maturation specific. If dietary intake was also simultaneously assessed alongside TEE, it would permit an accurate RQ to be determined for the calculation of TEE and would provide an insight as to whether or not academy soccer players are meeting their daily energy requirements.

There are also a number of other non-calorimetric methods that can be used to estimate energy expenditure, each with their own advantages and disadvantages (Table 5). Many of these non-calorimetric methods are validated against DLW (Westerterp, 2013).

Table 5. Advantages and limitations of different non-calorimetric methods to estimate energy expenditure.

Method	Overview of Method	Advantages	Limitations
Accelerometery (tri-axial)	Detects movement, specifically accelerations, in three different planes of motion (anterior-posterior, mediolateral and longitudinal planes). Frequency, velocity and duration of movement monitored. Requires participant to wear a small device, often on the hip, for a period of time (Ridgers and Fairclough, 2011; Hills, Mokhtar and Byrne, 2014).	Easily accessible. Easy to use. Low subject burden. Non-invasive. Portable. Low cost. (Ridgers and Fairclough, 2011; Hills, Mokhtar and Byrne, 2014)	Different physical activity intensity thresholds between studies makes comparisons difficult. There is currently no consensus on these physical activity intensity thresholds (Hills, Mokhtar and Byrne, 2014). Subject compliance can be an issue (Ridgers and Fairclough, 2011). Underestimates EE during intermittent team sport exercise (Taylor *et al.*, 2018).
Physical activity diaries	Participants self-record activities undertaken in specific time intervals (often 15 minutes) (Hills, Mokhtar and Byrne, 2014). Many activities have been assigned an estimated EE cost (MET) and these are added to calculate TEE for a 24 hour period (Ainsworth *et al.*, 2011).	Simple. Low cost. (Hills, Mokhtar and Byrne, 2014)	The energy cost (MET) of the different physical activities was developed in adults. The energy cost of many of these physical activities is greater in children and adolescents, so are therefore inappropriate to use in these populations (Harrell *et al.*, 2005). High subject burden (Hills, Mokhtar and Byrne, 2014).

Heart rate	There is a close relationship between heart rate and oxygen consumption (and thus EE) during submaximal exercise (Ainslie, Reilly and Westerterp, 2003).	Portable. Non-invasive. Relatively cheap. Low subject burden. (Achten and Jeukendrup, 2003; Hills, Mokhtar and Byrne, 2014).	Issues surrounding the validity of applying the principles of steady-state exercise (generally linear treadmill running) to the sudden and delayed (and random) heart rate responses to soccer training and match play (Drust, Atkinson and Reilly, 2007). During high intensity intermittent exercise (e.g. soccer), heart rate responds relatively slowly compared to sudden changes in work rate, and vice versa (Achten and Jeukendrup, 2003). Several factors (other than exercise) have an effect on heart rate including environmental conditions, psychological state, dehydration and illness (Ainslie, Reilly and Westerterp, 2003).
GPS devices	Estimates of EE derived from a number of external load metrics obtained from GPS devices, including velocity, accelerations and decelerations (often termed ‘metabolic power’) (Buchheit *et al.*, 2015).	Metabolic power value is easily accessible, particularly if GPS devices are already worn to quantify external load (Buchheit *et al.*, 2015).	Metabolic power significantly underestimates the oxygen cost of soccer training in academy soccer players, when compared to indirect calorimetry (Buchheit *et al.*, 2015).

EE = energy expenditure. TEE = total energy expenditure. GPS = global positioning system. MET = metabolic equivalent of task.

2.4 Dietary intakes in academy soccer players

2.4.1 Energy intake and availability

As an academy soccer player progresses through the academy pathway, their energy intake (EI) should at least match their TEE. To a greater extent than adult players, academy soccer players require energy to be deposited into newly formed tissue and for the synthesis of this new tissue (~5 kcal per gram of weight gain; Torun, 2005). An appropriate energy availability (EA) is therefore important to maximise growth, maturation and physical development but also to maintain health and minimise the risk of illness and injury (Loucks, Kiens and Wright, 2011). EA is the amount of energy left for homeostatic physiological functions and growth once AEE has been deducted from EI and is relative to FFM (EA = (EI – AEE) / FFM), which differs from the traditional energy balance equation (energy balance = EI – TEE) (Loucks, Kiens and Wright, 2011). Chronic periods of low EA (<30 kcal·kg FFM^{-1}.day^{-1}) 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; Mountjoy *et al.*, 2014, 2018). Not only is this likely to have potential detrimental effects on an academy soccer players performance but also their physical and psychological health. It should be noted however that many of the studies investigating the consequences of low EA were conducted in adult populations, and the low EA 'thresholds' are primarily based on findings from female populations.

An energy availability of ≥45 kcal·kg FFM^{-1}.day^{-1} is recommended for adult athletes to maintain normal physiological function and health (Loucks, Kiens and Wright, 2011). Considering academy soccer players have greater relative energy demands than adults players (Morgan, 2008), ≥45 kcal·kg FFM^{-1}.day^{-1} is likely to be the *minimum* a young athlete would require, however further research is required. Koehler *et al.* (2013) reported a mean energy availability of 28.5 and 29.4 kcal·kg $FFM^{-1}.day^{-1}$ in young male and female athletes respectively (11-25 years old), that competed in a range of sports (aesthetic, ball, endurance, racquet, water sports) at national or international level.

Whilst there is currently no data on the EA of academy soccer players, many studies have investigated the EI of academy soccer players worldwide (Table 6). Studies investigating the EI of EPL academy soccer players have reported EI of ~1900-2900 $kcal·day^{-1}$ in players aged 12-17 (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016). These intakes are significantly less than those of Spanish academy players (~3500 $kcal·day^{-1}$) aged 14-17, who reportedly consume more dietary fat compared to English academy players (Ruiz *et al.*, 2005). These differences in fat intake may be the result of cultural differences and dietary norms between the two countries (Birkenhead and Slater, 2015). Generally European academy players, irrespective of nationality or age, consume ~5-6 $g·kg^{-1}$ of carbohydrates and ~1.5-2.0 $g·kg^{-1}$ of protein (Table 6). Whether these energy and macronutrient intakes are appropriate or not for EPL academy soccer players is difficult to ascertain, given that no accurate data on the typical TEE of this population exist. Considering these EI values alongside the estimated TEE values in EPL academy soccer players (Table 6), it is plausible to suggest that energy availability may be compromised in this population as previously suggested by Briggs *et al.* (2015). It should be noted, however, that assessing EA is notoriously difficult to accurately quantify owing to the difficulties in obtaining accurate EI data (Burke *et al.*, 2018).

Table 6. Reported dietary intakes of European male academy soccer players.

Reference	Population (Ethnicity & Age)	Assessment Method & Duration	Energy (kcal)	Carbohydrates		Fat			Protein	
				g	$g{\cdot}kg^{-1}$	g	$g{\cdot}kg^{-1}$	% EI	g	$g{\cdot}kg^{-1}$
(Ruiz *et al.*, 2005)	Spanish academy players U15 (1): 14.0 ± 0.3 yrs U16 (2): 14.9 ± 0.2 yrs U17 (3): 16.6 ± 0.6 yrs	Food diary 3 days (in-season)	1: 3456 ± 309 2: 3418 ± 182 3: 3478 ± 223	1: 442 ± 45 2: 391 ± 27 3: 392 ± 37	1: 6.7 ± 0.9 2: 5.9 ± 0.4 3: 5.3 ± 0.4	1: 139 ± 11 2: 142 ± 6 3: 154 ± 5	1: 2.2 ± 0.2 2: 2.2 ± 0.1 3: 2.2 ± 0.1	1: 38.3 2: 39.1 3: 38.4	1: 129 ± 10 2: 142 ± 10 3: 150 ± 5	1: 2.0 ± 0.2 2: 2.1 ± 0.1 3: 2.0 ± 0.2
(Caccialanza, Cameletti and Cavallaro, 2007)	Italian academy players 16 ± 1 yrs	Food diary 4 days (in-season)	2560 ± 636	339 ± 89	4.9 ± 1.5	87 ± 25	-	30.5 ± 3.4	101 ± 23	1.5 ± 0.4
(Russell and Pennock, 2011)	English Championship academy players 17 ± 1 yrs	Food diary 7 days (in-season)	2831 ± 164	393 ± 18	5.9 ± 0.4	100 ± 9	1.5 ± 0.1	31 ± 1	114 ± 8	1.7 ± 0.1
(Iglesias-Gutiérrez *et al.*, 2012)	Spanish academy players 18 ± 2 yrs	Food diary 6 days (in-season)	2794 ± 526	338 ± 70	4.7 ± 1.1	116 ± 30	-	37 ± 5	119 ± 24	1.6 ± 0.4
(Briggs *et al.*, 2015)	English Premier League academy players 15.4 ± 0.3 yrs	Food diary & 24 hour recall 7 days (in-season)	2245 ± 321	318 ± 24	5.6 ± 0.4	70 ± 7	1.2 ± 0.1	29 ± 2	86 ± 10	1.5 ± 0.2
(Bettonviel *et al.*, 2016)	Dutch academy players 17.3 ± 1.1 yrs	24 hour recall x 4 occasions	2938 ± 465	411 ± 87	6.0 ± 1.5	84 ± 14	1.2 ± 0.2	25.7 ± 3.4	119 ± 22	1.7 ± 0.4
(Naughton *et al.*, 2016)	English Premier League academy players U13/14 (1): 12.7 ± 0.6 yrs U15/16 (2): 14.4 ± 0.5 yrs U18 (3): 16.4 ± 0.5 yrs	Food diary 7 days (in-season)	1: 1903 ± 432 2: 1927 ± 317 3: 1958 ± 390	1: 266 ± 58 2: 275 62 3: 224 ± 80	1: 6.0 ± 1.2 2: 4.7 ± 1.4 3: 3.2 ± 1.3	1: 56 ± 18 2: 55 ± 11 3: 60 ± 15	1: 1.3 ± 0.5 2: 0.9 ± 0.3 3: 0.9 ± 0.3	-	1: 97 ± 21 2: 96 ± 14 3: 143 ± 24	1: 2.2 ± 0.5 2: 1.6 ± 0.3 3: 2.0 ± 0.3

EI = energy intake.

2.4.2 Methods to assess dietary intake

Whilst it is of great importance, accurately quantifying dietary intake is an extremely complex and problematic process (Capling *et al.*, 2017; Burke *et al.*, 2018). This is particularly applicable when attempting to assess the dietary intakes of children and adolescents. Self-reported dietary intakes in this population are typically poor, owing to individuals losing focus and motivation, particularly over long periods of time (Livingstone, Robson and Wallace, 2004). In a recent systematic review, Capling *et al.* (2017) concluded that when compared to TEE (assessed by DLW) and changes in body mass, self-reported EI was under-reported by ~19% in athletic populations; which may be conscious or sub-conscious. Under-reporting of what athletes perceive to be 'unhealthy' foods and over-reporting of what athletes perceive to be 'healthy' foods is common during assessments of dietary intake in athletic populations (Burke *et al.*, 2018). Given that the majority of dietary intake assessments are self-reported there is a degree of burden on the individual being assessed. Consequently both researchers and practitioners should choose the method(s) that is/are most suitable to the population and situation, whilst acknowledging the limitations of the selected dietary intake method (Burke, 2015).

Whilst there is currently no accepted gold standard method for assessing dietary intake, there are a number of commonly used methods, each with their own advantages and limitations (Burke, 2015; Capling *et al.*, 2017). Routinely used prospective methods include traditional food diaries (Naughton *et al.*, 2016) and the more recently developed remote food photographic method (e.g. 'snap and send') (Anderson *et al.*, 2017; Costello *et al.*, 2017), and common retrospective methods include the 24 hour recall (Briggs, Cockburn, *et al.*, 2015). Briggs and colleagues reported that by combining two dietary intake methods (food diary and 24 hour recall), compared to using just one method, improved the accuracy of dietary intake data obtained in academy soccer players (Briggs, Rumbold, *et al.*, 2015). The typical duration of dietary intake assessments in academy soccer players is 4-7 days (Caccialanza, Cameletti and Cavallaro, 2007; Russell and Pennock, 2011; Iglesias-Gutiérrez *et al.*, 2012; Naughton *et al.*, 2016). This is deemed a suitable amount of time to capture habitual dietary intake in athletes, whilst ensuring scientific rigour and limiting athlete burden (Braakhuis *et al.*, 2003; Capling *et al.*, 2017).

2.4.2.1 Food diary

The food diary is the most commonly used method to assess dietary intake in athletic populations (Burke, 2015), including academy soccer players (Caccialanza, Cameletti and Cavallaro, 2007; Russell and Pennock, 2011; Iglesias-Gutiérrez *et al.*, 2012; Naughton *et al.*, 2016). This self-reported method requires the individual being assessed to write down specific information including food/drink consumed, quantity, brand (if appropriate), preparation and cooking method (if appropriate), time of consumption and any left-overs (if appropriate), in as much detail as possible (Braakhuis *et al.*, 2003; Manore and Thompson, 2015). Quantities of foods/drinks can be weighed or estimated using common household measures (e.g. teaspoon). Weighed food diaries provide a more accurate measure of dietary intake compared to using common household measures, however weighing all foods/drinks (and individual components of a meal) places a high level of burden on the athlete (Burke, 2015). This can lead to athletes failing to report consumed foods/drinks (i.e. under-reporting) or altering their usual dietary intake and habits (Burke, 2015). Using common household measures to assess dietary intake is less onerous but is not as accurate, often due to inaccuracies in subjective assessments of portion size (Burke, 2015). When using food diaries to assess dietary intake of children and adolescents, parental assistance is generally required (Livingstone, Robson and Wallace, 2004).

2.4.2.2 Remote food photograph method

The remote food photograph method (e.g. 'snap-n-send') is a novel prospective method that requires the individual being assessed to take a photo of their food/drink prior to consumption and immediately after (i.e. leftovers / empty packing etc) to identify what exactly was consumed (Boushey *et al.*, 2017). These photos, alongside a description of the food/drink are then sent to the investigator on a smart phone (e.g. via WhatsApp), reducing the emphasis on the individual being assessed to estimate food/drink quantities. By sending these photos and descriptions in real time, a timestamp of when the food or drink was consumed is also provided (Boushey *et al.*, 2017; Costello *et al.*, 2017). Adolescents prefer this method to traditional methods such as the food diary, as it reduces the burden placed on them and as such do not require any parental assistance whilst engaging in this method (Boushey *et al.*, 2017). The remote food photograph method holds high ecological validity, reduces memory bias and has been shown to reduce under-reporting in adolescents compared to a food diary (Boushey *et al.*, 2017). Costello *et al.* (2017) recently developed the 'snap-n-send' method which is a variation of remote food photograph method. In addition to sending through photos and descriptions, during the assessment period of this method, the individual (being assessed) is reminded of the importance of accurate dietary intake data, is promoted to report all food/drink that is consumed and is encouraged throughout. These prompts are particularly useful when assessing the dietary intakes of adolescent athletes. Costello *et al.* (2017) reported that 'snap-n-send' is a valid method to assess the dietary intakes of adolescent athletes, reporting a small mean bias for under-reporting (CI = -5.7% to - 2.2%) when compared to a researcher-observed weighed method.

2.4.2.3 24-hour recall

A 24-hour recall is a retrospective method to estimate dietary intake during which the individual being assessed provides information on their food/drink intake from the previous day (Burke, 2015). This method can be conducted quickly, is not onerous on the individual being assessed and can be fitted around the athlete's schedule. The triple or multiple pass method allows the interviewer to revisit the first recall (once or multiple times) and tease out any additional information, increasing the accuracy of the dietary intake data, however this requires a skilled 'interviewer' (Nightingale *et al.*, 2016). Given the retrospective nature of this method, it does not alter the athlete's dietary intake, though it does require honest and accurate memory recall (Burke, 2015). Considering the 24-hour recall is only of the previous days intake, the information obtained may not be representative of the athletes typical diet and so several 24-hour recalls may have to be performed to obtain an accurate representation of the athlete's true dietary intake and habits (Burke, 2015). This is particularly relevant in soccer players who may change their dietary intake (particularly carbohydrate intake) in accordance with their training and match demands (Anderson *et al.*, 2017). Using this method, in conjunction with another prospective method to assess dietary intake has been shown to increase the accuracy of data obtained in academy soccer players (Briggs, Rumbold, *et al.*, 2015).

2.4 Summary and directions for future research

It is well documented that as an academy soccer player transitions through the academy pathway, they grow in stature and body mass in accordance with increases in chronological and biological age. However, it is currently unclear how body composition, in particular FFM, changes throughout these key phases of growth and maturation in this population. Given that RMR is significantly influenced by a player's anthropometric profile, in particular their FFM, it is of interest to simultaneously characterise both FFM and RMR in EPL academy soccer players. It is also of practical importance to investigate whether or not current RMR prediction equations are accurate in estimating RMR of EPL academy soccer players, when compared to measured RMR. Given the influence of exercise on AEE (and thus TEE) it is important to quantify the typical TML of EPL academy soccer players across the academy age-ranges. This would also ascertain whether or not these typical TML are progressive in nature or if there is any evidence of periodisation of load throughout the week, which may have implications for TEE and subsequent energy requirements. Finally, due to the lack of accurate information on the typical TEE experienced by EPL academy soccer players, it is currently difficult to accurately prescribe population specific nutritional guidelines. Therefore, further research using gold standard methods to accurately quantify TEE in EPL academy soccer players is warranted. It is envisaged that the data arising from the studies undertaken in this thesis will help inform population specific nutritional guidelines for EPL academy soccer players that optimise growth, maturation and physical development.

Chapter 3

General Methodology

The aim of this Chapter is to provide details of common methodologies that were employed in each of the subsequent Chapters (Chapter's 4, 5 and 6). Methodologies that were unique to a specific Chapter are presented in the methods section of that relevant Chapter.

3.1 Ethical approval and location of testing

All experimental procedures and associated risks were explained both verbally and in writing to each player and their parent or guardian, and written informed consent and assent were obtained respectively. All players were informed that they could withdraw from participation at any stage throughout these studies. Ethical approval for all studies in this thesis 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).

All anthropometric assessments (stature, sitting height and body mass), dual-energy X-ray absorptiometry (DXA) scans and resting metabolic rate assessments were collected in the Tom Reilly Building, Liverpool John Moores University (Figure 4). Training load data collection occurred on the grass pitches at Finch Farm Training Complex, Halewood, Liverpool (Figure 5). Match load data collection also occurred on the grass pitches at Finch Farm Training Complex for home games, or at the relevant away teams training facility in the United Kingdom. Risk assessments were conducted and approved for all testing locations.

Figure 4. The Tom Reilly Building (TRB), Liverpool John Moores University. Facilities within the TRB were used for data collection of Chapters 4 and 6.

Figure 5. Finch Farm Training Complex. These facilities were used during training and match load data collection in Chapters 5 and 6.

3.2 Participant characteristics

Male soccer players from a Category One EPL academy volunteered to participate in these studies. Players were categorised according to their respective age-group (U12, U13, U14, U15, U16, U18 and U23) based upon their chronological age. A total of 129 individual players participated in these three studies. A summary of participant characteristics from all three studies can be seen in Table 7. Participant characteristics of each age-group within each study are included in the relevant chapter.

Table 7. Summary of participant characteristics from all three studies, including age, maturity offset, current percent of predicted adult stature (PAS), stature and body mass. Data are presented as mean ± SD.

Study	n	Age (years)	Maturity offset (years)	Current percent of PAS (%)	Stature (cm)	Body mass (kg)
1 (Chapter 4)	99	15.9 ± 2.6	2.0 ± 3.4	95 ± 5	175 ± 12	64.0 ± 14.8
2 * (Chapter 5)	76	14.1 ± 1.9	0.4 ± 1.9	92 ± 6	167 ± 12	56.1 ± 13.6
3 (Chapter 6)	24	14.9 ± 2.2	1.1 ± 2.1	94 ± 6	171 ± 11	57.7 ± 14

* Participant characteristics at the start of data collection (beginning of 2018/19 season).

3.3 Anthropometric assessments

3.3.1 Stature, sitting height and body mass

Participants removed jewellery and wore only underwear for assessments of stature, sitting height and body mass. Participant's body mass (SECA, model-875, Hamburg, Germany), stature and sitting height (SECA, model-217, Hamburg, Germany) were measured to the nearest 0.1 kg, 0.1 cm and 0.1 cm respectively, according to the International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Marfell-Jones *et al.*, 2006) by an ISAK Level-1 practitioner (PhD candidate). Leg length was subsequently calculated by subtracting sitting height from stature. Two measurements were taken for each anthropometric measure, with a third taken if the first two measures differed by more than 2%. Where two measures were taken, the mean was recorded and if a third measure taken, the median was recorded.

3.3.2 Dual-energy X-ray absorptiometry

In studies 1 (Chapter 4) and 3 (Chapter 6), participants were assessed for measures of body composition via dual-energy X-ray absorptiometry (DXA). Each participant underwent a whole-body fan-beam DXA scan (Hologic QDR Series, Discovery A, Bedford, MA, USA) where the effective radiation dose was 0.01 mSv per person, which is considered a safe and ethical radiation dose (COMARE, 2019). On the morning of each set of scans, calibration was initially carried out using an anthropometric spine and step phantom with a subsequent radiographic uniformity scan following the manufacturer's guidelines.

Players presented for their DXA scan (and RMR assessment) under standardised conditions: ≥8 hours overnight fast and ≥12 hours after exercise (Bone and Burke, 2018), between 07:00–11:00. Following assessments of stature, sitting height and body mass, players were positioned in a supine position within the scanning area on the DXA scanner. Arms were positioned along the side of the body, with the palmar surface of each hand facing towards each leg respectively. Custom made foam positioning aids were used to ensure standardised positioning between the arms and the body. Legs were subsequently positioned and feet were taped in a dorsiflexed position. Players were instructed to remain in the exact position for the entire duration of the whole-body scan (~180 seconds).

All scans were performed and analysed by the same trained operator (PhD candidate) in accordance with best practice procedures (Nana *et al.*, 2016). After conformation of regions of interest (left and right arms and legs and the trunk), each DXA scan was automatically analysed via the QDR software (version 12.4.3). Data included for analysis included whole-body and regional fat-free mass (kg), fat mass (kg) and whole-body percent body fat (%). These measures were reported as a sub-total, i.e. whole-body minus the head.

3.4 Resting metabolic rate assessments

In studies 1 (Chapter 4) and 3 (Chapter 6), following all anthropometric measures, RMR was measured via open-circuit indirect calorimetry (GEM Nutrition Ltd, UK) using the recent protocol outlined by Bone and Burke (Bone and Burke, 2018). Players presented for their (DXA scan and) RMR assessment under standardised conditions: ≥8 hours overnight fast (no food, alcohol or caffeine consumption) and ≥12 hours after exercise (Compher *et al.*, 2006; Bone and Burke, 2018), according to best practice conditions (Compher *et al.*, 2006). 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 (Figure 6). 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 and steady state conditions were accepted if the CV for $\dot{V}O_2$ and $\dot{V}CO_2$ was <10% (Compher *et al.*, 2006). $\dot{V}O_2$, $\dot{V}CO_2$ and RQ were determined using the Haldane transformation (Haldane, 1918) and energy expenditure (kcal·day^{-1}) calculated using the modified Weir equation (Weir, 1949): *Energy expenditure* $(kcal \cdot day^{-1}) = [(\dot{V}O_2 \times 3.941) + (\dot{V}CO_2 \times 1.11)] \times 1440$.

Figure 6. A soccer player from a Category One English Premier League academy undergoing a resting metabolic rate assessment using the ventilated hood metabolic cart.

To determine reliability of the open-circuit indirect calorimeter (GEM Nutrition Ltd, UK) test re-test RMR assessments were performed on two consecutive days on eight participants (Table 8). An independent t-test determined that there was no significant difference between the first and second RMR assessment ($P=0.66$; 95% CI = -59 to 40 $kcal \cdot day^{-1}$). The CV between assessments was 2% (range: 0 - 4%) which is within the typical range for RMR assessments measured using the ventilated hood (Donahoo, Levine and Melanson, 2004).

Table 8. Individual data from the test re-test RMR assessments.

Participant no.	**1st RMR ($kcal·day^{-1}$)**	**2nd RMR ($kcal·day^{-1}$)**	**Difference ($kcal·day^{-1}$)**	**Difference (%)**
1	1908	1969	61	3
2	1851	1813	-38	-2
3	2086	2012	-74	-4
4	2001	2013	12	1
5	1789	1815	26	1
6	1960	1998	38	2
7	1836	1788	-48	-3
8	1883	1982	99	5

3.5 Calculation of maturity offset and percent of predicted adult stature

In all 3 studies (Chapters 4, 5 and 6), somatic maturity (timing) was determined for each participant by calculating maturity offset (Mirwald *et al.*, 2002). This equation estimates the time in years from PHV is accurate to ± 0.24 years (Mirwald *et al.*, 2002). A maturity offset value was calculated for all players in the U12-U16 age-groups as this is typically the timeframe in which PHV occurs in youth soccer players (Towlson *et al.*, 2017) and also the age-range in which the equation was developed (Mirwald *et al.*, 2002).

Maturity offset calculation = -9.236 + (0.0002708 × leg length and sitting height interaction) + (-0.001663 × age and leg length interaction) + (0.007216 × age and sitting height interaction) + (0.02292 × weight by height ratio)

A worked example:

$$-9.236 + (0.0002708 \times 6606) + (-0.001663 \times 990) + (0.007216 \times 1077) + (0.02292 \times 28)$$

$$= -0.7 \text{ years [maturity offset]}$$

In the U12-U18 age-groups predicted adult stature (PAS) was calculated using the Sherar equation which is accurate to ± 5.35 cm (Sherar *et al.*, 2005). A worked example:

162.7 cm [current stature] + 22.99 [stature left to grow] = 185.7 cm [predicted adult stature]

Current percent of PAS (maturity status) was then calculated using the following equation: *(current stature ÷ predicted adult stature) × 100*.

A worked example:

(162.7 cm ÷ 185.7 cm) × 100 = 87.6 % of predicted adult stature

3.6 Quantification of training and match load

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 at 10 Hz providing information on positioning and time, thus velocity and distance. These devices have been shown to provide valid and reliable estimates of distance and velocity (<2% typical error of measurement) when compared to criterion measures during a range of typical team sport movement activities (Beato *et al.*, 2018; Thornton *et al.*, 2019). These types of GPS devices have also been shown to provide both valid and reliable estimates of immediate (e.g. quick accelerations) and continuous (e.g. linear running) movements during linear and multidirectional soccer-specific movements (Coutts and Duffield, 2010; Varley, Fairweather and Aughey, 2012). 10 Hz GPS devices are also considered the most accurate and reliable (when compared with 1, 5 and 15 Hz devices) in quantifying locomotion at higher speed thresholds during team sport movements (Johnston *et al.*, 2014; Rampinini *et al.*, 2014). 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 (as per the manufacturer's instructions) to obtain a sufficient satellite signal (i.e. at least four different satellites) and to synchronise the GPS clock with the atomic clock in the satellites (Larsson, 2003). Whilst inter-unit reliability for most GPS derived metrics from the same manufacturer (including TD and different speed thresholds) is considered good (CV: 0.2-1.5 %; Thornton *et al.*, 2019), players wore the same unit for all sessions (Malone *et al.*, 2017) unless there was a hardware failure with their unit in which case they were provided with a new unit. 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 organised drill or end of match play, on the manufacture's software (Apex 10 Hz version 2.0.2.4, STATSports, Newry, Northern Ireland). 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 (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016).

3.7 Statistical analyses

Statistical analyses for Study 1 (Chapter 4) were completed using SPSS (version 24, SPSS, Chicago, IL) and statistical analyses for studies 2 (Chapter 5) and 3 (Chapter 6) were completed using SPSS (version 26, SPSS, Chicago, IL). All data were initially assessed for normality of distribution using to the Shapiro–Wilk's test. Normally distributed data are presented as mean ± SD whereas non-normally distributed data are presented as median ± interquartile range. In Studies 1 (Chapter 4), 2 (Chapter 5) and 3 (Chapter 6), statistical comparisons between age-groups were performed using a one-way between-groups analysis of variance (ANOVA). Where significant main effects were present, Bonferroni post-hoc analysis was conducted to locate specific differences (level of significance [α] set at $P<0.05$). Ninety-five % confidence intervals (95% CI) for the differences are also presented.

Chapter 4

Cross-sectional comparison of body composition and resting metabolic rate in English Premier League academy soccer players: implications for growth and maturation

The aims of this Chapter were to assess body composition and RMR in a cohort of Category One English Premier League academy soccer players; to compare measured RMR with estimated RMR according to previously published prediction equations, and to develop a novel prediction equation that is specific to English Premier League academy soccer players.

Daniel Carney, Stephen Floyd & Lloyd Parker assisted with data collection for this study. Carl Langan-Evans & Keith George assisted with statistical analysis for this study.

This study was published in the Journal of Sports Sciences in 2020.

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4.1 Abstract

Purpose: We aimed to: (1) assess FFM and RMR in EPL academy soccer players, (2) compare measured RMR to estimated RMR using previously published prediction equations, and (3) develop a novel population specific prediction equation.

Methods: In a cross-sectional design, ninety-nine males from an EPL academy (U12, n=13; U13, n=13; U14, n=13; U15, n=12; U16, n=9; U18, n=22; U23, n=17) underwent assessments of body composition (DXA) and RMR (indirect calorimetry). Measured RMR was compared to estimated RMR values from five different prediction equations. A novel RMR prediction equation was developed using stepwise multiple regression.

Results: FFM increased ($P<0.05$) between U12 (31.6 ± 4.2 kg) and U16 (56.3 ± 5.3 kg) after which no further increases occurred ($P > 0.05$). RMR in the U12s (1655 ± 195 $kcal \cdot day^{-1}$), U13s (1720 ± 205 $kcal \cdot day^{-1}$) and U14s (1846 ± 218 $kcal \cdot day^{-1}$) was significantly lower than the U15s (1957 ± 128 $kcal \cdot day^{-1}$), U16s (2042 ± 155 $kcal \cdot day^{-1}$), U18s (1875 ± 180 $kcal \cdot day^{-1}$) and U23s (1941 ± 197 $kcal \cdot day^{-1}$) squads ($P > 0.05$). FFM was the single best predictor of RMR ($r^2 = 0.43$; $P < 0.01$) and was subsequently included in the novel prediction equation: RMR ($kcal \cdot day^{-1}$) = 1315 + (11.1 x FFM in kg).

Conclusion: Both FFM and RMR increase from U12-U16 years old, thus highlighting the requirement to adjust daily energy intake to support growth and maturation. The novel prediction RMR equation developed may help to inform daily energy requirements.

4.2 Introduction

The function of soccer academies is to produce players who can progress to and represent the club's first team (Wrigley *et al.*, 2014). As a player transitions through the academy pathway to the first team and adulthood, they undergo distinct phases of growth and maturation (Buchheit and Mendez-Villanueva, 2013; Towlson *et al.*, 2017). From a physical perspective, this elicits significant changes in fat-free mass (FFM), which has associated implications for the development of strength and soccer specific explosive movements (Wrigley *et al.*, 2014). Indeed, whilst it has previously been observed that U18, U21 and first team players from an EPL team possess similar amounts of absolute fat mass (~8 kg), there is an approximate difference of ~7 kg in FFM between U18 and first team players (Milsom *et al.*, 2015). In relation to physical development, these data therefore suggest that fat mass is less affected by age and that it may be more appropriate to monitor changes in FFM in youth soccer players.

Despite such comparisons of U18, U21 and first team players, no research has yet quantified changes in FFM as players progress through the academy pathway and through key periods of growth and maturation, i.e. peak height velocity (PHV). An understanding of muscle growth and development (as quantified by dual-energy X-ray absorptiometry, DXA) is especially important as this will help practitioners tailor age-specific training and nutritional guidelines. Indeed, considering that FFM is the most metabolically active compartment (Müller *et al.*, 2013), progressive increases in FFM will also influence an individual's resting metabolic rate (RMR) and thus their energy requirements.

In this regard, an assessment of RMR (a major component of total energy expenditure; TEE) at least provides a platform to begin to develop age-specific energy requirements. Indeed, data from Indian youth soccer players demonstrates that RMR increases by ~400 kcal·day^{-1} from the (chronological) ages of 10 to 13 (Cherian *et al.*, 2018). However, no research to date has yet quantified RMR in EPL academy soccer players across the full age-range of a professional soccer academy, i.e. U12-U23. Whilst RMR can be assessed via indirect calorimetry, this method can be time consuming and requires specialist equipment, thus making it impractical in the applied environment. Consequently, an array of predictive equations have been developed to estimate RMR though such equations may be limited as they are derived from non-athletic populations (Cunningham, 1980; Henry, 2005) and may not take into account FFM (Schofield, Thorpe and Sims, 2019). The latter is especially important considering FFM is the most metabolically active tissue (Müller *et al.*, 2013), and it has also recently been suggested that athlete specific equations should include FFM (within the equation) when estimating RMR (Schofield, Thorpe and Sims, 2019). Thus, there is a definitive need to develop population specific predictive equations according to changes in stature, body mass and FFM (Herrmann *et al.*, 2017) and importantly, across the age-range that is representative of soccer academies.

With this in mind, the aims of this study were three-fold: (1) to assess changes in body composition (in particular FFM) and RMR in a cohort of youth soccer players from a Category One academy in the EPL; (2) to compare measured RMR with estimated RMR according to previously published prediction equations, and (3) to develop a novel prediction equation that is specific to EPL academy soccer players.

4.3 Methods

4.3.1 Participants

Ninety-nine (n=99; white = 82; black = 8; mixed race = 9) male soccer players from a Category One EPL soccer academy volunteered to participate the study, representing 87% of the club's academy players at the time of data collection. Participant characteristics are presented in Table 9.

4.3.2 Overview of study design

In a cross-sectional design, participants were assessed for measures of body composition and RMR, under standardised conditions: ≥8 hours overnight fast and ≥12 hours after exercise (Bone and Burke, 2018), between 07:00–11:00. All testing procedures were conducted over a four-week period at the end of the 2017/18 season.

4.3.3 Anthropometric measures

Players underwent assessments of stature, sitting height, body mass in accordance with the procedures outlined in section 3.3.1. Subsequently, all players underwent a whole-body DXA scan to determine body composition, in accordance with the procedures outlined in section 3.3.2.

4.3.4 Resting metabolic rate

Following all anthropometric measures, RMR was measured in accordance with the procedures outlined in section 3.4.

Table 9. A comparison of age, maturity offset, current percent of predicted adult stature (PAS), stature and body mass between youth soccer players (U12-U23 age-groups; n = 99) from a Category One English Premier League academy.

	U12	**U13**	**U14**	**U15**	**U16**	**U18**	**U23**
n	13	13	13	12	9	22	17
Age (years)*	12.3 ± 0.2 [bcdefg] (12.2 – 12.4)	13.2 ± 0.2 [acdefg] (13.1 – 13.4)	14.3 ± 0.3 [abdefg] (14.2 – 14.5)	15.3 ± 0.3 [abcefg] (15.2 – 15.5)	16.4 ± 0.2 [abcdfg] (16.2 – 16.5)	17.6 ± 0.7 [abcdeg] (17.3 – 17.9)	19.9 ± 1.5 [abcdef] (19.1 – 20.7)
Maturity offset (years)*	-1.2 ± 0.4 [bcdef] (-1.4 – -1.0)	-0.5 ± 0.5 [acdef] (-0.8 – -0.2)	0.8 ± 0.7 [abdef] (0.4 – 1.2)	1.7 ± 0.5 [abcef] (1.3 – 2.0)	3.0 ± 0.6 [abcdf] (2.5 – 3.4)	-	-
Current percent of PAS (%)*	86.0 ± 1.3 [bcdef] (85.2 – 86.8)	88.8 ± 2.3 [acdef] (87.4 – 90.2)	94.2 ± 2.8 [abdef] (92.4 – 95.9)	97.4 ± 1.2 [abcf] (96.7 – 98.2)	99.3 ± 0.5 [abc] (99.0 – 99.7)	99.7 ± 0.3 [abcd] (99.6 – 99.9)	-
Stature (cm)*	157 ± 4 [cdefg] (155 – 160)	163 ± 6 [cdefg] (159 – 167)	173 ± 8 [abefg] (168 – 177)	176 ± 7 [abfg] (172 – 180)	182 ± 6 [abc] (178 – 187)	183 ± 4 [abcd] (181 – 185)	186 ± 6 [abcd] (183 – 190)
Body Mass (kg)*	45.5 ± 5.9 [cdefg] (42.0 – 49.1)	47.4 ± 5.6 [defg] (44.0 – 50.8)	56.9 ± 10.0 [aefg] (50.9 – 62.9)	63.1 ± 7.1 [abfg] (58.6 – 67.6)	72.9 ± 7.9 [abc] (66.8 – 78.9)	73.2 ± 8.1 [abcd] (69.6 – 76.8)	80.3 ± 8.8 [abcd] (75.7 – 84.8)

* denotes significant main effect. [a] denotes significant difference from U12 age group, P<0.05. [b] denotes significant difference from U13 age group, P<0.05. [c] denotes significant difference from U14 age group, P<0.05. [d] denotes significant difference from U15 age group, P<0.05. [e] denotes significant difference from U16 age group, P<0.05. [f] denotes significant difference from U18 age group, P<0.05. [g] denotes significant difference from U23 age group, P<0.05. Numbers in parentheses represent the 95% confidence intervals.

Resting metabolic rate was also estimated for each player using five different prediction equations (as outlined in Table 10). These equations were selected as they were developed using a similar sample size to the present study (n range: 51 - 223) and adhered to at least one of the two pre-determined criteria: (1) they were developed using participants of a similar age-range to those in the present study and (2) they were developed using healthy, non-obese participants (athletic populations also included). The De Lorenzo (De Lorenzo *et al.*, 1999), Kim (Kim *et al.*, 2015) and Wong (Wong *et al.*, 2012) equations were developed using athletic populations with the Kim (Kim *et al.*, 2015) equation using recreational soccer players.

Table 10. An overview of the five selected prediction equations that were used to estimate resting metabolic rate.

Study	Prediction Equation (kcal·day^{-1})
Cunningham (1980)	(22 x fat-free mass [kg]) + 500
De Lorenzo *et al.* (1999)	-857 + (9 x body mass [kg]) + (11.7 x stature [cm])
Henry (2005)	(18.4 x body mass [kg]) + 581
Kim *et al.* (2015)	730.4 + (15 x fat-free mass [kg])
Wong *et al.* (2012)	669 + (13 x body mass [kg]) + 192

4.3.5 Calculation of maturity offset and percent of predicted adult stature

For players in the U12-U16 age-groups, somatic maturity timing was determined by calculating the maturity offset (Mirwald *et al.*, 2002) and in all players maturity status was determined using the Sherar equation (Sherar *et al.*, 2005), in accordance with the procedures outlined in section 3.5.

4.3.6 Statistical Analyses

Statistical comparisons between squads were performed using a one-way between-groups ANOVA. Where significant main effects were present, Bonferroni post-hoc analysis was conducted to locate specific differences. Ninety-five % confidence intervals (95% CI) for the differences are also presented.

The relationship between body size variable(s) (stature and FFM) and RMR were initially checked for linearity (with a zero intercept), to identify if there was a linear, proportional relationship (significant correlation and slope b = 1.0) between body size variable and RMR (Tanner, 1949). Statistical and graphical (Figure 9) exploration identified that a linear, proportional relationship did not exist. Subsequently allometric scaling procedures were investigated to describe the relationship between body size variable and RMR. Firstly, a power function ratio (y/x^b) for each body size variable had to be determined, from log-linear regression analysis. The slope of the log-linear regression line for each body size variable (stature = 0.825; FFM = 0.285) generated the b exponent for which each body size variable was scaled to. This allometric approach produces a size independent RMR value by correlating the power function ratio with the body size variable. If the influence of body size has been removed, then this correlation should not differ from zero.

Pearson's correlation analysis was performed to determine the strength of association between measured RMR and predicted RMR (for each prediction equation). Least squares regression analysis was performed to determine the validity of the five prediction equations, where each prediction equation was regressed against the measured RMR value separately. If the 95% prediction interval (95% PI) of the intercept of the regression line does not include zero it was deemed that fixed bias was present, and if the 95% PI of the slope of the regression line does not include one, proportional bias was deemed present. Random error was quantified using standard error of the estimate (SEE) from the regression line. To evaluate the accuracy of each prediction equation, the mean 95% PI was also calculated.

A novel population specific prediction equation was derived using stepwise multiple regression. Stature, % PAS, body mass and FFM were all entered as predictor variables. This analysis selects (one or more) significant predictor variables that produce the best model (i.e. equation), as described in detail by Field (2018). Data for the regression analysis conformed to the assumptions of non-zero variance, no multicollinearity, homoscedasticity, independent and normally distributed errors, independent data points and linearity (Field, 2018). Similar to the other prediction equations, this novel prediction equation was also analysed via least squares regression.

4.4 Results

Participant characteristics including age, maturity offset, percent of PAS, stature and body mass are presented in Table 9.

4.4.1 Fat-Free Mass

There was a main effect of playing squad on FFM ($P < 0.01$; Figure 7A). FFM of the U12's (31.6 ± 4.2 kg) was not different compared to the U13's (34.6 ± 4.7 kg; $P = 1.00$), though was lower than that of the U14's (43.2 ± 8.9 kg; 95% CI = -19.23 to -4.00; $P < 0.01$), U15's (49.3 ± 6.5 kg; 95% CI = -25.48 to -9.94; $P < 0.01$), U16's (56.3 ± 5.3 kg 95% CI = -33.14 to -16.31; $P < 0.01$), U18's (57.9 ± 6.6 kg; 95% CI = -32.58 to -19.00; $P < 0.01$) and U23's (62.6 ± 5.9 kg; 95% CI = -38.45 to -24.15; $P < 0.01$). FFM of the U13's was lower than that of the U14's (95% CI = -16.25 to -1.02; $P=0.01$), U15's (95% CI = -22.50 to -6.96; $P<0.01$), U16's (95%

CI = -30.17 to -13.33; P < 0.01), U18’s (95% CI = -29.60 to -16.02; P < 0.01) and U23’s (95% CI = -35.47 to -21.17; P < 0.01). There were no differences between the U14’s and U15’s (P = 0.34), although the U14’s had lower FFM than the U16’s (95% CI = -21.53 to -4.69; P < 0.01), U18’s (95% CI = -20.96 to -7.38; P < 0.01) and U23’s (95% CI = -26.83 to -12.53; P < 0.01). The U15’s and U16’s had similar FFM (P = 0.25), however FFM of the U15’s was lower than the U18’s (95% CI = -15.05 to -1.11; P = 0.01) and U23’s (95% CI = -20.91 to -6.27; P < 0.01). FFM of the U16’s and U18’s (P = 1.00) and U16’s and U23’s (P = 0.25) was similar, and there was no difference between the U18 and U23 players (P = 0.15).

4.4.2 Fat Mass

There was a main effect of playing squad on fat mass (P = 0.02; Figure 7B), with the U13’s (8.2 ± 2.2 kg) displaying less fat mass than the U23’s (11.1 ± 3.4 kg; 95% CI = -5.83 to -0.07; P = 0.04). There were no differences in fat mass between any other squads (P > 0.05 for all pairwise comparisons).

4.4.3 Percent Body Fat

There was a main effect of playing squad on percent body fat (P < 0.01; Figure 7C). Percent body fat of the U12’s (22.3 ± 5.7 %) was not different from the U13’s (18.7 ± 4.3 %; P = 0.23), however was higher than the U14’s (16.8 ± 4.3 %; 95% CI = 1.18 to 9.82; P < 0.01), U15’s (14.2 ± 2.2 %; 95% CI = 3.63 to 12.44; P < 0.01), U16’s (15.0 ± 2.4 %; 95% CI = 2.47 to 12.02; P < 0.01), U18’s (14.4 ± 2.1 %; 95% CI = 3.98 to 11.68; P < 0.01) and U23’s (14.3 ± 2.8 %; 95% CI = 3.90 to 12.02; P < 0.01). The U13’s percent body fat did not differ from the U14’s (P = 1.00) or the U16’s (P = 0.40), however was higher than the U15’s (95% CI = 0.04 to 8.85; P = 0.05), U18’s (95% CI = 0.39 to 8.09; P = 0.02) and U23’s (95% CI = 0.31 to 8.42;

P = 0.02). There were no differences in percent body fat between the U14, U15, U16, U18 and U23 playing squads (P > 0.05 for all pairwise comparisons).

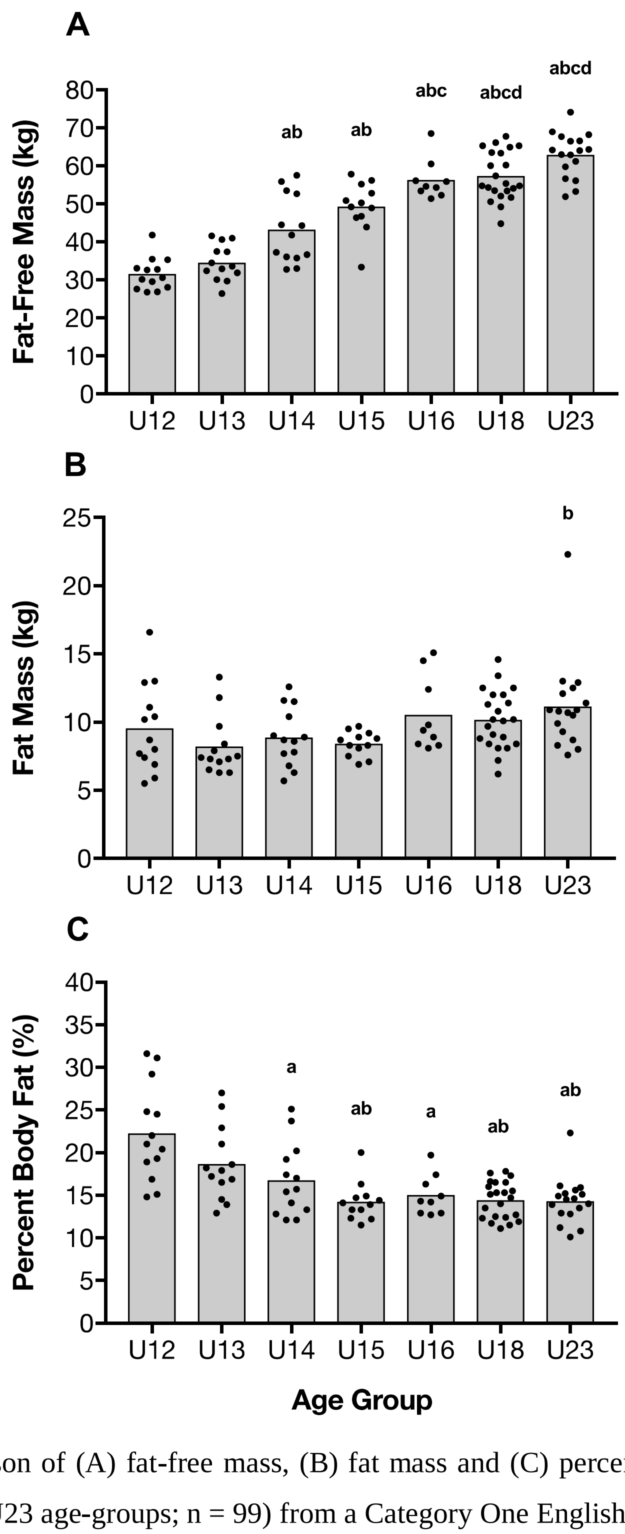

Figure 7. A comparison of (A) fat-free mass, (B) fat mass and (C) percent body fat between youth soccer players (U12-U23 age-groups; n = 99) from a Category One English Premier League academy. [a] denotes significant difference from U12 age-group, P<0.05. [b] denotes significant difference from U13 age-group, P<0.05. [c] denotes significant difference from U14 age-group, P<0.05. [d] denotes significant difference from U15 age-group, P<0.05. Black circles represent individual players.

4.4.4 Resting Metabolic Rate

There was a main effect of playing squad on RMR (P < 0.01; Figure 8). RMR of the U12's (1655 ± 195 kcal·day^{-1}) was similar to that of the U13's (1720 ± 205 kcal·day^{-1}; P = 1.00) and U14's (1846 ± 218 kcal·day^{-1}; P = 0.23), however was lower than the U15's (1957 ± 128 kcal·day^{-1}; 95% CI = -534.90 to -67.67; P < 0.01), U16's (2042 ± 155 kcal·day^{-1}; 95% CI = -639.90 to -133.78; P < 0.01), U18's (1875 ± 180 kcal·day^{-1}; 95% CI = -423.54 to -15.24; P = 0.02) and U23's (1941 ± 197 kcal·day^{-1}; 95% CI = -500.98 to -70.96; P < 0.01). The U13's RMR was not different to the U14's (P = 1.00), U18's (P = 0.42) or U23's (P = 0.04), however was lower than the U15's (95% CI = -470.21 to -2.97; P = 0.04) and U16's (95% CI = -575.20 to -69.09; P < 0.01). There were no differences in RMR between the U14, U15, U16, U18 and U23 playing squads (P > 0.05 for all pairwise comparisons).

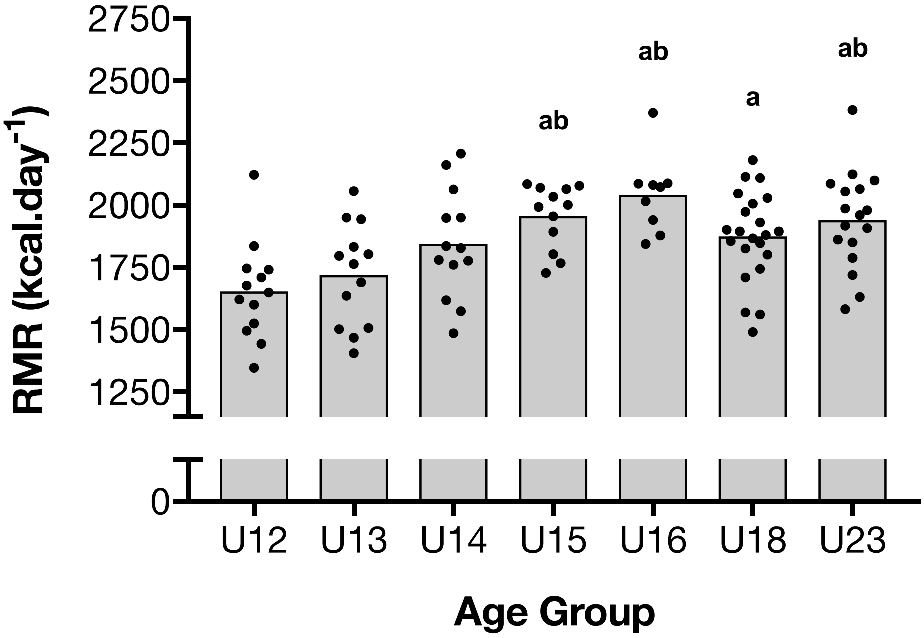

Figure 8. A comparison of resting metabolic rate (RMR) between youth soccer players (U12-U23 age-groups; n = 99) from a Category One English Premier League academy. [a] denotes significant difference from U12 age-group, P<0.05. [b] denotes significant difference from U13 age-group, P<0.05. Black circles represent individual players.

Once the influence of body size variable on RMR was removed, there was no significant relationship between stature ($r^2 < 0.01$, $p = 0.78$; Figure 9C) and RMR or between FFM ($r^2 < 0.01$, $p = 0.85$; Figure 9F) and RMR respectively.

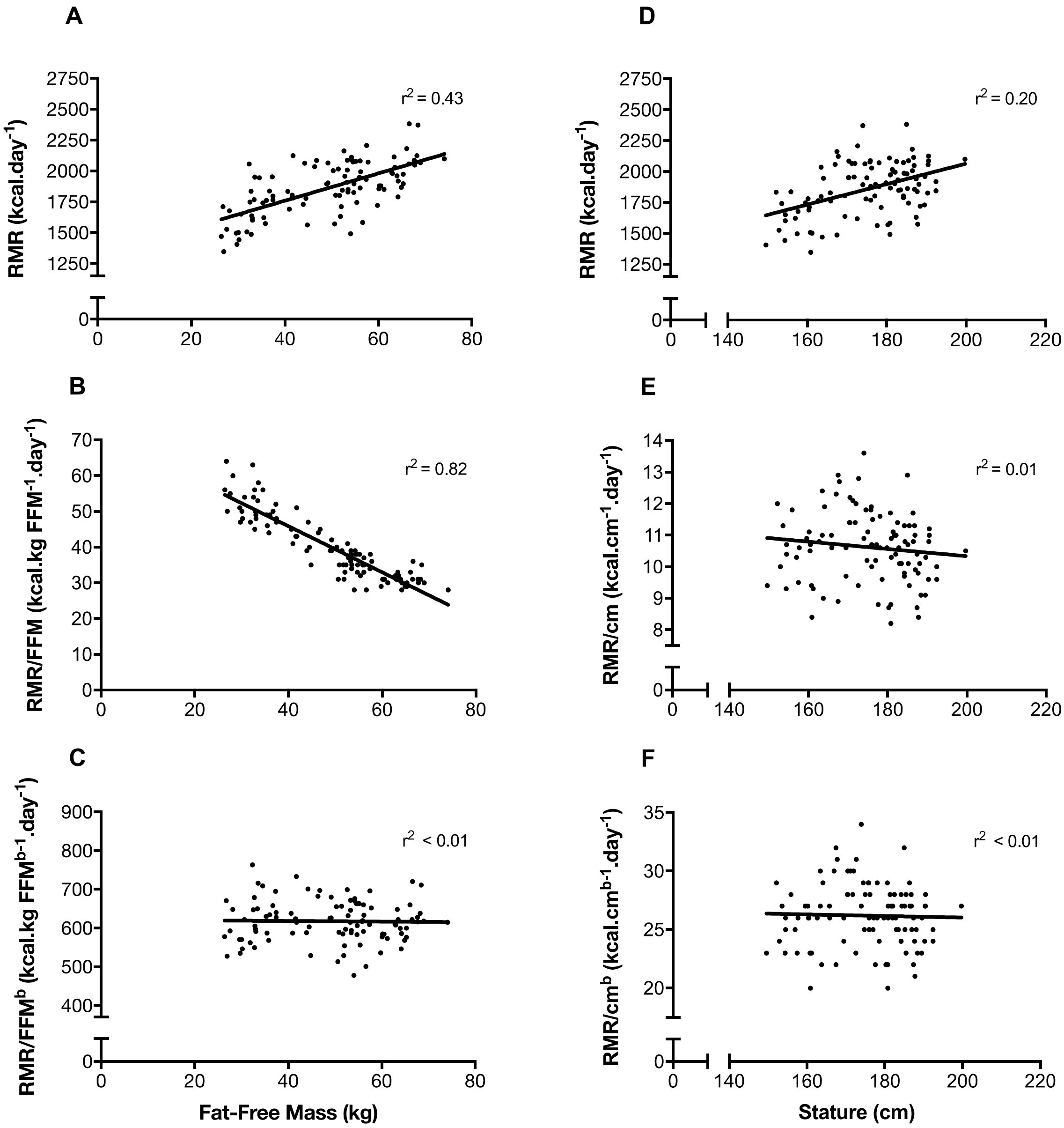

Figure 9. Relationships between: (A) resting metabolic rate (RMR) and fat-free mass (FFM), (B) RMR/FFM and FFM, (C) RMR/FFM^b ($b = 0.285$) and FFM, (D) RMR and stature, (E) RMR/stature and stature, and (F) RMR/stature^b ($b = 0.825$) and stature in youth soccer play from a Category One English Premier League academy (U12-U23 age-groups; n = 99). Black circles represent individual players. Figures 9C & 9F demonstrate that the influence of body size (i.e. fat-free mass and stature) has been removed as each correlation does not differ from zero.

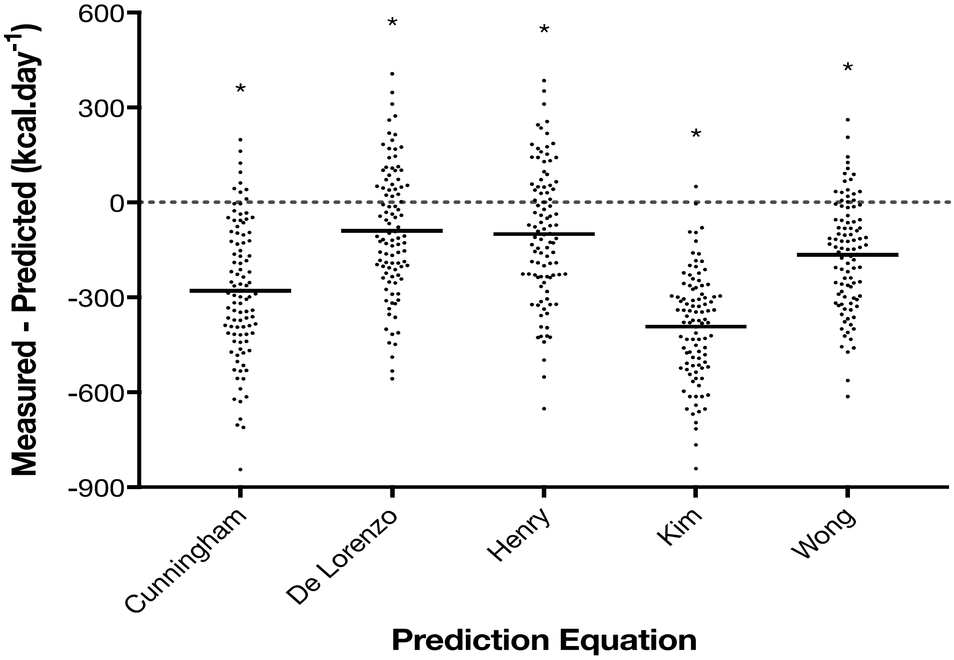

Figure 10. Difference between measured resting metabolic rate (RMR) and predicted RMR using five different prediction equations in youth soccer players (U12-U23 age-groups; n = 99) from a Category One English Premier League Academy. * denotes significant difference from measured RMR; P<0.01. Black circles represent individual players.

4.4.5 Measured RMR vs. Predicted RMR

Predicted RMR using the Cunningham (1578 kcal·day^{-1}; 95% CI = 237 to 323; P < 0.01), DeLorenzo (1769 kcal·day^{-1}; 95% CI = 49 to 130; P < 0.01), Henry (1758 kcal·day^{-1}; 95% CI = 58 to 142; P < 0.01), Kim (1466 kcal·day^{-1}; 95% CI = 359 to 427; P < 0.01) and Wong (1693 kcal·day^{-1}; 95% CI = 131 to 200; P < 0.01) equations all differed from measured RMR (see Figure 10). The random error (SEE) associated with each prediction equation was similar across all equations (163-165 kcal·day^{-1}), as was the 95% prediction interval for each prediction equation (327 - 330 kcal·day^{-1}; Table 11). The potential for any bias was assessed via visual inspection of the regression line (Figure 11). Apart from the novel prediction equation presented in the current study, all other prediction equations presented with both fixed and proportional bias, with the intercepts and slopes of all regression lines differing from zero and one respectively.

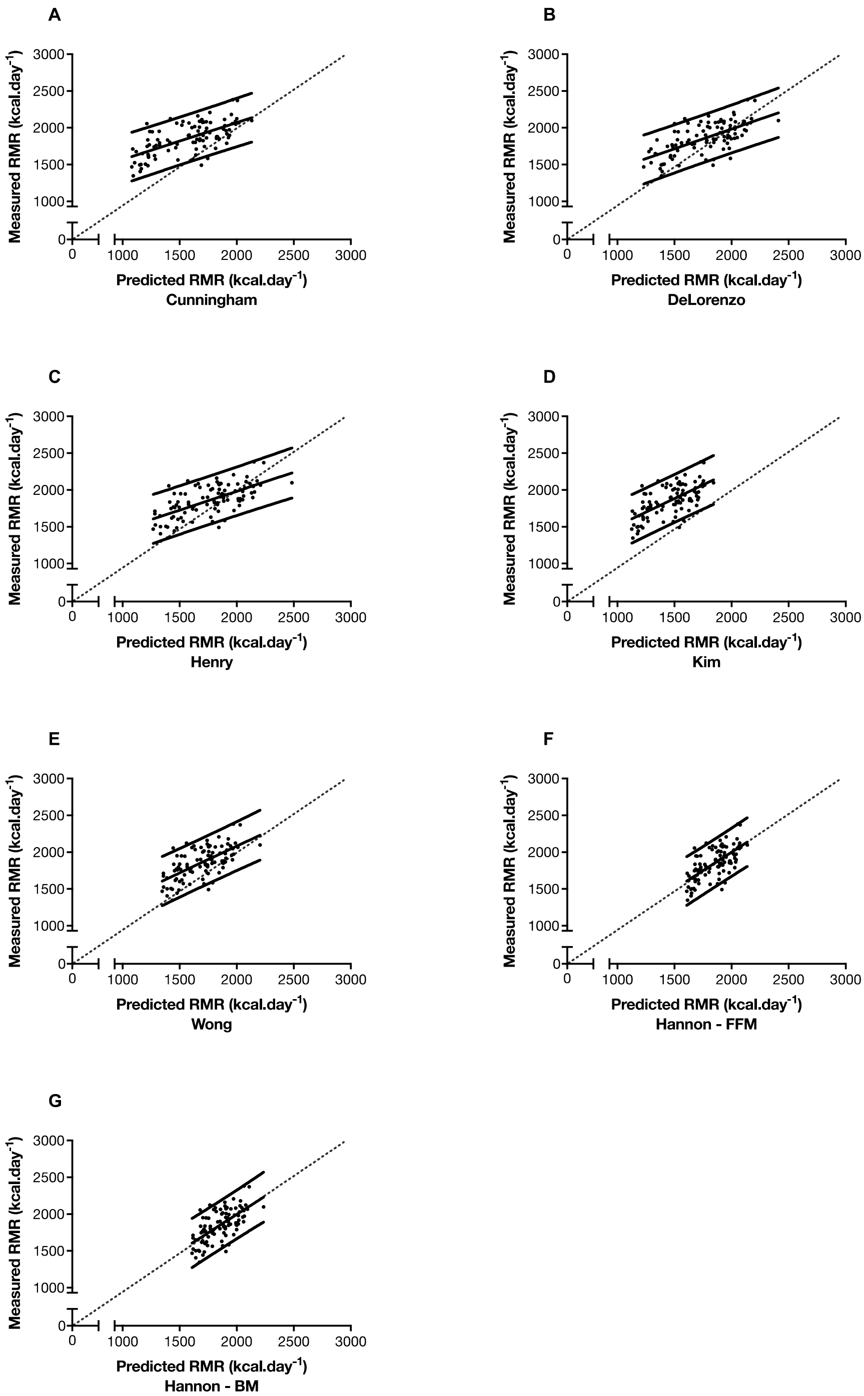

Figure 11. Least squares regression plots of measured resting metabolic rate (RMR) vs. predicted RMR in youth soccer players from a Category One English Premier League Academy (U12-U23 age-groups; n = 99). Comparison prediction equations: (A) Cunningham (1980); (B) De Lorenzo *et al.* (1999); (C) Henry (2005); (D) Kim *et al.* (2015); (E) Wong *et al.* (2012); (F) Hannon [fat-free mass, FFM prediction equation]; (G) Hannon [body mass, BM prediction equation]. Plots indicate line of unity (dashed line), line of regression and 95% prediction intervals (solid lines). Black circles represent individual players.

Table 11. Least Squares regression analysis (r) of the slopes, intercepts, standard error of estimate (SEE) and the mean of the 95 % prediction interval (95% PI) of measured resting metabolic rate (RMR) vs. predicted RMR in youth soccer players from a Category One English Premier League Academy (U12-U23 age-groups; n = 99).

Method	Mean ± SD	Slope	Intercept	SEE	*r*	Mean 95% PI
Measured	1858 ± 215	-	-	-	-	-
Cunningham (1980)	1578 ± 281	0.50 (0.39 - 0.62)	1063 (876 - 1250)	163	0.66 * (0.53 - 0.76)	327 (654)
De Lorenzo *et al.* (1999)	1769 ± 263	0.54 (0.41 - 0.66)	906 (683 - 1129)	163	0.66 * (0.53 - 0.76)	327 (654)
Henry (2005)	1758 ± 272	0.51 (0.39 - 0.64)	955 (739 - 1171)	165	0.65 * (0.52 - 0.75)	330 (660)
Kim *et al.* (2015)	1466 ± 191	0.74 (0.57 - 0.91)	776 (523 - 1028)	163	0.66 * (0.53 - 0.76)	327 (654)
Wong *et al.* (2012)	1693 ± 193	0.73 (0.56 - 0.90)	627 (335 - 920)	165	0.65 * (0.52 - 0.75)	330 (660)
Hannon [FFM equation]	1859 ± 142	1.00 (0.77 - 1.23)	2 (-429 - 433)	163	0.66 * (0.53 - 0.76)	327 (654)
Hannon [BM equation]	1859 ± 140	1.00 (0.76 - 1.23)	6 (-433 - 445)	165	0.65 * (0.52 - 0.75)	330 (660)

FFM: fat-free mass. BM: body mass. *significant correlation with measured resting metabolic rate ($P<0.05$). *PI ranges may be calculated by multiplying the 95% PI interval by 2 (ranges are in parentheses).*

Stepwise multiple regression revealed that stature ($r^2 = 0.41$), % PAS ($r^2 = 0.34$), body mass ($r^2 = 0.42$) and FFM ($r^2 = 0.43$) were all significant predictors of RMR ($P < 0.01$). However, FFM was the single best predictor of RMR (accounting for 43% of the variation in RMR) and was the only predictor variable included in the novel prediction equation, with all other variables rejected as they did not significantly improve the fit of the model:

RMR (kcal·day^{-1}) = 1315 + (11.1 x FFM in kg)

Given the potential difficulties of obtaining FFM (via DXA) and the simplicity of obtaining stature and body mass, a second prediction equation was derived (also using stepwise multiple regression) with only body mass and stature entered as predictor variables. In this second equation, body mass was the only predictor variable included, with stature being rejected:

RMR (kcal·day^{-1}) = 1254 + (9.5 x body mass in kg)

4.5 Discussion

The aims of this study were three-fold: (1) to assess changes in body composition (in particular FFM) and RMR in a cohort of youth soccer players from a Category One academy in the EPL; (2) to compare measured RMR with estimated RMR according to previously published prediction equations, and (3) to develop a novel prediction equation that is specific to EPL academy soccer players. Using a cross-sectional design, this study reports for the first time the changes in both FFM and RMR (as assessed by DXA and indirect calorimetry) between different age groups of EPL academy soccer players. Importantly, data demonstrate that the largest differences in FFM and RMR typically occur between U12-U16, highlighting this as a key period for growth and maturation. Additionally, these data also demonstrate that common prediction equations significantly underestimate RMR (in some cases as much as -844 kcal·day^{-1}) and that FFM is the single best predictor of RMR in this population. Subsequently, two novel prediction equations are presented that account for the FFM (and body mass), are cost and time effective and are specific to academy soccer players (U12-U23). From a practical perspective it is hoped that these data will help formulate age-specific estimates of RMR which may assist towards calculations of energy prescription.

Similar to previous observations on the transition from U18 to first team (Milsom *et al.*, 2015), these data also demonstrate little change in fat mass between the U12-U23 age groups. However, there was marked differences in FFM between the U12-U16 squads (Figure 7A), with each year of development associated with a different magnitude of increase in FFM (U12-U13: ~3.0 kg; U13-U14: ~8.6 kg; U14-U15: ~6.1 kg; U15-U16: ~7.0 kg). The largest increase in FFM occurred during the transition from U13-U14, which also coincided with the largest increases in stature and body mass (Table 9). This is also the time-frame during which most players went through PHV (Table 9), the period of most rapid growth during the adolescent years (Malina *et al.*, 2015). Whilst mean differences in FFM between the U16, U18 and U23 squads may not be statistically different, it is important to consider individual differences. For example, examination of Figure 7 clearly demonstrates the within and between squad differences in such parameters of body composition. Considering the focus of an academy is to develop their player's characteristics towards those of their first team, these data clearly demonstrate the necessity to adopt an individualised approach to player development.

In accordance with changes in stature, body mass and FFM, an increase in RMR between the U12-U14 age groups (U12: 1655 ± 195 kcal·day^{-1}; U13 1720 ± 205 kcal·day^{-1}; U14: 1846 ± 218 kcal·day^{-1}) was also observed, thus highlighting the requirement to adjust total energy intake accordingly. Such data correspond with data from Indian soccer players where an increase in RMR of ~400 kcal·day^{-1} from the ages of 10 to 13 (Cherian *et al.*, 2018) was also observed. It is noteworthy, however, that the RMR values in the present study are higher than those previously reported in youth soccer players. For example, the RMR values of the U13 players (1720 ± 205 kcal·day^{-1}) were higher than those of Indian soccer payers of a similar age (1118 ± 265 kcal·day^{-1}), despite players in the present study being smaller in stature and having less body mass and FFM (Cherian *et al.*, 2018). Similarly, the U16 players studied here had higher RMR than age-matched Korean soccer players (2042 ± 155 vs. 1,648 ± 111 kcal·day^{-1}), though players in the present study were comparatively taller, heavier and had more FFM (Kim *et al.*, 2015). Such differences may be due to ethnicity (Henry, 2005) or methodological differences between studies, e.g. different rest periods prior to RMR measurements.

Once the influence of both stature and FFM were removed via allometric scaling (Figure 9), there was no significant relationship between either of these body size variables and RMR, i.e. when considering per cm of stature or per kg of FFM, RMR was the same across all age groups. These data contradict that of Harrell and colleagues (Harrell *et al.*, 2005), who suggested that relative RMR is greater in children and adolescents than adults. However, these researchers used standard ratio scaling which is deemed inappropriate (Weinsier, Schutz and Bracco, 1992) due to the contribution of body size variable (i.e. stature or FFM) to RMR not being constant.

The prediction equations evaluated in this study provide inaccurate estimations of RMR in EPL academy soccer players (Figures 10 & 11). As an extreme example, estimated RMR using the Kim equation (Kim *et al.*, 2015) underestimated RMR by ~850 kcal·day^{-1} in one individual, despite this equation being developed in a population most similar to those in the present study (16-year-old recreational soccer players). Whilst such differences may be due to population specific factors (e.g. ethnicity, elite athletes vs. non-elite), methodological differences in assessment of predictor variables may also contribute. For example, although the Cunningham and the Kim equations both include FFM as a predictor variable, different methods were used to assess FFM. Indeed, FFM was estimated by Cunningham (Cunningham, 1980) using an equation that included body mass and age, whereas Kim and colleagues estimated FFM using bioelectrical impedance (Kim *et al.*, 2015). Thus, practitioners wishing to use prediction equations to estimate RMR should carefully consider not only the population in which the equation was developed, but also the precise methodologies used to determine the predictor variable(s). The use of inappropriate prediction equations could be potentially harmful to a player (or any athlete) if used to prescribe energy requirements, given the consequences of chronic low energy availability (Mountjoy *et al.*, 2018). In this regard, the development of the novel prediction equation(s) presented here holds ecological validity owing to the assessment of FFM (using DXA) as well as the assessment of RMR during a training phase that is representative of the typical training and match loads undertaken by academy soccer players. In situations where assessment of FFM is not possible, an alternative equation with only body mass required as a predictor variable has been generated.

The novel and population specific prediction equation presented here subsequently allows practitioners to estimate RMR in conditions where direct measurement (via indirect calorimetry) is not possible. Further studies are now required in other cohorts of youth soccer players (perhaps in different ethnicities) to validate this equation. We also acknowledge that no information on training load or TEE is provided, both of which likely increase with age (Smith *et al.*, 2018). Indeed, the assessment of the typical training and match loads completed by players throughout the academy pathway is another essential step that is required to optimise nutritional guidelines. Additionally, the cross-sectional design does not allow us to assess longitudinal changes during key phases of growth and maturation.

In summary, we provide novel data quantifying changes in FFM and RMR of youth soccer players from a Category One EPL academy. We demonstrate that the largest differences in FFM and RMR typically occur between U12-U16, suggesting this is a key period for physical development during which energy requirements are increased. Our analysis also demonstrates that commonly used prediction equations significantly underestimate RMR and that FFM is the single best predictor of RMR in this population. As such, our novel prediction equation (that accounts for FFM) may be used when estimating RMR in academy soccer players.

Chapter 5

Seasonal quantification of training and match load in English Premier League academy soccer players: implications for energy expenditure

Having assessed body composition and resting energy requirements in Study 1 (Chapter 4), the aim of this Chapter was to quantify the typical weekly training and match loading patterns in a cohort of Category One English Premier League academy soccer players at different stages of the academy pathway. In this way, this Chapter aimed to increase our understanding of the associated daily energy requirements of academy soccer players.

Nick Coleman assisted with data collection and analysis for this study.

5.1 Abstract

Purpose: The present study aimed to quantify the typical weekly training and match loading patterns of English Premier League (EPL) academy soccer players across the academy pathway.

Methods: Over the course of an entire competitive season, cumulative weekly training and match load was quantified using global positioning system technology in 76 soccer players from a Category One EPL academy (U12, n=15; U13, n=13; U14, n=12; U15, n=10; U16, n=11; U18, n=15 age-groups).

Results: Weekly training and match duration and total distance (i.e. volume), respectively, was similar in the U12 (329 ± 29 min; 19.9 ± 2.2 km), U13 (323 ± 29 min; 20.0 ± 2.0 km) and U14 (339 ± 25 min; 21.7 ± 2.0 km; P>0.05 for all comparisons) but was lower than the U15 (421 ± 15 min; 26.2 ± 2.1 km), U16 (427 ± 20 min; 25.9 ± 2.5 km) and U18 (398 ± 30 min; 26.1 ± 2.6 km) age-groups (P<0.05 for all comparisons). Weekly high-speed running and sprint distance (i.e. intensity), respectively, in the U12 (220 ± 95 m and 6 ± 9 m respectively), U13 (331 ± 212 m and 6 ± 27 m) and U14 (448 ± 193 m and 21 ± 29 m) age-groups was similar (P>0.05 for all pairwise comparisons), however was less than the U15 (657 ± 242 m and 49 ± 98 m), U16 (749 ± 152 m and 95 ± 55 m) and U18 (979 ± 254 m and 123 ± 56 m) age-groups (P<0.05 for all pairwise comparisons).

Conclusion: Both training and match volume and intensity in EPL academy soccer players is progressive in nature throughout the academy pathway. Additionally, although players in the older academy age-groups (i.e. U16-U18) are capable of achieving the training and match volumes experienced by adult EPL players, they do not yet achieve the typical absolute intensities of adult EPL players.

5.2 Introduction

Despite more than four decades of research examining the physical demands of soccer match play in adult players (Reilly and Thomas, 1979; Di Salvo *et al.*, 2009; Barnes *et al.*, 2014), detailed analysis of the customary training loads of elite players is comparatively limited (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016). Such data demonstrate that training loads are lower than those experienced in match play, as evidenced by parameters such as total distance (<7km vs. ~10-13km), high-speed running distance (<300m vs. >900m), sprint distance (<150m vs. >200m) and average speed (<80 $m \cdot min^{-1}$ vs. ~100-120 $m \cdot min^{-1}$) (Anderson, Orme, Di Michele, *et al.*, 2016). Absolute daily training loads depend on a multitude of factors such as: phase of the season (Malone *et al.*, 2015), player position (Malone *et al.*, 2015), coaching philosophy (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016), frequency of matches (Morgans *et al.*, 2014), player starting status (Anderson, Orme, Di Michele, *et al.*, 2016) and player-specific goals such as manipulation of body composition (Milsom *et al.*, 2015) or rehabilitation from injury (Anderson, Close, Konopinski, *et al.*, 2019).

In contrast to adult players, the habitual training load completed by academy soccer players is less well studied. Reports to date are limited to quantifying the accumulative training and match load (TML) over a period of one to two weeks (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015) and are often confined to internal measures such as heart rate and RPE (Wrigley *et al.*, 2012) or single training metrics such as session duration (Brownlee *et al.*, 2018). Given the use of GPS technology as a monitoring tool to quantify external loading in adult soccer players (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016), there is a definitive need to also quantify the absolute loading patterns completed by academy players so as to ascertain when players are physically capable of achieving similar volumes (i.e. total distances) and intensities (i.e. distances attained within specific absolute speed thresholds) that are associated with adult soccer. A detailed understanding of progressions in loading patterns (especially during periods of growth and maturation) is also important to reduce injury risk (Bowen *et al.*, 2017) and minimise time lost from training (Wrigley *et al.*, 2012; Bourdon *et al.*, 2017). Whilst previous reports have documented increases in both training and match volume and intensity between U14 and U18 age-groups (Wrigley *et al.*, 2012), it is noteworthy that such data were collected before the introduction of the Premier League's Elite Player Performance Plan (EPPP), the latter recommending ~12 hours of pitch-based training per week for an U12 player rising to ~16 hours per week for an U21 player. Although such recommendations are congruent with traditional long-term athletic development models (Balyi and Hamilton, 2004; Lloyd *et al.*, 2015), no data exists to corroborate whether EPL academies are adhering to such training models.

Research from adult players also demonstrates that daily training load is periodised across the weekly micro-cycle, largely as a reflection of fixture schedule and proximity to the next game (Anderson, Orme, Di Michele, *et al.*, 2016). The periodisation of daily loading also has implications for nutritional guidelines in that daily energy intake is adjusted in accordance with workload. Whilst it is tempting to adopt such principles to the academy soccer player, it is not yet clear whether daily energy intake should also be adjusted each day owing to the fact that the potential periodisation of loading across the weekly micro-cycle has not yet been studied in academy players. Moreover, given that academy players are still undergoing growth and maturation, it is possible that players should adopt a consistent daily energy intake so as to optimise growth and development even on lower intensity or non-training days. Clearly, a detailed understanding of academy players' habitual training loads is therefore an essential step in developing population specific nutritional guidelines.

With this in mind, the aims of the present study were: (1) to quantify accumulative weekly training and match load for each age-group during a "typical", "low" and "high" week, and (2) to determine the loading patterns within a typical weekly micro-cycle for each age-group.

5.3 Methods

5.3.1 Participants

One hundred and eleven (n=111) male outfield soccer players from a Category One EPL soccer academy initially volunteered to participate in the study. However, following the data filtering process (described in section 5.3.2) only 76 were included for final analysis. Players were categorised according to their respective age-group (U12, U13, U14, U15, U16 and U18) based upon their chronological age. Participant characteristics are presented in Table 12.

5.3.2 Overview of study design

Training and match data were collected throughout the 2018/19 season (pre-season and competitive season) from July 2018 until May 2019 at the club's training ground. Players underwent assessments of stature, sitting height and body mass in accordance with the procedures outlined in section 3.3.1 in July 2018 (start of season) and May 2019 (end of season). Additionally at these time-points, for players in the U12-U16 age-groups somatic maturity timing was determined by calculating the maturity offset (Mirwald *et al.*, 2002) and for all players maturity status was determined using the Sherar equation (Sherar *et al.*, 2005), in accordance with the procedures outlined in section 3.5.

Table 12. A comparison of youth soccer players (U12-U18 age-groups; n = 76) from a Category One English Premier League academy. Table shows data for each age-group at the start and end of the 2018/19 season and the change throughout the season for (chronological) age, maturity offset, current percent of predicted adult stature (PAS), stature and body mass.

Age-group	n	Time-point	Age (years)	Maturity offset (years)	Current percent of PAS (%)	Stature (cm)	Body Mass (kg)
U12	15	SS	11.7 ± 0.2	-2.1 ± 0.4	84 ± 2	152 ± 6	41.0 ± 7.7
		ES	12.3 ± 0.2	-1.4 ± 0.4	86 ± 2	156 ± 6	43.4 ± 7.5
		Δ	**0.7 ± 0.1**	**0.7 ± 0.1**	**2 ± 1**	**3 ± 1** [f]	**2.5 ± 1.4** [d]
U13	13	SS	12.6 ± 0.3	-0.9 ± 0.5	88 ± 3	161 ± 5	48.6 ± 6.8
		ES	13.3 ± 0.3	-0.2 ± 0.5	91 ± 3	166 ± 5	53.5 ± 5.1
		Δ	**0.7 ± 0.1**	**0.7 ± 0.1**	**2 ± 2** [f]	**5 ± 1** [ef]	**4.9 ± 3.1** [f]
U14	12	SS	13.7 ± 0.2	-0.3 ± 0.6	90 ± 2	164 ± 7	50.8 ± 6.0
		ES	14.4 ± 0.2	0.5 ± 0.6	93 ± 3	169 ± 8	54.8 ± 8.9
		Δ	**0.7 ± 0.1**	**0.7 ± 0.1**	**3 ± 1** [f]	**5 ± 2** [ef]	**4.0 ± 4.1**

U15	10	SS	14.5 ± 0.3	0.7 ± 0.5	94 ± 2	172 ± 8	58.4 ± 8.1
		ES	15.4 ± 0.3	1.5 ± 0.5	97 ± 2	177 ± 6	65.5 ± 7.2
		Δ	**0.8 ± 0.0**	**0.8 ± 0.0**	**3 ± 2** [ef]	**5 ± 2** [ef]	**7.1 ± 1.9** [af]
U16	11	SS	15.5 ± 0.2	1.7 ± 0.6	97 ± 1	176 ± 8	65.9 ± 8.5
		ES	16.3 ± 0.2	2.5 ± 0.6	99 ± 1	178 ± 8	69.7 ± 7.4
		Δ	**0.8 ± 0.0**	**0.8 ± 0.0**	**1 ± 1** [d]	**2 ± 2** [bcd]	**3.8 ± 3.5**
U18	15	SS	17.0 ± 0.4	-	100 ± 1	181 ± 5	73.3 ± 6.9
		ES	17.9 ± 0.5	-	100 ± 1	182 ± 5	74.4 ± 6.1
		Δ	**0.8 ± 0.0**	-	**1 ± 1** [bcd]	**1 ± 1** [abcd]	**1.1 ± 2.3** [bd]

SS = start of season. ES = end of season. Δ = delta i.e. changes throughout the season. [a] denotes significant difference from U12 age-group, P<0.05. [b] denotes significant difference from U13 age-group, P<0.05. [c] denotes significant difference from U14 age-group, P<0.05. [d] denotes significant difference from U15 age-group, P<0.05. [e] denotes significant difference from U16 age-group, P<0.05. [f] denotes significant difference from U18 age-group, P<0.05.

Only main squad sessions were considered for analysis; defined as a pitch-based training session or match that at least 50% of the respective age-group squad completed. Individual sessions such as additional training or rehabilitation were excluded from analysis. Goalkeepers were also excluded from analysis. In total, 14,556 individual sessions from 111 players were initially considered for analysis. Of these sessions, 217 (1.5%) had estimated data either due to malfunctioning GPS hardware or players forgetting to wear their GPS units, and consequently were excluded from analysis. To be included in the next stage of analysis, players must have completed at least 70% of the total number of sessions for their respective age-group for the season - leaving 77 players (69%) remaining. Completion of 60% of total sessions (90 players / 81%) was deemed too few and completion of 80% (59 players / 53%) excluded too many players.

The mean number of sessions per week per age-group was three for the U12's, U13's & U14's and four for the U15's, U16's and U18's. As such, to be considered a 'representative' week and to be included in the next stage of analysis, at least three sessions had to be completed by players in the U12, U13 and U14 age-groups and at least four in the U15, U16 and U18 age-groups. The final number of sessions included for analysis was 10,986. Session content was not influenced by the research team.

5.3.3 Quantification of session load

Pitch based training and match load was measured using global positioning system (GPS) technology (Apex, STATSports, Newry, Northern Ireland) in accordance with the procedures outlined in section 3.6. The external load variables selected for analysis were training and match duration (minutes), total distance covered (km), average speed ($m \cdot min^{-1}$; total distance covered divided by duration), high-speed running distance (meters; 19.8-25.2 $km \cdot h^{-1}$) and sprint distance (>25.5 km·h^{-1}) (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016). To ascertain when academy soccer players are capable of achieving the training and match intensities of adult EPL players, we deliberately selected absolute speed thresholds commonly used within the adult game (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016).

5.3.4 Data analysis

The number of weeks included in the final analysis was 28 ± 3, 28 ± 5, 28 ± 5, 26 ± 3, 23 ± 6 and 29 ± 3 weeks in the U12, U13, U14, U15, U16 and U18 age-groups, respectively. From these included weeks, to determine a "typical", "low" and "high" week the mean (mean of all included weeks), minimum (one single value from one week, i.e. the "lowest" week) and maximum (one single value from one week, i.e. the "highest" week) values for each TL variable were determined for each player respectively. To determine if any periodisation within the week occurred, mean values (for all included weeks) for each TL variable were determined for each player for each day of the week. Days were classified as number of days from match day (MD): MD-5, MD-4, MD-3, MD-2, MD-1 and MD (Malone *et al.*, 2015). Each age-group always had a rest day the day after a match (MD+1). Additionally, the U12, U13 and U14 age-groups had MD-1 off, and the U15, U16 and U18 age-groups had MD-3 off.

5.3.5 Statistical analysis

To determine differences in "typical", "low" and "high" weeks between age-groups, statistical comparisons for normally distributed data were assessed using a one-way between-groups analysis of variance (ANOVA). Where significant main effects were present, Bonferroni post-hoc analysis was conducted to locate specific differences (level of significance [α] set at $P<0.05$). For non-normally distributed data, statistical comparisons were assessed via the non-parametric, Kruskal-Wallis test. Where significant main effects were present, Mann-Whitney

U post-hoc analysis with a Bonferroni correction was conducted to locate specific differences (level of significance [α] set at $P<0.003$). To determine between-day differences within each age-group, statistical comparisons for normally distributed data were assessed using a one-way within-group ANOVA. If Mauchly's test of sphericity was violated (Greenhouse Geisser epsilon of <0.75), data were corrected using Greenhouse Geisser epsilon. Where significant main effects were present, Bonferroni post-hoc analysis was conducted to locate specific differences (level of significance [α] set at $P<0.05$). For non-normally distributed data, statistical comparisons were assessed via the non-parametric, Friedman's ANOVA. Where significant main effects were present, Wilcoxon signed-rank post-hoc analysis with a Bonferroni correction was conducted to locate specific differences (level of significance [α] set at $P<0.005$).

5.4 Results

5.4.1 Comparisons of 'typical' accumulative training and match loads between squads

Typical weekly training and match load for each metric per each age-group can be seen in Figure 12. Weekly duration and TD for a typical week in the U12 (329 ± 29 min; 19.9 ± 2.2 km), U13 (323 ± 29 min; 20.0 ± 2.0 km) and U14 (339 ± 25 min; 21.7 ± 2.0 km) age-groups was not different between squads ($P>0.05$ for all comparisons), though all three age-groups were lower than the U15 (421 ± 15 min; 26.2 ± 2.1 km), U16 (427 ± 20 min; 25.9 ± 2.5 km) and U18 (398 ± 30 min; 26.1 ± 2.6 km) age-groups ($P<0.01$ for all comparisons). No differences existed in either duration or TD between the U15 to U18 players ($P>0.05$ for all comparisons).

Weekly average speed in the U18 age-group (66 ± 6 $m \cdot min^{-1}$) was higher than the U12's (60 ± 3 $m \cdot min^{-1}$; $P=0.001$) and U16's (60 ± 5 $m \cdot min^{-1}$; $P=0.003$). There were no differences in average speed between any other age-group (U13 63 ± 2 $m \cdot min^{-1}$; U14 61 ± 11 $m \cdot min^{-1}$; U15 64 ± 6 $m \cdot min^{-1}$; P>0.05 for all comparisons).

Weekly HSR distance in the U12 (220 ± 95 m) and U13 (331 ± 212 m) age-groups was similar to the U14's (448 ± 193 m; P>0.05 for all comparisons), but less than the U15 (657 ± 242 m), U16 (749 ± 152 m) and U18 (979 ± 254 m) age-groups (P<0.01 for all comparisons). The U14's HSR distance was similar to the U15's (P=0.25), but less than the U16 (P<0.01; 95% CI = -553 to -49 m) and U18 (P<0.01; 95% CI = -762 to -301 m) age-groups. HSR distance in the U15 age-group was similar to the U16 (P=1.00) but less than the U18's (P<0.01; 95% CI = -565 to -79 m), with no differences in mean weekly HSR distance between the U16 and U18 age-groups (P=0.06).

Weekly sprint distance in the U12's (6 ± 9 m) was similar to the U13's (6 ± 27 m; P=0.279) and U14's (21 ± 29 m; P=0.009), but lower than the U15's (49 ± 98 m; P<0.001), U16's (95 ± 55 m; P<0.001) and U18's (123 ± 56 m; P<0.001). Sprint distance in the U13's was similar to the U14's (P=0.264) and U15's (P=0.014), but lower than the U16's (P<0.001) and U18's (P<0.001). Sprint distance in the U14's was similar to the U15's (P=0.093) but lower than the U16's (P=0.001) and U18's (P<0.001). Sprint distance was similar between the U15, U16 and U18 age-groups (P>0.003 for all pairwise comparisons).

5.4.2 Comparisons of 'low' accumulative training and match loads between squads

Low weekly training and match load for each metric per each age-group can be seen in Figure 12. Weekly duration and TD for a low week was similar in the U15 (269 ± 59 min; 15.8 ± 2.6 km), U16 (268 ± 60 min; 15.0 ± 2.6 km) and U18 (241 ± 41 min; 15.1 ± 2.8 km; P>0.003 for all pairwise comparisons) age-groups, and higher than the U12 (203 ± 78 min; 12.1 ± 2.8 km), U13 (140 ± 63 min; 11.2 ± 5.6 km) and U14 (177 ± 31 min; 10.8 ± 2.9 km; P<0.001 for all pairwise comparisons) age-groups. TD for a low week was similar between the U12, U13 and U14 age-groups (P>0.003 for all pairwise comparisons). Duration for a low week in the U13 age-group (140 ± 63 min) was lower than both the U12's (203 ± 78 min) and U14's (177 ± 31 min; P<0.001 for both pairwise comparisons), with no difference in duration between the U12 and U14 age-groups (P=0.118).

Median average speed for a low week was similar between the U12 (45 ± 7 m·min^{-1}), U13 (47 ± 5 m·min^{-1}), U14 (48 ± 11 m·min^{-1}), U15 (48 ± 3 m·min^{-1}), U16 (47 ± 6 m·min^{-1}) and U18 (49 ± 5 m·min^{-1}) age-groups (P=0.063).

Weekly HSR distance for a low week in the U12's (20 ± 30 m) was similar to the U13's (85 ± 83 m; P=0.088), but lower than the U14 (96 ± 83 m), U15 (129 ± 150 m), U16 (231 ± 104 m) and U18 (292 ± 86 m; P<0.001 for all pairwise comparisons) age-groups. HSR distance for a low week in the U13's was similar to the U14's (P=0.123), but lower than the U15's, U16's and U18's (P<0.001 for all pairwise comparisons). HSR distance for a low week in the U14's was similar to the U15's (P=0.107) but lower than the U16's (P<0.001) and U18's (P<0.001). HSR distance for a low week in the U15's was similar to the U16's (P=0.043) but lower than the U18 age-group (P=0.001). HSR distance for a low week in the U16 and U18 age-groups was similar (P=0.069).

Weekly sprint distance for a low week was similar in the U12 (0 ± 0 m), U13 (0 ± 0 m), U14 (0 ± 0 m;) and U15 (1 ± 5 m; P>0.003 for all pairwise comparisons) age-groups and lower than the U16 (6 ± 10 m) and U18 (21 ± 25 m) age-groups (P<0.001 for all pairwise comparisons). There was no difference in sprint distance for a low week between the U16 and U18 (P=0.077) age-groups.

5.4.3 Comparisons of 'high' accumulative training and match loads between squads

High weekly training and match load for each metric per each age-group can be seen in Figure 12. Weekly duration and TD for a high week was similar in the U15 (573 ± 61 min; 38.9 ± 4.6 km), U16 (575 ± 64 min; 37.3 ± 6.7 km) and U18 (658 ± 79 min; 40.5 ± 4.4 km; P>0.003 for all pairwise comparisons) age-groups. Duration and TD for a high week did not differ between the U12 (473 ± 72 min; 29.2 ± 3.0 km) and U13 (487 ± 60 min; 31.1 ± 3.8 km) age-groups ($P>0.05$ for all pairwise comparisons) but was lower than the U15, U16 and U18 age-groups ($P<0.02$ for all pairwise comparisons). Duration for a high week in the U14 (546 ± 60 min) age-group was similar to the U13, U15 and U16 age-groups ($P>0.01$ for all pairwise comparisons), was higher than the U12's ($P<0.001$) and lower than the U18's ($P=0.001$). TD for a high week in the U14 age-group (34.3 ± 4.3 km) was lower than the U18 age-group ($P<0.01$) but similar to all other age-groups ($P>0.05$ for all pairwise comparisons).

Average speed for a high week in the U16 age-group (70 ± 7 $m.min^{-1}$) was lower than the U12 (83 ± 11 $m.min^{-1}$), U13 (87 ± 18 $m.min^{-1}$) and U18 (83 ± 14 $m.min^{-1}$) age-groups ($P<0.001$ for all pairwise comparisons). Average speed for a high week was similar between the U12, U13, U14 (77 ± 20 $m.min^{-1}$), U15 (82 ± 13 $m.min^{-1}$) and U18 age-groups ($P>0.003$ for all pairwise comparisons).

Weekly HSR and sprint distance for a high week was similar between the U12 (552 ± 333 m; 51 ± 60 m), U13 (584 ± 378 m; 59 ± 97 m) and U14 (864 ± 492 m; 78 ± 105 m) age-groups ($P>0.001$ for all pairwise comparisons), respectively. HSR and sprint distance for a high week in the U12 and U13 age-groups was lower than the U15 (1140 ± 805 m; 160 ± 210 m), U16 (1484 ± 322 m; 359 ± 219 m) and U18 (2806 ± 835 m; 307 ± 73 m) age-groups ($P<0.003$ for all pairwise comparisons), respectively. HSR and sprint distance for a high week was similar in the U14 and U15 age-groups ($P>0.10$ for all pairwise comparisons), but lower than the U16 and U18 age-groups ($P<0.003$ for all pairwise comparisons), respectively. HSR distance for a high week was similar between the U15 and U16 age-groups ($P=0.132$), but less than the U18 age-group ($P<0.001$ for both pairwise comparisons). Sprint distance for a high week was similar between the U15, U16 and U18 age-groups ($P>0.003$ for all pairwise comparisons).

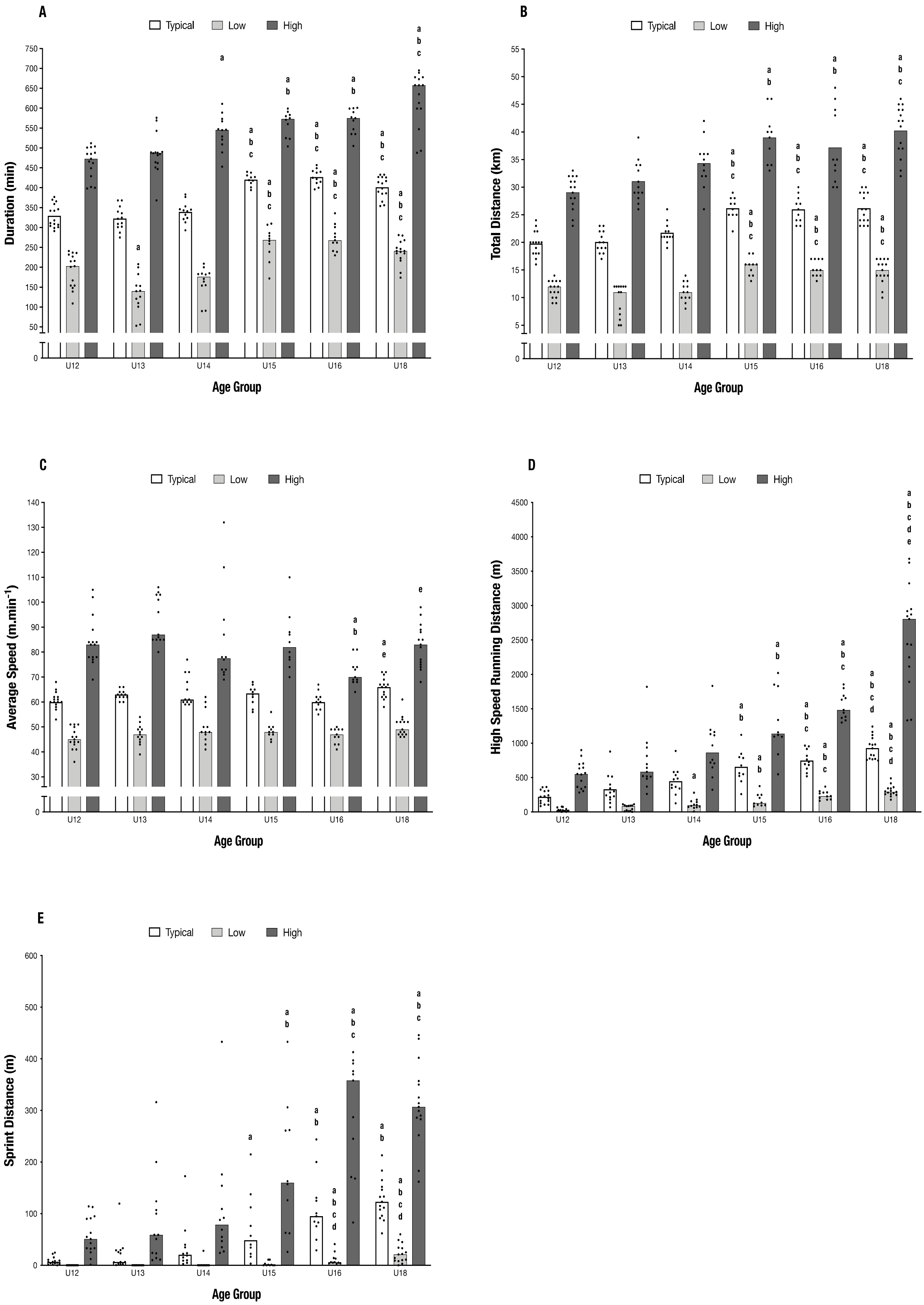
A
B
C
D
E
Typical
Low
High
Duration (min)
Total Distance (km)
Average Speed (m.min-1)
High Speed Running Distance (m)
Sprint Distance (m)
U12
U13
U14
U15
U16
U18
Age Group

Figure 12. Typical, low and high accumulative weekly loading patterns of youth soccer players (U12-U28 age-groups; n = 76) from a Category One English Premier League academy. Pitch-based training and match (A) duration, (B) total distance, (C) average speed, (D) high speed running distance and (E) sprint distance. [a] denotes significant difference from U12 age-group. [b] denotes significant difference from U13 age-group. [c] denotes significant difference from U14 age-group. [d] denotes significant difference from U15 age-group. [e] denotes significant difference from U16 age group. Black circles represent individual players.

5.4.2 Periodisation of weekly loading patterns within each age-group

5.4.2.1 Duration

Daily session duration for each age-group can be seen in Figure 13. Session duration did not differ between MD-5 (87 ± 26 min), MD-4 (85 ± 11 min), MD-3 (89 ± 11 min), MD-2 (91 ± 12 min) and MD (83 ± 5 min) for the U12 age-group (P=0.33).

Session duration on MD-4 (87 ± 11 min), MD-3 (88 ± 12 min), MD-2 (89 ± 9 min) and MD (84 ± 16 min) was similar (P>0.005 for all pairwise comparisons), but was less than MD-5 (101 ± 19 min; P<0.001 for all pairwise comparisons) in the U13 age-group.

Session duration on MD-5 (103 ± 27 min) was similar to MD (93 ± 29 min; P=0.088) but higher than MD-4 (87 ± 8 min), MD-3 (84 ± 7 min) and MD-2 (88 ± 3 min; P<0.005 for all pairwise comparisons) in the U14 age-group. Session duration was similar on MD-4, MD-3, MD-2 and MD (P>0.005 for all pairwise comparisons).

In the U15 age-group, session duration on MD-5 (96 ± 7 min) was similar to MD-4 (110 ± 17 min; P=0.024), MD-2 (90 ± 11 min; P=0.138) and MD (89 ± 23 min; P=0.116) but higher than MD-1 (87 ± 5 min; P=0.002). Session duration on MD-4 was similar to MD-2 (P=0.010) but higher than MD-1 (P=0.001) and MD (P=0.001). Median session duration on MD-2, MD-1 and MD was similar (P>0.005 for all pairwise comparisons).

In the U16 age-group, session duration on MD-5 (93 ± 3 min) was similar to MD-2 (91 ± 6 min; P=1.00), MD-1 (88 ± 7 min; P=0.49) and MD (104 ± 13 min; P=0.10), but less than

MD-4 (115 ± 9 min; P<0.01; 95% CI = -30 to -14 min). Session duration on MD-4 was longer than MD-2 (P<0.01; 95% CI = 13 to 35 min) and MD-1 (P<0.01; 95% CI = 15 to 39 min), but similar to MD (P=0.12). Session duration was similar on MD-2, MD-1 and MD (P>0.05 for all comparisons).

In the U18 age-group, session duration on MD-5 (90 ± 6 min) was similar to MD (99 ± 16 min; P=0.66), lower than MD-4 (116 ± 13 min; P<0.01; -35 to -16 min) and MD-2 (96 ± 7 min; P<0.01; -10 to -3 min) but higher than MD-1 (67 ± 4 min; P<0.01; 19 to 26 min). On MD-4, session duration was similar to MD (P=0.06) but higher than MD-2 (P<0.01; 11 to 28 min) and MD-1 (P<0.01; 39 to 57 min). Session duration on MD-2 was similar to MD (P=1.00) but higher than MD-1 (P<0.01; 25 to 33 min). Session duration on MD-1 was less than MD (P<0.01; -45 to -18 min).

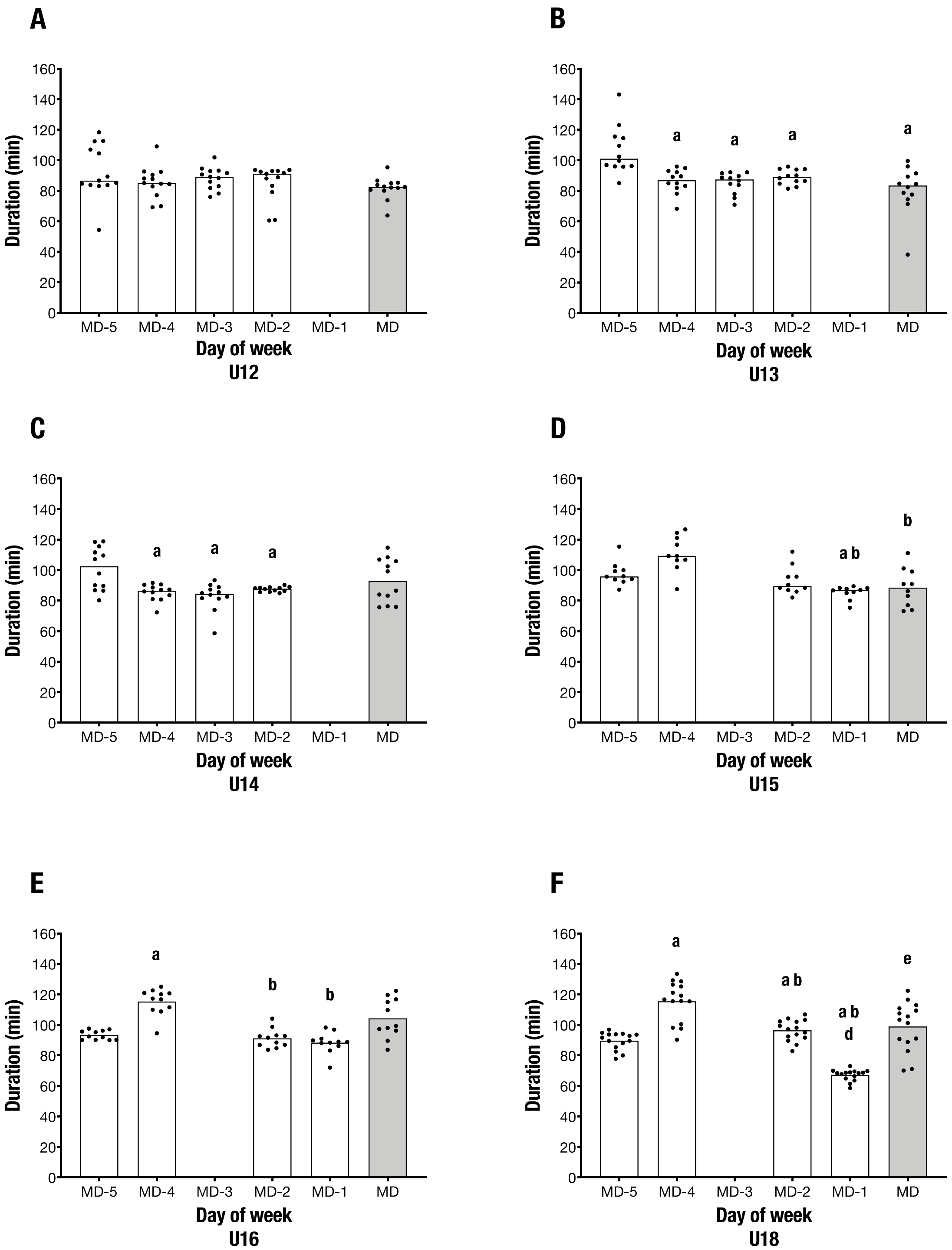

Figure 13. Daily training and match duration of the (A) U12, (B) U13, (C) U14, (D) U15, (E) U16 and (F) U18 age-groups from a Category One English Premier League soccer academy (n = 76). White bars represent training days, denoted as days away from match day (MD) i.e. MD-5 etc. Grey bars represent match day. No training was completed on days with no data bars. [a] denotes significant difference from MD-5. [b] denotes significant difference from MD-4. [c] denotes significant difference from MD-3. [d] denotes significant difference from MD-2. [e] denotes significant difference from MD-1. Black circles represent individual players.

5.4.2.2 Total Distance

Daily total distance for each age-group can be seen in Figure 14. TD on MD was higher than all training days (i.e. MD-5, MD-4, MD-3, MD-2 and MD-1) in the U12 (7.1 ± 1.5 m), U14 (8.6 ± 1.4 km), U15 (8.5 ± 1.4 km), U16 (9.5 ± 2.3 km) and U18 (9.0 ± 2.4 km) age-groups (P<0.05 for all pairwise comparisons). TD on MD-5 and MD-4 was similar in the U12 (4.8 ± 1.7 km; 5.3 ± 0.7 km), U13 (5.3 ± 2.3 km; 4.8 ± 0.8 km), U14 (5.3 ± 0.9 km; 5.2 ± 0.5 km) and U15 (5.2 ± 0.5 km; 6.0 ± 0.8 km) age-groups, respectively (P>0.01 for all pairwise comparisons).

In the U12 age-group, TD on MD-3 (4.4 ± 0.8 km) and MD-2 (4.1 ± 1.0 km) was similar to MD-5 (P>0.10 for all pairwise comparisons) but lower than MD-4 (P<0.003 for both pairwise comparisons).

In the U13 age-group, TD on MD (7.3 ± 1.7 km) was similar to MD-5 (5.3 ± 2.3 km; P=0.031), but higher than MD-4 (4.8 ± 0.8 km), MD-3 (7.3 ± 1.7 km) and MD-2 (4.2 ± 0.6 km; P<0.001 for all pairwise comparisons). TD on MD-3 and MD-2 was similar (P=0.515), but less than MD-5 (P<0.003 for both pairwise comparisons). TD on MD-2 was less than MD-4 (P=0.004).

In the U14 age-group, TD on MD-3 (4.3 ± 0.5 km) similar to MD-2 (4.8 ± 0.4 km; P=0.13) but less than MD-5 and MD-4 (P<0.05 for both pairwise comparisons).

In the U15 age-group, TD on MD-2 (5.2 ± 0.5 km) was similar to MD-5, MD-4 and MD-1 (4.6 ± 0.3 km; P>0.05 for all pairwise comparisons). TD on MD-1 was lower than MD-4 (P<0.01; 95% CI = 0.4 to 2.3 km).

In both the U16 and U18 age-groups, TD on MD-5 (4.9 ± 0.4 km; 5.0 ± 1.1 km) was similar to MD-2 (4.8 ± 0.6 km; 5.8 ± 0.7 km; P>0.05 for all pairwise comparisons), lower than MD-4 (6.2 ± 0.8 km; 6.6 ± 0.8 km; P<0.01 for all pairwise comparisons) and higher than MD-1 (4.5 ± 0.3 km; 3.8 ± 1.1 km; P<0.01 for all pairwise comparisons). TD on MD-4 was higher than both MD-2 and MD-1 (P<0.01 for all pairwise comparisons). TD on MD-2 was higher than MD-1 (P<0.01 for both pairwise comparisons).

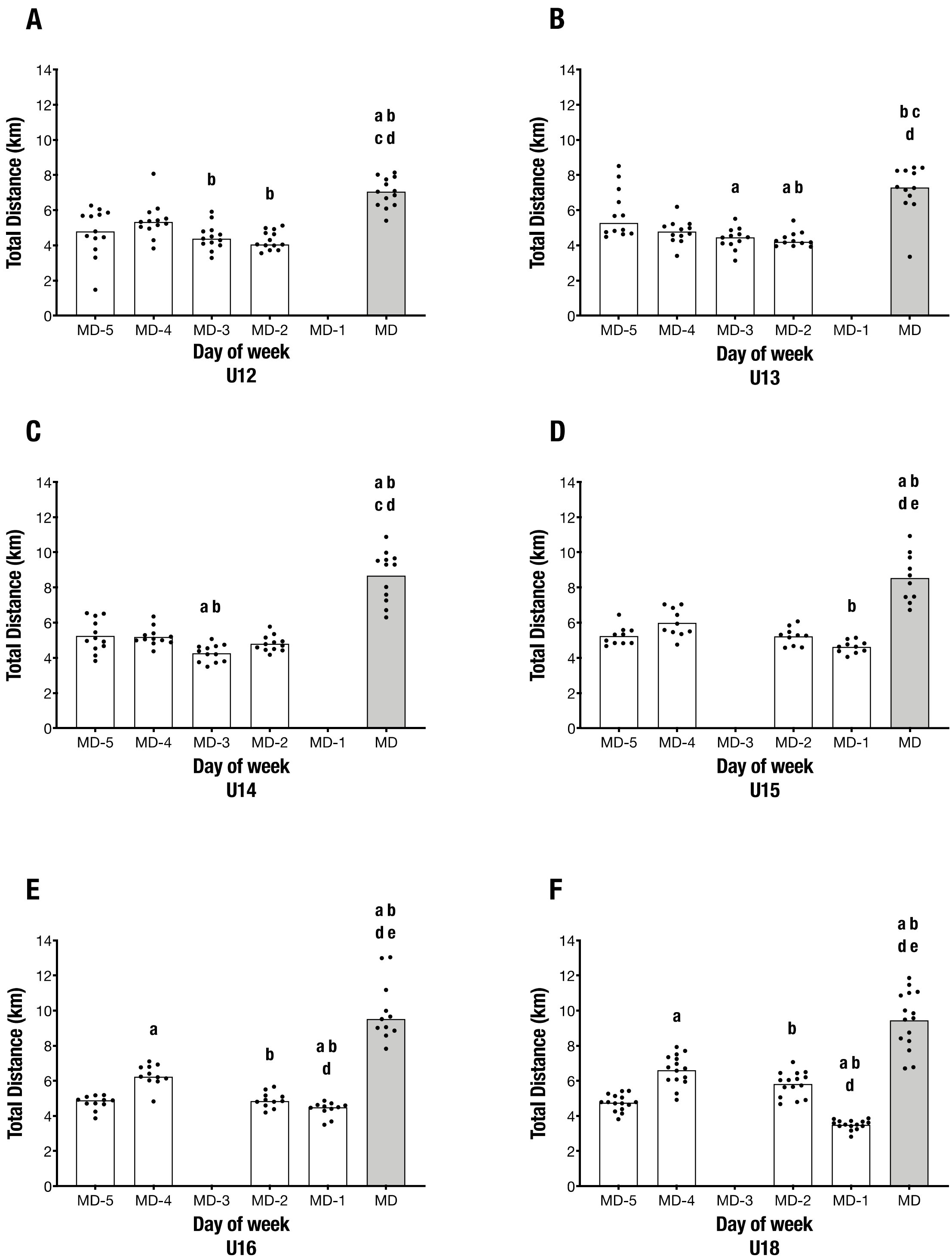

Figure 14. Daily training and match total distance of the (A) U12, (B) U13, (C) U14, (D) U15, (E) U16 and (F) U18 age-groups from a Category One English Premier League soccer academy (n = 76). White bars represent training days, denoted as days away from match day (MD) i.e. MD-5 etc. Grey bars represent match day. No training was completed on days with no data bars. [a] denotes significant difference from MD-5. [b] denotes significant difference from MD-4. [c] denotes significant difference from MD-3. [d] denotes significant difference from MD-2. [e] denotes significant difference from MD-1. Black circles represent individual players.

5.4.2.3 Average Speed

Daily average speed for each age-group can be seen in Figure 15. Average speed on MD was higher than all training days (i.e. MD-5, MD-4, MD-3, MD-2 and MD-1) in the U12 (86 ± 8 m.min^{-1}), U13 (89 ± 8 m.min^{-1}), U14 (90 ± 16 m.min^{-1}), U15 (96 ± 4 m), U16 (98 ± 12 m.min^{-1}) and U18 (96 ± 5 m.min^{-1}) age-groups (P<0.01 for all pairwise comparisons), respectively.

In both the U12 and U14 age-groups, average speed on MD-5 (51 ± 10 m.min^{-1}; 53 ± 9 m.min^{-1}) was slower than MD-4 (64 ± 7 m.min^{-1}; 60 ± 8 m.min^{-1}; P<0.05 for all pairwise comparisons), but similar to MD-3 (50 ± 7 m.min^{-1}; 52 ± 9 m.min^{-1}) and MD-2 (51 ± 8 m.min^{-1}; 56 ± 8 m.min^{-1}; P>0.01 for all pairwise comparisons). Average speed on MD-4 was higher than MD-3 and MD-2 (P<0.01 for all pairwise comparisons), with no difference in average speed between MD-3 and MD-2 (P>0.05 for both pairwise comparisons).

In the U13 age-group, average speed was similar on MD-5 (51 ± 10 m.min^{-1}), MD-4 (55 ± 6 m.min^{-1}) and MD-3 (50 ± 7 m.min^{-1}; P>0.005 for all pairwise comparisons). Average speed on MD-2 (49 ± 7 m.min^{-1}) was slower than MD-4 (P<0.001) but similar to MD-5 and MD-3 (P>0.005 for both pairwise comparisons).

Average speed on MD-5 (54 ± 4 m.min^{-1}), MD-4 (54 ± 6 m.min^{-1}), MD-2 (56 ± 3 m.min^{-1}) and MD-1 (54 ± 3 m.min^{-1}) was similar in the U15 age-group (P>0.05 for all comparisons).

In the U16 age-group, average speed was similar on MD-5 (52 ± 4 m.min^{-1}), MD-4 (56 ± 5 m.min^{-1}) and MD-2 (54 ± 7 m.min^{-1}; P>0.005 for all pairwise comparisons). Average speed on MD-1 (50 ± 5 m.min^{-1}) was similar to MD-5 and MD-2 (P>0.005 for both pairwise comparisons) but was slower than MD-4 (P<0.001).

In the U18 age-group, average speed on MD-5 (53 ± 3 m.min^{-1}) was slower than MD-4 (58 ± 4 m.min^{-1}; P<0.01) but similar to MD-2 (61 ± 5 m.min^{-1}; P=0.06) and MD-1 (53 ± 3 m.min^{-1}; P=1.00). Average speed on MD-4 was similar to MD-2 (P=1.00) but faster than MD-1 (P=0.04) and average speed on MD-2 was faster than MD-1 (P<0.01).

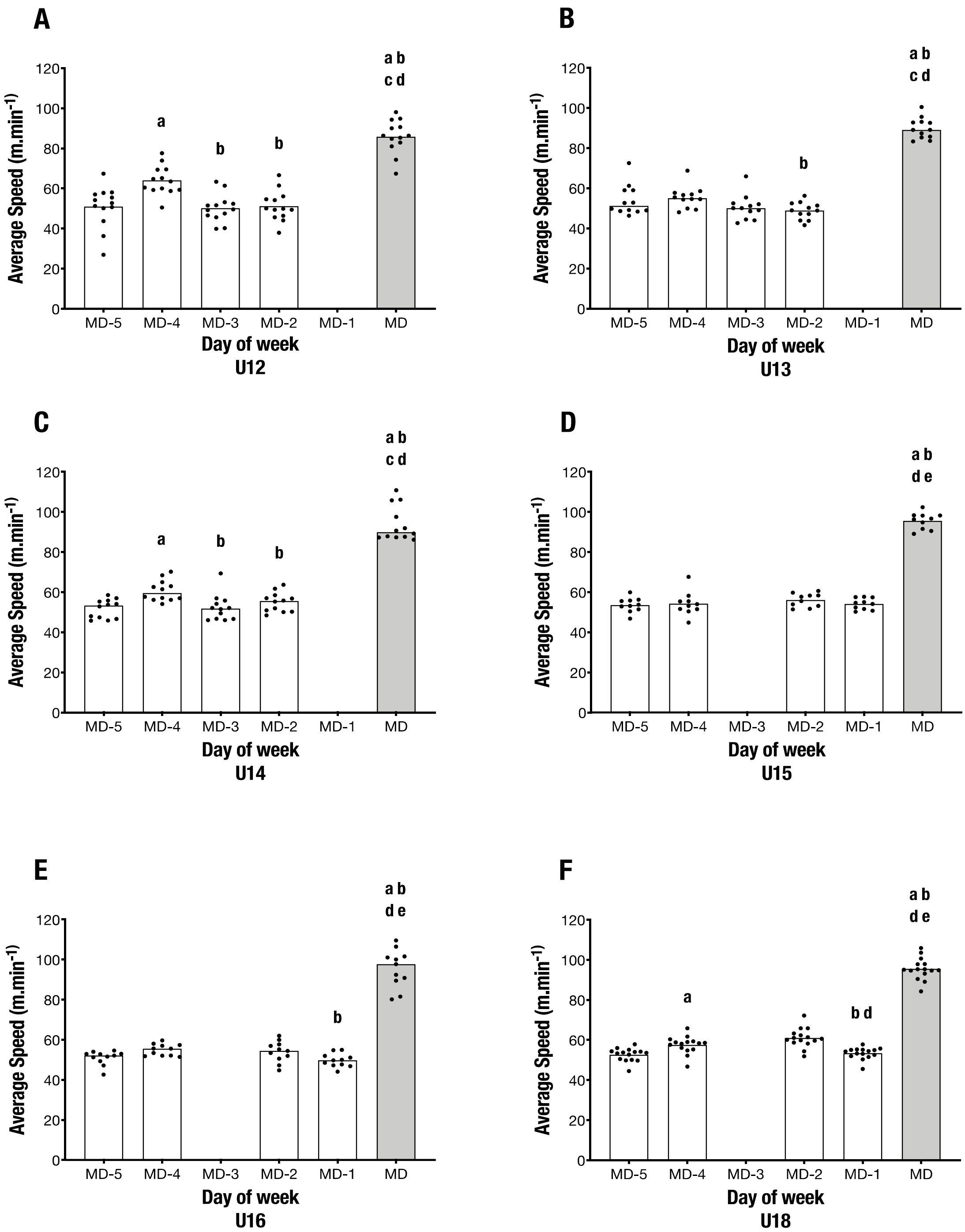

Figure 15. Daily training and match average speed of the (A) U12, (B) U13, (C) U14, (D) U15, (E) U16 and (F) U18 age-groups from a Category One English Premier League soccer academy (n = 76). White bars represent training days, denoted as days away from match day (MD) i.e. MD-5 etc. Grey bars represent match day. No training was completed on days with no data bars. [a] denotes significant difference from MD-5. [b] denotes significant difference from MD-4. [c] denotes significant difference from MD-3. [d] denotes significant difference from MD-2. [e] denotes significant difference from MD-1. Black circles represent individual players.

5.4.2.4 High Speed Running Distance

Daily HSR distance for each age-group can be seen in Figure 16. Similar to average speed, HSR distance on MD was higher than all training days (i.e. MD-5, MD-4, MD-3, MD-2 and MD-1) in the U12 (135 ± 64 m), U13 (170 ± 234 m), U14 (260 ± 214 m), U15 (355 ± 132 m), U16 (424 ± 103 m), U18 (475 ± 211 m) age-groups ($P<0.05$ for all pairwise comparisons), respectively.

In the U12 age-group, HSR distance was similar on MD-5 (33 ± 29 m), MD-4 (44 ± 27 m), MD-3 (35 ± 25 m) and MD-2 (29 ± 26 m) ($P>0.05$ for all comparisons).

In the U13 age-group, HSR distance on MD-4 (48 ± 76 m) was higher than MD-5 (22 ± 55 m; P=0.003) but was similar between all other training days (MD-3 = 34 ± 45 m; MD-2 = 40 ± 36 m; $P>0.005$ for all pairwise comparisons).

In the U14 age-group, HSR distance on MD-5 (69 ± 59 m) was similar to MD-2 (61 ± 48 m; P=0.088), higher than MD-3 (36 ± 30 m; P=0.001) and lower than MD-4 (129 ± 72 m; P=0.001). HSR distance on MD-4 was higher than MD-3 ($P<0.001$) and MD-2 (P=0.002), and on MD-3 was lower than MD-2 (P=0.002).

In the U15 age-group, HSR distance on MD-5 (63 ± 17 m) was similar to MD-1 (76 ± 48 m; P=1.00) but lower than MD-4 (176 ± 78 m; P=0.01) and MD-2 (106 ± 45 m; P=0.03). HSR distance on MD-4 was similar to MD-2 (P=0.16) but higher than MD-1 (P=0.01) and on MD-2 was similar to MD-1 ($P>0.99$).

In the U16 age-group, HSR distance on MD-5 (69 ± 18 m) was lower than MD-4 (216 ± 60 m; $P<0.01$) and MD-2 (110 ± 31 m; P=0.03) but was similar to MD-1 (80 ± 29 m; P= $P>0.99$). HSR distance on MD-4 was higher than MD-2 ($P<0.01$; 95% CI = 36 to 177 m) and MD-1 ($P<0.01$; 95% CI = 73 to 201 m) and HSR distance on MD-2 and MD-1 was similar (P=0.18).

In the U18 age-group, HSR distance on MD-5 (112 ± 42 m) was lower than MD-4 (204 ± 57 m) and MD-2 (219 ± 130 m) but higher than MD-1 (71 ± 31 m; $P<0.001$ for all pairwise comparisons). On MD-4, HSR distance was similar to MD-2 ($P=0.076$) but higher than MD-1 ($P<0.001$) and HSR distance on MD-2 was higher than MD-1 ($P<0.001$).

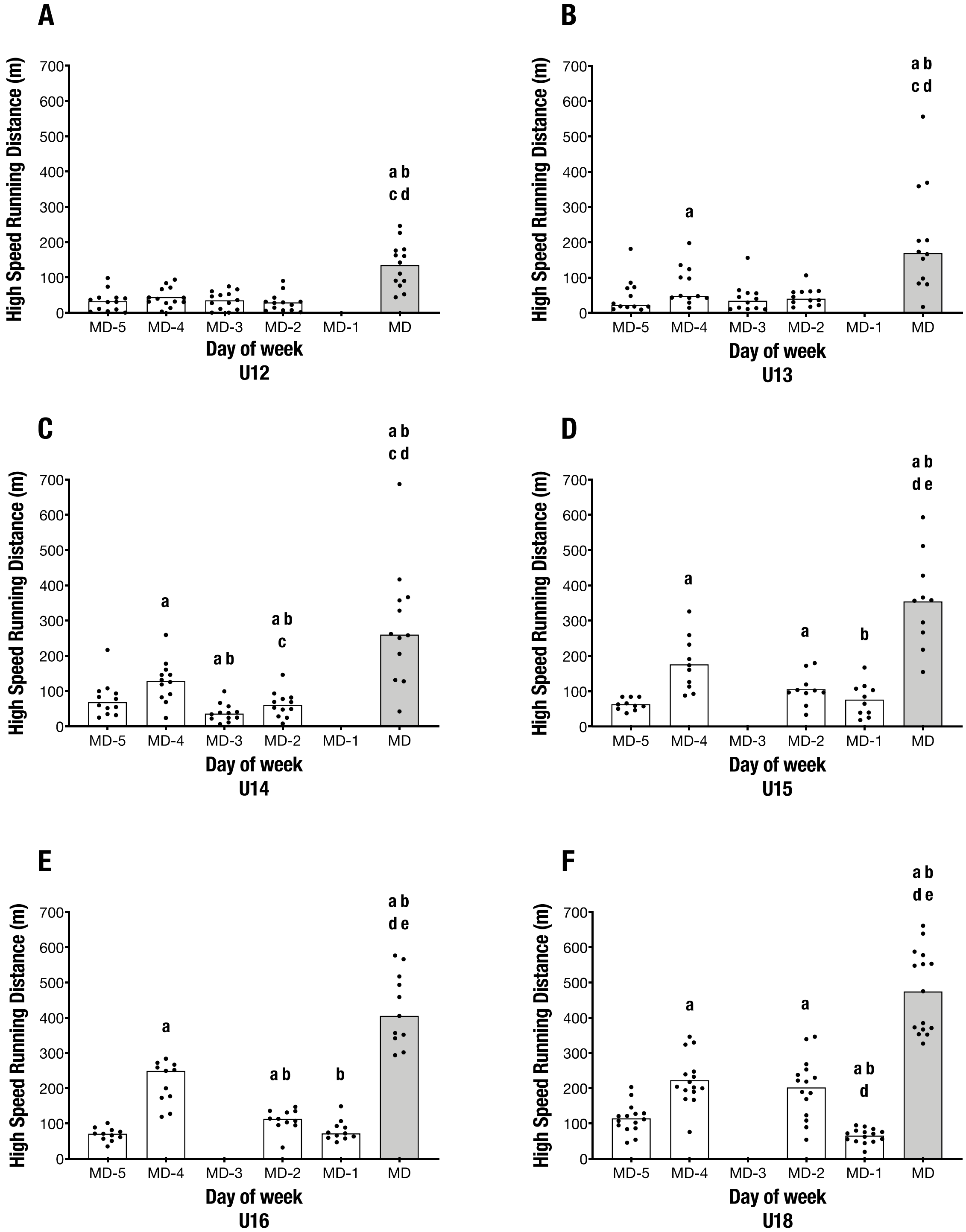

Figure 16. Daily training and match high speed running distance of the (A) U12, (B) U13, (C) U14, (D) U15, (E) U16 and (F) U18 age-groups from a Category One English Premier League soccer academy (n = 76). White bars represent training days, denoted as days away from match day (MD) i.e. MD-5 etc. Grey bars represent match day. No training was completed on days with no data bars. [a] denotes significant difference from MD-5. [b] denotes significant difference from MD-4. [c] denotes significant difference from MD-3. [d] denotes significant difference from MD-2. [e] denotes significant difference from MD-1. Black circles represent individual players.

5.4.2.4 Sprint Distance

Daily sprint distance for each age-group can be seen in Figure 17. In the U12 age-group, sprint distance on MD (1 ± 10 m) was higher than MD-4 (0 ± 1 m; P=0.001). Sprint distance was similar between all other training days (MD-5 = 0 ± 1 m; MD-3 = 1 ± 2 m; MD-2 = 0 ± 4 m; P>0.005 for all pairwise comparisons).

In the U13 age-group, sprint distance on MD (2 ± 16 m) was higher than MD-5 (0 ± 2 m), MD-4 (0 ± 7 m) and MD-3 (0 ± 1 m; P<0.005 for all pairwise comparisons) but similar to MD-2 (0 ± 3 m; P=0.039). Sprint distance was similar on MD-5, MD-4, MD-3 and MD-2 (P>0.005 for all pairwise comparisons).

In the U14 age-group, sprint distance on MD (19 ± 29 m) was higher than MD-5 (2 ± 3 m), MD-4 (3 ± 12 m), MD-3 (1 ± 3 m) and MD-2 (1 ± 2 m; P<0.001 for all pairwise comparisons). Sprint distance on MD-2 was higher than MD-4 (P=0.002) but did not differ between all other training days (P>0.005 for all pairwise comparisons).

In both the U15 and U16 age-groups, sprint distance on MD-5 (1 ± 6 m; 5 ± 3 m) was similar to MD-2 (4 ± 16 m; 12 ± 8 m) and MD-1 (2 ± 10 m; 6 ± 3 m; P>0.005 for all pairwise comparisons), but less than MD-4 (20 ± 37 m; 35 ± 19 m) and MD (26 ± 64 m; 75 ± 48 m; P<0.01 for all pairwise comparisons). Sprint distance on MD-4 was similar to MD (P>0.05 for both pairwise comparisons) but was higher than MD-2 and MD-1 (P<0.01 for all pairwise comparisons). Sprint distance on MD-2 and MD-1 was similar (P>0.005 for both pairwise comparisons) but was lower than MD (P<0.01 for both comparisons).

Sprint distance on MD (76 ± 39 m) was higher than MD-5 (9 ± 6 m), MD-4 (26 ± 14 m), MD-2 (18 ± 11 m) and MD-1 (8 ± 5 m) in the U18 age-group (P<0.01 for all pairwise comparisons). Mean sprint distance on MD-5 was similar to MD-1 (P=1.00), but lower than MD-4 (P<0.01) and MD-2 (P<0.01). Sprint distance on MD-4 was similar to MD-2 (P=0.62) but higher than MD-1 (P<0.01) and on MD-2 was higher than MD-1 (P<0.01).

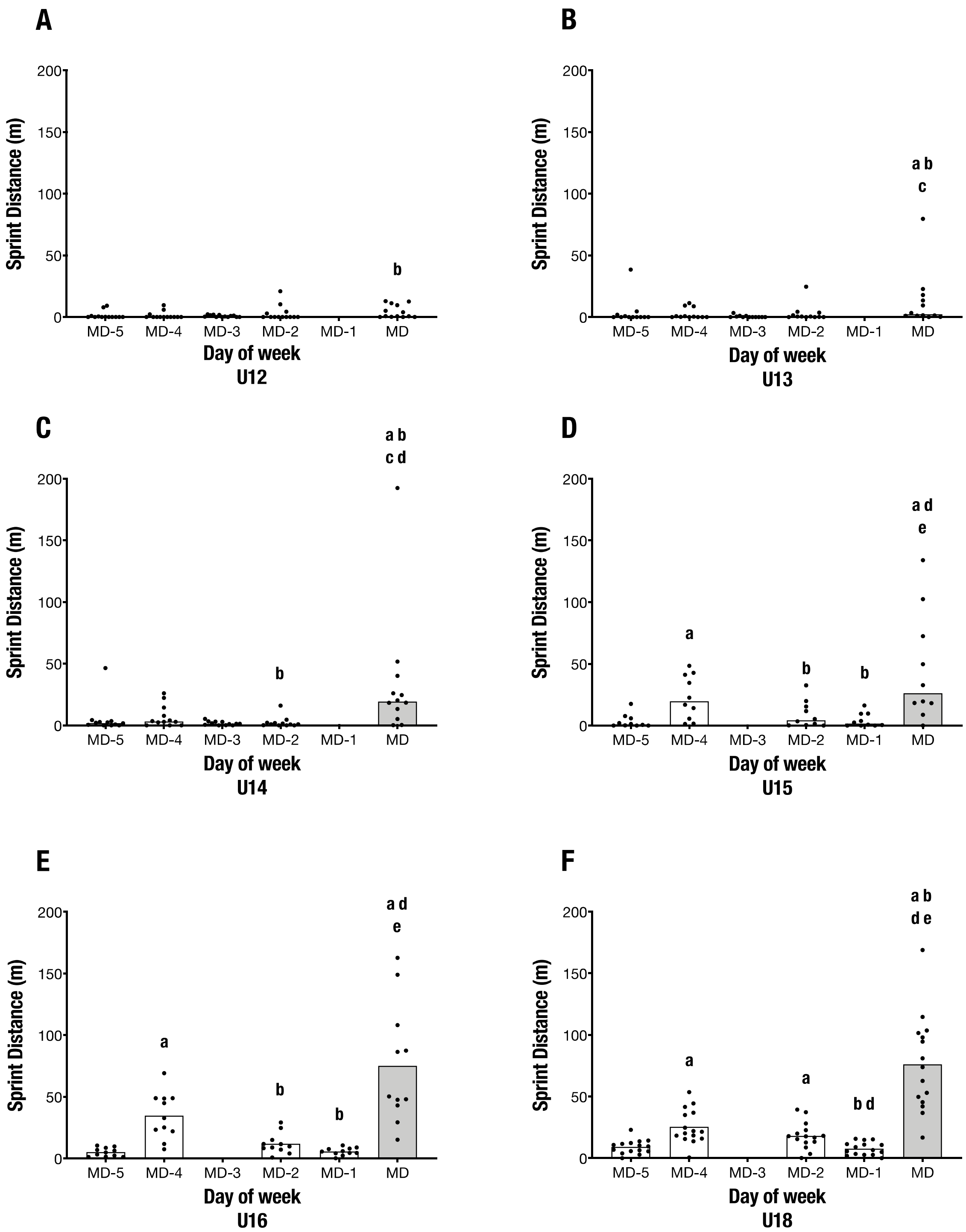

Figure 17. Daily training and match sprint distance of the (A) U12, (B) U13, (C) U14, (D) U15, (E) U16 and (F) U18 age-groups from a Category One English Premier League soccer academy (n = 76). White bars represent training days, denoted as days away from match day (MD) i.e. MD-5 etc. Grey bars represent match day. No training was completed on days with no data bars. [a] denotes significant difference from MD-5. [b] denotes significant difference from MD-4. [c] denotes significant difference from MD-3. [d] denotes significant difference from MD-2. [e] denotes significant difference from MD-1. Black circles represent individual players.

5.5 Discussion

The aim of the present study was to quantify the weekly training and match load in youth soccer players from a Category One EPL academy. Using a season-long analysis, we provide the first report to quantify absolute training and match load (according to commonly used GPS metrics) across the range of academy age-groups. Our data demonstrate that weekly training and match load is progressive in nature between age-groups whereby absolute loading patterns are comparable between U12-U15 players, whereas U16-U18 players experience absolute loading patterns that are comparable to adult players (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016). Additionally, we also observed that periodisation of loading across the weekly micro-cycle (as commonly observed in adult soccer players) only becomes apparent in the U16-U18 players.

To address our aim, we performed a seasonal long analysis to quantify the load of pitch-based training and games using typical GPS metrics and crude markers such as training and match duration. In relation to the latter, we observed that weekly ("typical", "low" and "high") training and match duration was comparable amongst the younger age-groups (U12-U14: ~330 min per week, range: 275-383 min), before increasing in the older age-groups (U15-U18: ~400-420 min per week, range: 354-457 min). Whilst the higher volumes in the U18 age-group is not unexpected given their full-time training status, it is somewhat surprising the U15 and U16 age-groups experienced similar volumes to U18 players given their part-time training status. Indeed, these data appear to contrast with Wrigley *et al.* (2012), who reported that U18 players (~700 min per week) experienced greater TML over a two-week period compared to U16 (~560 min per week) and U14 (~500 min per week) age-groups, a finding attributed to the increased number of sessions completed in the U18 players. We acknowledge, however, that a comparison between studies is limited given that the previous authors also accounted for the duration of gym-based training in their U18 (~90 min per week), U16 (~60 min per week) and U14 (60 min per week) players. Nonetheless, even when accounting for gym based training, the typical duration of activity presented here is still somewhat lower than those reported by Wrigley *et al.* (2012). In contrast, a more recent study reported a higher pitch-based training and match duration in the younger age-groups (U12-U14: ~400 min per week) when compared to U15 (~200 min per week), U16 and U18 players (~250 min per week) also from a Category One EPL soccer academy (Brownlee *et al.*, 2018). When taken together, these data demonstrate clear differences between different EPL academies, likely a reflection of differences in coaching and training philosophies between clubs. Moreover, such data also suggest that academy players are not being exposed to the required coaching time initially stated in the EPPP i.e. ~720 mins per week for U12 players increasing to ~920 mins per week for U21 (now U23) players (Premier League, 2011).

In accordance with training and match duration, "typical" weekly TD in the younger age-groups (U12-U14: ~20-22 km per week, range: 16-26 km) was similar between squads but less than that of the older age-groups (U15-U18: ~26 km per week, range: 22-30 km). Interestingly, such data are largely comparable with average weekly distances completed by adult EPL players (~26 km per week), as also completed during a one game per week micro-cycle (Anderson *et al.*, 2016). It is noteworthy, however, that during a "high" week in the U15-U18 age-groups, TD increased to ~40 km and in some individual players, almost doubled to ~45 km (Figure 12B). These data are comparable to those also reported during a perceived "high" week in U18 EPL academy players (~39 km; Bowen *et al.*, 2017). As such, these data therefore demonstrate the necessity to consider week-to-week variations in loading patterns especially when considering the risk of injury and of course, the energy and macronutrient intake and timing to support adequate energy availability. The increase in TD (and duration) in the older age-groups (U15-U18) coincides with increases in chronological and biological age as most players have progressed through PHV (Table 12). This apparent progression in load is congruent with traditional long-term athletic development models (Balyi and Hamilton, 2004; Lloyd *et al.*, 2015) and follows the trend advised (i.e. progressive increase in TMV) by the Premier League (Premier League, 2011). However, given that full skeletal maturation generally occurs at ~18 years in male academy soccer players (Johnson, Farooq and Whiteley, 2017), it is questionable whether or not the TMV experienced during 'high' weeks is appropriate for EPL academy players, particularly those in the U15 and U16 age-groups.

Weekly HSR and sprint distance (i.e. TMI) was higher in the older age-groups compared to the younger age-groups (Figure 12). In the U18 age-group, weekly HSR distances were consistent with those previously reported for EPL academy players of a similar age for a "typical" (~1000 m) and a "low" (~250-300 m) week, but greater than previously reported for a "high" week (~2800 m compared to ~2000 m) (Bowen *et al.*, 2017). The progressive increases in both HSR and sprint distance throughout the age-groups coincides with increases in both chronological and biological age (Table 12) and is likely, therefore, simply a product of growth and maturation (Malina, Bouchard and Bar-Or, 2004). Indeed, it is well documented that maximal speed progressively increases in academy soccer players until ~12-18 months post-PHV (Philippaerts *et al.*, 2006; Vaeyens *et al.*, 2006). Specific developments that influence speed production include anatomical growth (e.g. increase in leg length), biomechanical (e.g. changes in stride frequency and length) and metabolic (e.g. larger phosphocreatine storage capacity and re-synthesis ability) changes, morphological changes to the muscle and tendon (e.g. increased stiffness) and motor skill improvements (e.g. sprinting mechanics) (Ford *et al.*, 2011; Oliver, Cahill and Uthoff, 2019). It is likely that the combination of such factors improve speed production and capabilities (Ford *et al.*, 2011; Oliver, Cahill and Uthoff, 2019).

To ascertain when academy soccer players are capable of achieving the training and match intensities of adult EPL players, we deliberately selected absolute speed thresholds commonly used within the adult game (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016). In the U16 and U18 age-groups, HSR distance was similar to that of adult EPL players during a two and a three match week, though sprint distance was significantly less than adult players for a two (~520 m) and three (~1000 m) match week (Anderson, Orme, Di Michele, *et al.*, 2016). In addition to the physical developments described above, it is noteworthy that academy players possess considerably less FFM than adult players (Milsom *et al.*, 2015; Hannon *et al.*, 2020 [Study 1]), an important component that is closely associated with power and speed production (Wrigley *et al.*, 2014; Murtagh *et al.*, 2018). When considered in this way, our data demonstrate that whilst academy players in the older age-groups (i.e. U16 and U18) are capable of achieving the training and match volumes experienced by adult EPL players, they do not achieve the absolute intensities completed by elite adult soccer players. Such data are of practical relevance given that the physical demands of match play are typically completed as an absolute demand and have increased between the seasons of 2006 and 2013 (Barnes *et al.*, 2014), as opposed to individualised demands.

Similar to adult players (Anderson, Orme, Di Michele, *et al.*, 2016), players in all age-groups experienced the greatest physical load on MD, as was the case for markers of volume (e.g. TD, Figure 14) and intensity such as average speed (Figure 15) and HSR distance (Figure 16). Consequently, MD is likely to incur the largest daily energy expenditure for academy soccer players. Whilst there are some elements of daily periodisation of loading across the weekly micro-cycle in U12-U15 age-groups, the periodisation pattern that is typically observed in adult players (Anderson, Orme, Di Michele, *et al.*, 2016) only appears evident in the U16 and U18 age-groups. For example, during the training week preceding a match, TD (Figure 14), HSR

(Figure 16) and sprint distance (Figure 17) was greatest on MD-4, with significant reductions in all parameters on MD-1 in preparation for the match. These fluctuations in loading (of both volume and intensity) throughout the week are likely a reflection of the goal of each training day (e.g. a greater emphasis on technical and tactical elements versus a greater emphasis on specific physical elements). The TML patterns experienced by the U16 and U18 age-groups are consistent with previous reports in both academy (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015) and adult (Anderson, Orme, Di Michele, *et al.*, 2016) soccer players and may reflect a shift in focus from technical development in the younger age-groups towards preparation for competition in the older age-groups (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015). From a nutritional perspective, the periodisation of daily loading in adult players has resulted in the suggestions that daily energy intake should also be adjusted and periodised accordingly (Anderson *et al.*, 2017). However, given the lack of periodisation of TML in the younger age-groups in combination with the fact these players are progressing through a period of rapid biological growth and maturation, (i.e. through PHV, Table 12), such data demonstrate that daily periodisation of energy intake is not necessary within these age-groups.

In summary, we report for the first time the weekly training and match loads of youth soccer players between age-groups of the same EPL soccer academy. Our data demonstrate that weekly training and match load is progressive in nature, whereby absolute loading patterns are comparable between U12-U14 players, whereas U15-U18 players experience absolute loading patterns that are comparable to adult players. Additionally, we also observed that periodisation of loading across the weekly micro-cycle (as commonly observed in adult soccer players) only becomes apparent in the U16-U18 players. Such differences in loading patterns between age-groups in combination with differences in body composition and RMR (Study 1) is likely to result in differences in absolute energy requirements when players are pre, circa and post-PHV.

Future studies should therefore quantify the daily TEE of academy soccer players using the gold standard DLW method. Importantly, the quantification of load across a low, typical and high week now allows for the assessment of TEE during an appropriately selected week.

Chapter 6

Energy expenditure and intake in English Premier League academy soccer players

Having assessed body composition (Study 1, Chapter 4), resting energy requirements (Study 1, Chapter 4) and typical weekly training loads (Study 2, Chapter 5), the aim of this Chapter was now to quantify the daily total energy expenditure and energy intake in a cohort of soccer players from a Category One English Premier League academy. Importantly, our assessment of daily total energy expenditure was conducted via the gold standard doubly labelled water method.

Lloyd Parker & Daniel Carney assisted with data collection for this study. Catherine Hambly & John Speakman conducted the DLW analysis for this study.

This study has been accepted for publication in Medicine & Science in Sports & Exercise.

Hannon, M. P., Parker, L. J., Carney, D. J., McKeown, J., Speakman, J. R., Hambly, C., Drust, B., Unnithan, V. B., Close, G. L. and Morton, J. P. (2020). Energy requirements of male academy soccer players from the English Premier League. *Medicine & Science in Sports & Exercise*, published ahead of print.

6.1 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 soccer players from an EPL academy (U12/13, n = 8; U15, n = 8; U18, n = 8) were assessed for baseline maturity (maturity offset and current percentage of predicted adult stature), body composition (DXA) and resting metabolic rate (RMR; indirect calorimetry). Subsequently, TEE and physical loading patterns were assessed over a 14-day in-season period using doubly labelled water and global positioning system technology respectively, and for the first 7 days energy intake (EI) was assessed via the remote food photographic method.

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.

6.2 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 (Elferink-Gemser *et al.*, 2012). The development of academy soccer players is multi-faceted, where a significant emphasis is placed upon technical, tactical, physical and psychological development (Premier League, 2011). In English Premier League (EPL) academies, formal registration of players commences at the under (U) nine age group (Premier League, 2011) and so, as an academy player transitions through the academy pathway they will undergo biological growth and maturation (Malina, Bouchard and Bar-Or, 2004) during which time sufficient energy is required to synthesize new tissues (Torun, 2005). 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 (Desbrow *et al.*, 2014). 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 Study 1 (Chapter 4), changes in body composition and resting metabolic rate (RMR) was quantified in a cohort of male English Premier League academy soccer players (U12 – U23 age-groups). In accordance with progressive increases in physical characteristics (e.g. stature, body mass and fat free mass), an increase in RMR of approximately 400 kcal·day^{-1} between ages 12 and 16 (i.e. the period corresponding with peak height velocity, PHV) was observed, thus highlighting the requirement to adjust total energy intake accordingly. However, given that RMR only represents a proportion of total daily energy expenditure (TEE) (Manore and

Thompson, 2015), there is a definitive requirement to accurately quantify TEE (alongside assessments of training load) in order to prescribe specific energy requirements. Indeed, in Study 2 (Chapter 5) we also reported that absolute training volume and intensity progressively increases as players transition through the academy pathway thus suggesting that TEE is likely to increase accordingly. Whilst previous studies have reported daily TEE in both U18 (Russell and Pennock, 2011) and U15 (Briggs, Cockburn, *et al.*, 2015) 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 findings from Study 1 (Chapter 4) demonstrates that such prediction equations significantly underestimate RMR in this population (Hannon *et al.*, 2020).

The doubly labelled water (DLW) method is the gold standard method of assessing energy expenditure in free-living conditions *in vivo* (Westerterp, 2017). 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 (Westerterp, 2017). Using the DLW method, a mean daily TEE of 3566 ± 585 kcal·day^{-1} in adult (~27 years old) male Premier League soccer players was recently reported, as assessed in a seven day in-season period comprising of two matches and five training sessions (Anderson *et al.*, 2017). 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 (Hannon *et al.*, 2020 [Study 1]), daily schedule (e.g. schooling and training demands) and a higher (relative) energy cost of exercise (Morgan, 2008).

In addition to quantifying TEE, there is also a requirement to simultaneously quantify energy intake so as 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 (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016). Considering these values alongside the aforementioned estimated TEE values in academy soccer players (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015), it is plausible to suggest that energy availability may be compromised in this population as previously highlighted by Briggs and colleagues (Briggs, Cockburn, *et al.*, 2015). 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 (Loucks, Kiens and Wright, 2011). 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 (Loucks, Kiens and Wright, 2011).

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. On the basis of Study 1 (Chapter

4) and Study 2 (Chapter 5), 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.

6.3 Methods

6.3.1 Participants

Twenty-four (n=24) male outfield soccer players from a Category One EPL soccer academy volunteered to participate in this study. Players were of differing chronological and biological ages and categorised according to their age group (U12/13, U15, U18). Participant characteristics are presented in Table 14. 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.

6.3.2 Overview of study design

In a cross-sectional design, total energy expenditure, energy intake and physical loading (comprising of both training and matches) was assessed 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 13. 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.

Table 13. 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)	Rest (8)	Training (8)	Training (8)	Rest (1)	Rest (1)
		Match (2)		~15:30-17:30	~15:30-17:30	Training (7)	Training (7)
		~11:00-12:10				~15:30-17:30	~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.

6.3.3 Baseline measures

On the morning of day 1 (07:00–11:00) and after providing a urine sample, players were assessed for body composition, maturity status and RMR under standardised conditions (≥8 hours overnight fast and ≥12 hours after exercise). In short, body mass, stature and sitting height were measured in accordance with the procedures outlined in section 3.3.1, followed by assessment of body composition via a whole-body fan-beam DXA scan in accordance with the procedures outlined in section 3.3.2. For players in the U12/13 and U15 age-groups somatic maturity timing was determined by calculating the maturity offset (Mirwald *et al.*, 2002) and for all players maturity status was determined using the Sherar equation (Sherar *et al.*, 2005) in accordance with the procedures outlined in section 3.5. Following all anthropometric measures, RMR was measured in accordance with the procedures outlined in section 3.4.

6.3.4 Body mass and hydration status

In addition to a baseline measurement (day one), fasted body mass was also collected on days 7 and 14 (SECA, model-875, Hamburg, Germany). Prior to each body mass assessment (days 1, 7 and 14), all players provided a urine sample to establish hydration status (PAL-1 refractometer, Atago, Japan). This measurement assisted in determining if any change in body mass was likely due to a change in energy balance as opposed to a change in hydration status.

6.3.5 Quantification of training and match loads

Pitch based training and match load was measured using global positioning system (GPS) technology in accordance with the procedures outlined in section 3.6. In accordance with Study 2 (Chapter 5), 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 ($m.min^{-1}$) 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. In accordance with previous academy training load studies (Wrigley *et al.*, 2012; Brownlee *et al.*, 2018) and given we did not account for duration of gym-based training in Study 2 (Chapter 5), duration of gym-based training (min) was quantified and added to pitch based training and match play duration to see if it significantly changed total training duration. No training or match load data was included for the two players that sustained an injury during the study.

6.3.6 Measurement of total energy expenditure using the doubly labelled water method

Measurement of TEE (kcal·day^{-1}) was quantified using the DLW method (Lifson and McClintock, 1966; Speakman, 1997) over a 14-day period. This method has been previously validated on multiple occasions by comparison to simultaneous indirect calorimetry in humans (Speakman, 1997). On the evening of day 0, players provided a background urine sample. A single oral bolus dose of DLW ($^{2}H_2{}^{18}O$) 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% $^{2}H_2$, using the calculation:

$$\text{Dose (mL)} = 0.65 \text{ (body mass, grams) x DIE / IE}$$

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 (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 another urine sample, allowing for isotope enrichment to be determined following total body water equilibrium (Speakman, 1997). 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 (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. 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) (Berman *et al.*, 2012) at the University of Aberdeen, Scotland, UK. Initially the urine was encapsulated in capillaries, then vacuum distilled (Nagy, 1983), 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 (Schoeller *et al.*, 1986) as modified by Schoeller (Schoeller, 1988), was used to calculate rates of CO_2 production as recommended for use in humans (Speakman, 1993), 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 one and two and also a 14-day mean. Physical activity level (PAL) was also calculated for each player by dividing TEE by RMR (Westerterp, 2013).

6.3.7 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 (Costello *et al.*, 2017) and previously used by our laboratory when assessing adult soccer players (Anderson *et al.*, 2017). 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 principle investigator on a smart phone via WhatsApp messaging service (Costello *et al.*, 2017). Seven-days was chosen as it is was considered an appropriate duration to assess habitual dietary intake (Braakhuis *et al.*, 2003), with the research team also deeming 14 days too long a timeframe to obtain good quality dietary information (Burke, 2015).

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 (Capling *et al.*, 2017). 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.

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·day^{-1}) and macronutrient intakes were reported in grams (g) and grams per kilogram of body mass (g·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·day^{-1}), carbohydrate (P=0.28; 95% CI = -41 to 12 g·day^{-1}), fat (P=0.10; 95% CI = -1 to 17 g·day^{-1}) or protein (P=0.97 ; 95% CI = -12 to 11 g·day^{-1}) intake. The thermic effect of food (TEF) was assumed to be 10% of EI for each individual (Westerterp, 2004), subsequently enabling estimations of activity energy expenditure (AEE; TEE – (RMR + TEF)) and energy availability (EA = EI – AEE / FFM).

6.3.8 Statistical analyses

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, Bonferroni post-hoc analysis was conducted to locate specific differences. Comparisons between week one and week two and also between energy intake and expenditure for each age-group 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. 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.

6.4 Results

6.4.1 Baseline characteristics

Player characteristics (n=24) 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 14. 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).

Table 14. 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]	-
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 age-group, $P<0.05$. [b] denotes significant difference from U15 age-group, $P<0.05$. [c] denotes significant difference from U18 age-group, $P<0.05$.

6.4.2 Training and match load

Accumulative 14-day training and match duration (n=22; Figure 18A) 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 18B) 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, although 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 18C). Average speed was higher in week one compared with week two in both the U12/13 (71 ± 6 and 55 ± 5 m·min^{-1}, respectively: 95% CI = 10 to 22 m·min^{-1}; P<0.01) and U15 (73 ± 5 and 61 ± 3 m·min^{-1}, respectively: 95% CI = 6 to 18 m·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·min^{-1}, respectively).

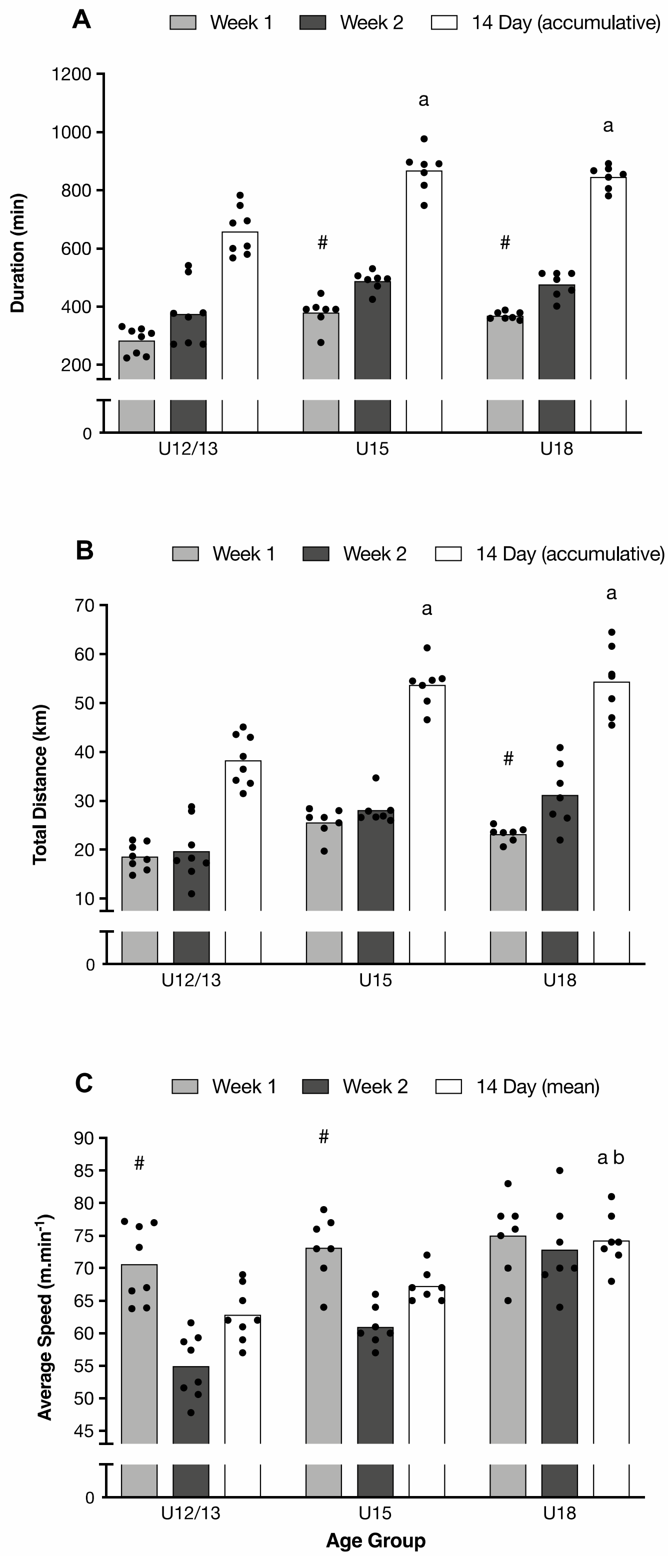

Figure 18. (A) training and match-play duration, (B) total distance, and (C) average speed in the U12/13, U15 and U18 age-groups from a Category One English Premier League academy (n=22). [a] denotes significant difference from U12/13 age-group, P<0.05. [b] denotes significant difference from U15 age-group, 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.

6.4.3 Energy expenditure

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 (Figure 19A).

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 19B). 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 19C) 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 19D) 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).

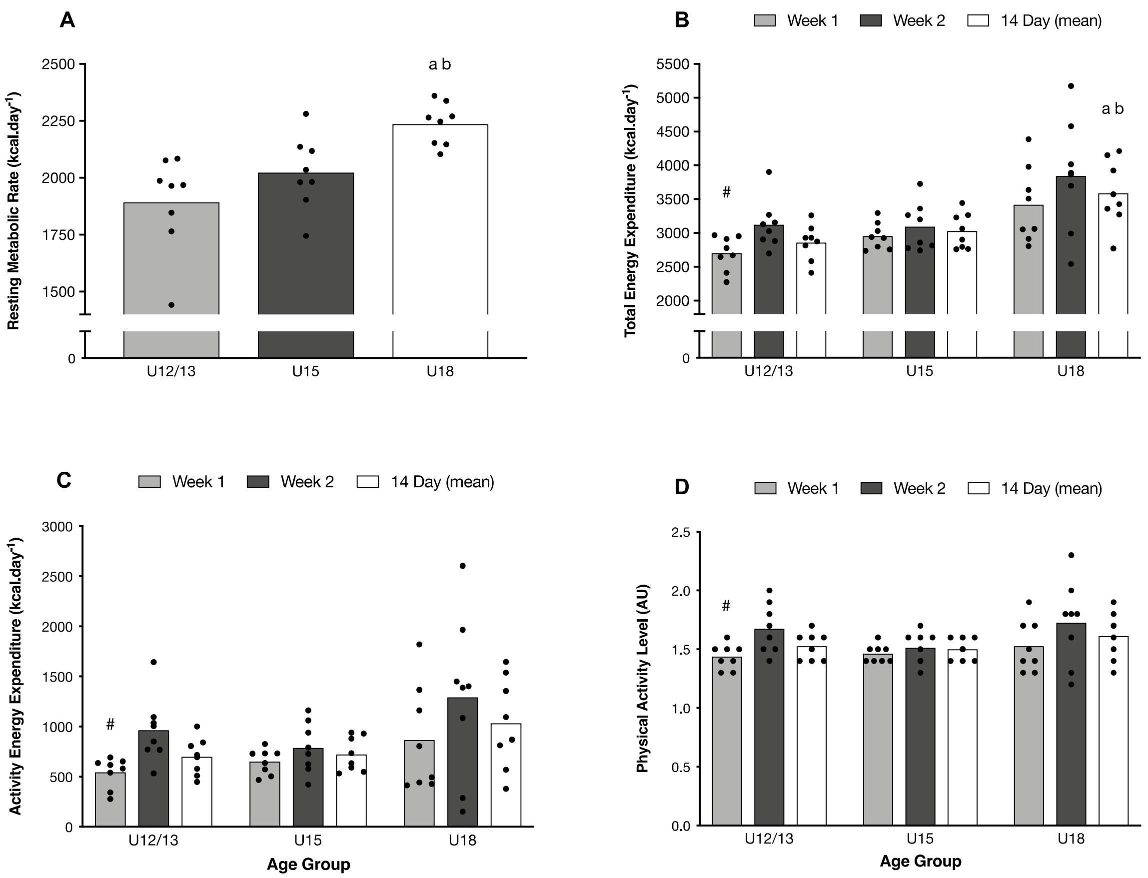

Figure 19. (A) Resting metabolic rate, (B) mean daily total energy expenditure, (C) mean daily activity energy expenditure, and (D) physical activity level (PAL) in the U12/13, U15 and U18 age-groups (n=24) from a Category One English Premier League academy. [a] denotes significant difference from U12/13 age-group, P<0.05. [b] denotes significant difference from U15 age-group, 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.

6.4.4 Self-reported energy and macronutrient intake

Both absolute ($P<0.01$) and relative ($P<0.01$) mean energy intake (Figures 20A & 20B) was significantly different between playing squads (n=24). In absolute terms, the U18 players consumed more energy (3180 ± 279 $kcal \cdot day^{-1}$) than the U15 players (2821 ± 338 $kcal \cdot day^{-1}$; 95% CI = 0 to 717 $kcal \cdot day^{-1}$; P=0.05) and U12/13 players (2659 ± 187 $kcal \cdot day^{-1}$; 95% CI = 162 to 878 $kcal \cdot day^{-1}$; $P<0.01$). 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 $kcal \cdot kg^{-1} . day^{-1}$) consumed more energy than the U15 (50 ± 7 $kcal \cdot kg^{-1} \cdot day^{-1}$; 95% CI = 3 to 22 $kcal \cdot kg^{-1} \cdot day^{-1}$; P=0.01) and U18 players (44 ± 7 $kcal \cdot kg^{-1} \cdot day^{-1}$; 95% CI = 9 to 28 $kcal \cdot kg^{-1} \cdot day^{-1}$; $P<0.01$) age-groups, though there was no difference between the U15 and U18 age-groups (P=0.39).

Mean absolute carbohydrate intake (Figure 20C) was similar between the U12/13 (309 ± 27 $g \cdot day^{-1}$), U15 (325 ± 44 $g \cdot day^{-1}$) and U18 (346 ± 28 $g \cdot day^{-1}$) age-groups (P=0.12). When expressed in relative terms (Figure 20D), the U12/13 players (7.3 ± 1.0 $g \cdot kg^{-1} \cdot day^{-1}$) consumed more than the U15 (5.8 ± 0.8 $g \cdot kg^{-1} \cdot day^{-1}$; 95% CI = 0.5 to 2.5 $g \cdot kg^{-1} \cdot day^{-1}$; $P<0.01$) and U18 (4.8 ± 0.6 $g \cdot kg^{-1} \cdot day^{-1}$; 95% CI = 1.4 to 3.5 $g \cdot kg^{-1} \cdot day^{-1}$; $P<0.01$) 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 20E & 20F) 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 20G) 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 (Figure 20G) 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}).

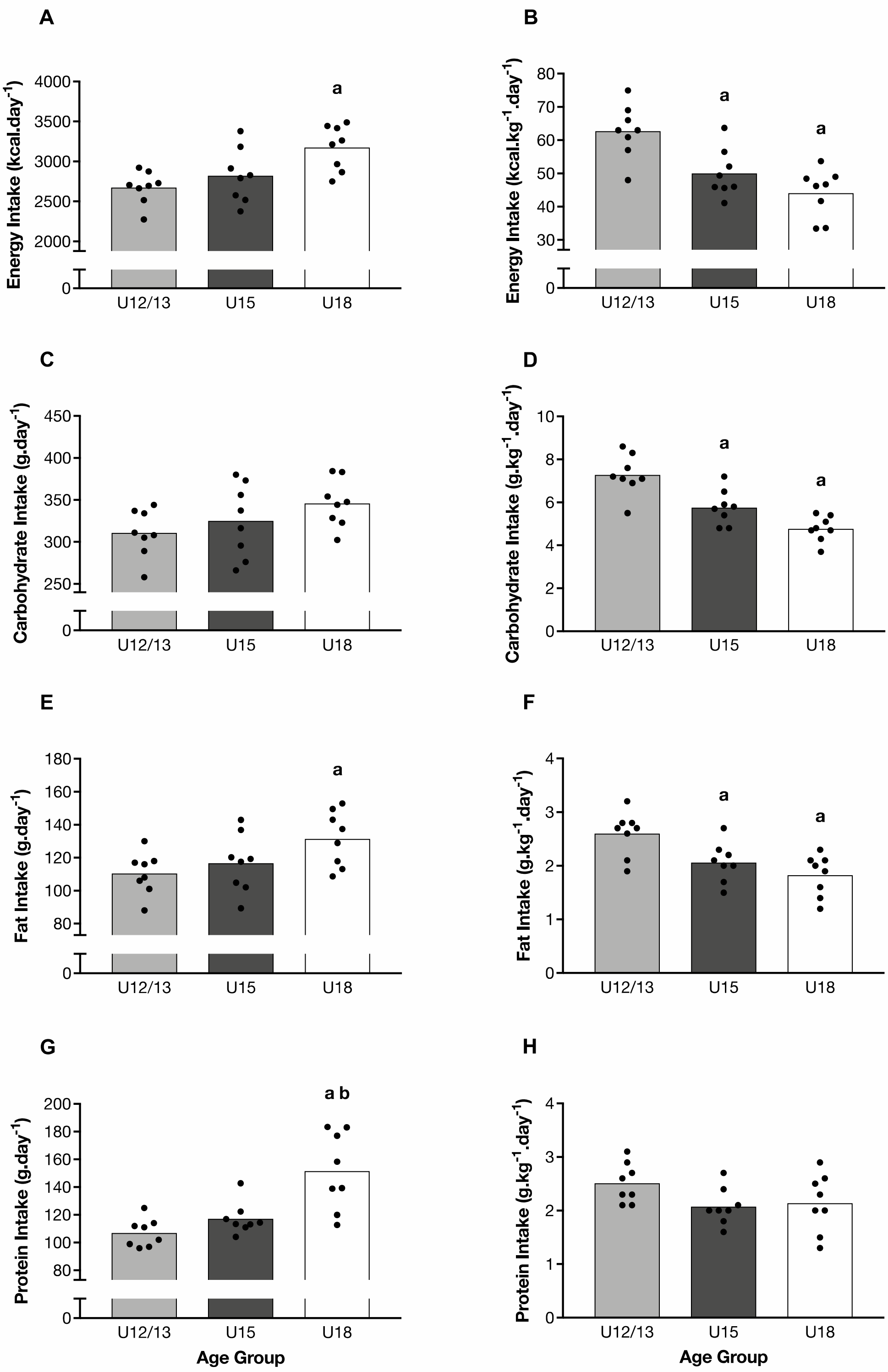

Figure 20. Absolute and relative energy and macronutrient intake over 7-days. (A) Absolute and (B) relative energy intake; (C) absolute and (D) relative carbohydrate intake; (E) absolute and (F) relative fat intake; and (G) absolute and (H) relative protein intake in the U12/13, U15 and U18 age-groups from a Category One English Premier League academy over 7-days (n = 24). [a] denotes significant difference from U12/13 age-group, $P<0.05$. [b] denotes significant difference from U15 age-group, $P<0.05$. Black circles represent individual players.

6.4.5 Energy intake versus energy expenditure and energy availability

There was no difference between EI and TEE in the U12/13 (-29 ± 277 kcal·day^{-1}; P=0.78), U15 (-134 ± 327 kcal·day^{-1}; P = 0.28) or U18 (-243 ± 724 kcal·day^{-1}; P = 0.37) age-groups (n=24; Figure 21A). Similarly, body mass (Figure 21B) 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·kg^{-1}) to seven (775 ± 206 mOsmol·kg^{-1}) and fourteen (867 ± 177 mOsmol·kg^{-1}), respectively (P=0.08).

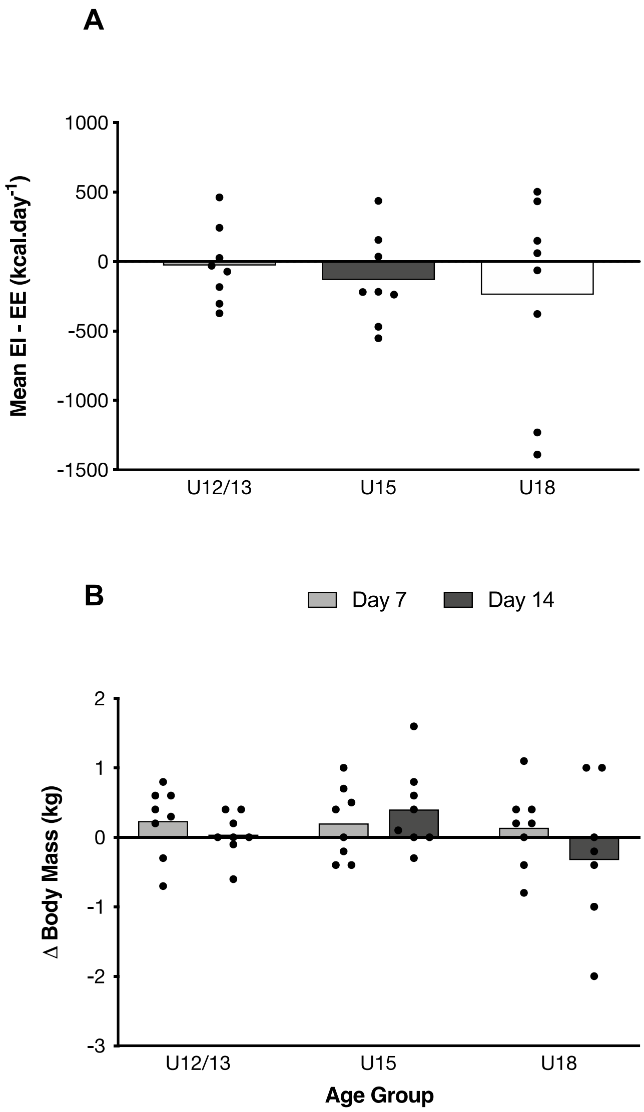

Figure 21. (A) Difference between mean energy intake and expenditure over 7-days, and (B) body mass change (Δ) from baseline, on days 7 and 14 in the U12/13, U15 and U18 age-groups (n = 24) from a Category One English Premier League academy. Black circles represent individual players.

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

6.4.6 Factors affecting TEE and AEE

There was a significant positive relationship between TEE and body mass (r^2 = 0.65; P<0.01), fat-free mass (r^2 = 0.65; P<0.01), stature (r^2 = 0.41; P<0.01), RMR (r^2 = 0.56; P<0.01) and AEE (r^2 = 0.79; P<0.01) (Figure 22). 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 23).

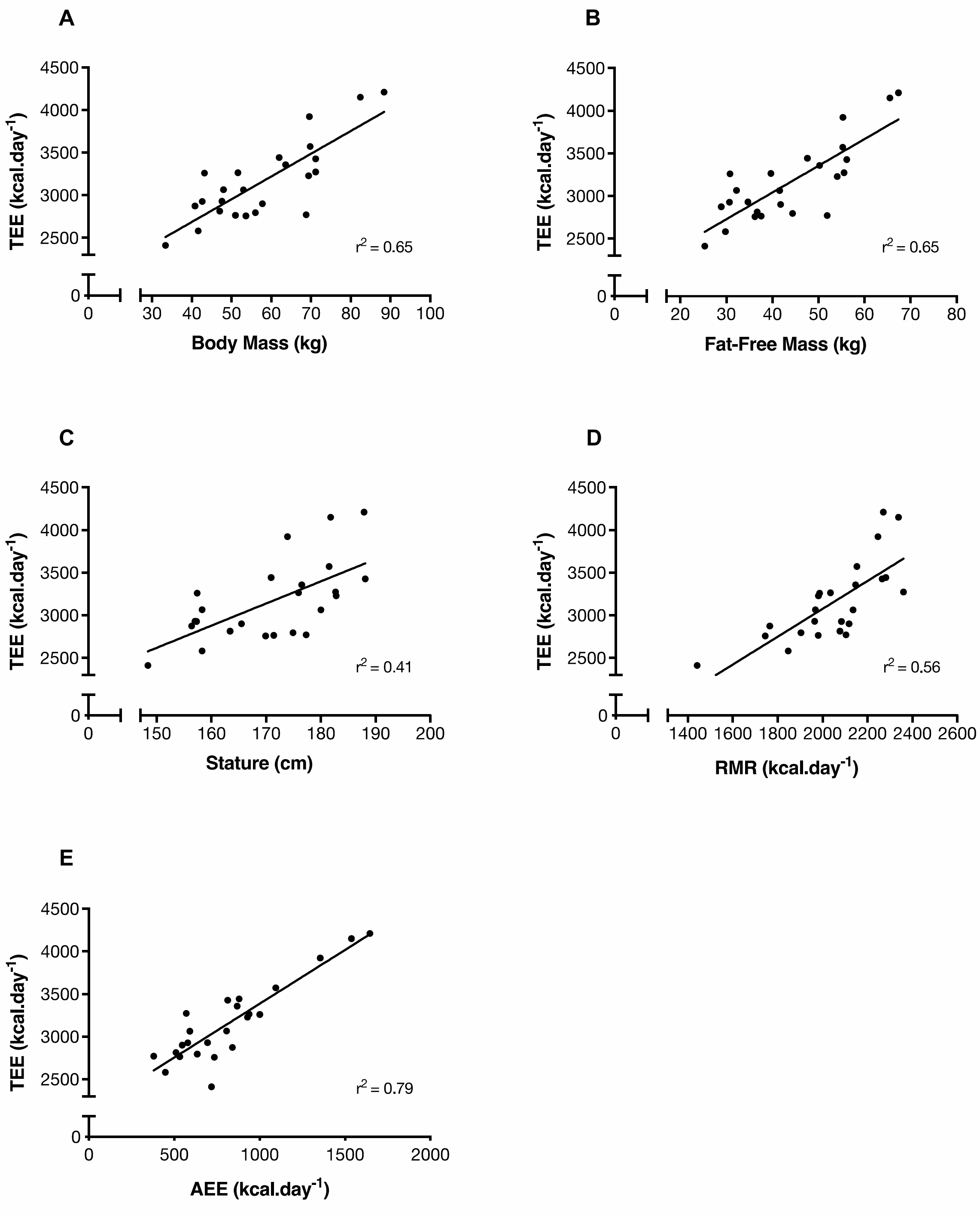

Figure 22. The relationship between mean daily total energy expenditure (TEE) and (A) body mass ($P<0.01$), (B) fat-free mass ($P<0.01$), (C) stature ($P<0.01$), (D) resting metabolic rate (RMR; $P<0.01$) and (E) activity energy expenditure (AEE; $P<0.01$) in youth soccer players from a Category One English Premier League academy (n=24). Black circles represent individual players.

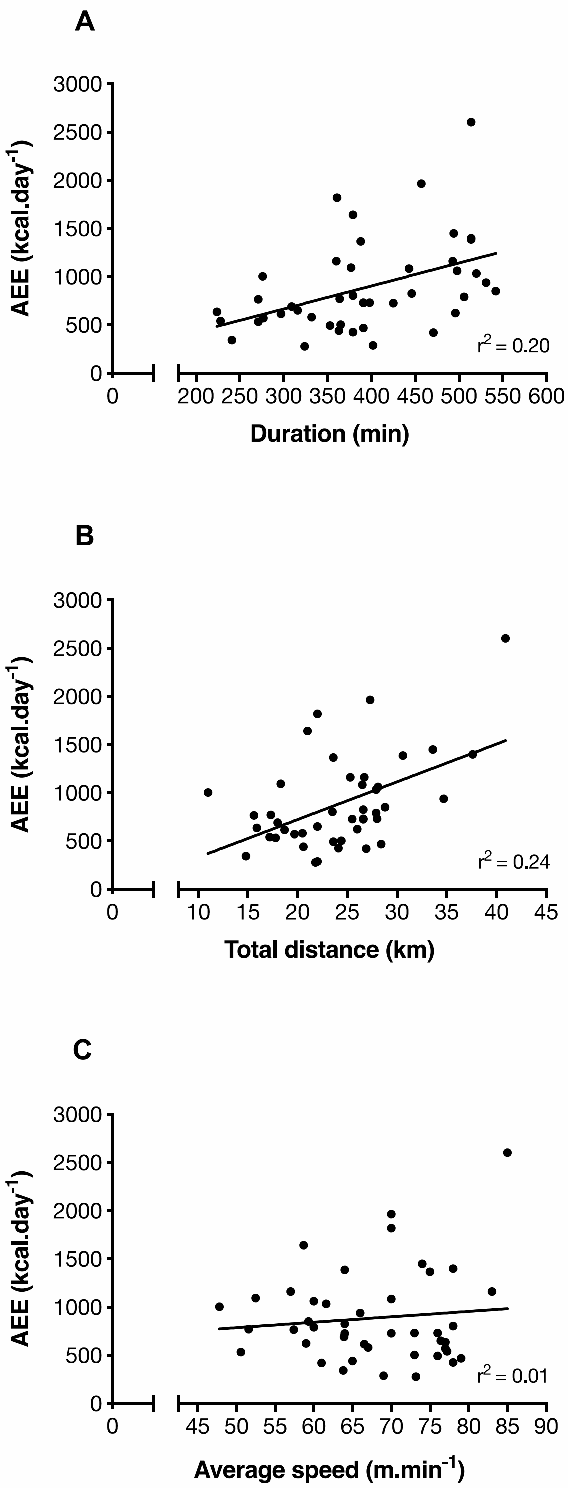

Figure 23. The relationship between mean daily activity energy expenditure (AEE) and (A) training and match-play duration (P<0.01), (B) total distance (P<0.01) and (C) average speed (P=0.49) in youth soccer players from a Category One English Premier League academy (n=22). Black circles represent individual players. Two data points per player, representing values from two different weeks.

6.5 Discussion

In using the doubly labelled water method, we provide the first direct measurement of total daily energy expenditure of male academy soccer players from the English Premier League. Confirming our hypothesis, our data demonstrate that TEE progressively increases between age-groups, 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 using the same methodology.

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. In accordance with Study 1 (Chapter 4), 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 (Figure 22). 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, a similar finding to that reported in Study 2 (Chapter 5). As such, 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 23) than crude markers of exercise intensity (i.e. average speed). It would appear prudent, therefore, 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 (Anderson *et al.*, 2017; Brinkmans *et al.*, 2019). Additionally, TEE was similar to that reported in U18 Championship (i.e. second tier) academy soccer players (3618 ± 61 kcal·day^{-1}) (Russell and Pennock, 2011), 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 (Briggs, Cockburn, *et al.*, 2015). 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 (Silva *et al.*, 2013; Smith *et al.*, 2018), we also observed a strong correlation between TEE and AEE (thus suggesting that training load has a clear role on energy expenditure). 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 (Anderson *et al.*, 2017). Additionally our data also demonstrate large differences from adolescent athletes from other team sports where both age matched basketball (Silva *et al.*, 2013) and rugby players (Smith *et al.*, 2018) present with an absolute TEE ~1000 $kcal \cdot day^{-1}$ greater than that observed here, likely due to these athletes being significantly taller and heavier. Indeed, when comparing relative TEE in the U18 (~49 $kcal \cdot kg^{-1} \cdot day^{-1}$) and U15 (~54 $kcal \cdot kg^{-1} \cdot day^{-1}$) age-groups with age-matched basketball (~57 $kcal \cdot kg^{-1} \cdot day^{-1}$; 35) and rugby (~50 $kcal \cdot kg^{-1} \cdot day^{-1}$; 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, injured players etc).

In relation to estimation of energy intake, U18 players reported higher intakes (3180 ± 279 $kcal \cdot day^{-1}$) than both U15 (2821 ± 338 $kcal \cdot day^{-1}$) and U12/13 players (2659 ± 187 $kcal \cdot day^{-1}$). Such data contrast from previous observations on academy soccer players where similar values (~2000 $kcal \cdot day^{-1}$) in U13/14, U15/16 and U18 players were observed (Naughton *et al.*, 2016). Additionally, our data are also ~500 $kcal \cdot day^{-1}$ greater than previous observations on U18 (Russell and Pennock, 2011) and U15 (Briggs, Cockburn, *et al.*, 2015) 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 carbohydrate and fat intake, given that the absolute intake of both macronutrients was approximately 100 g more than previous observations (Naughton *et al.*, 2016). 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·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 (Russell and Pennock, 2011; Silva *et al.*, 2013; Briggs, Cockburn, *et al.*, 2015). On the basis of our estimation of total energy requirements, it is suggested that relative intakes of carbohydrate, fat and protein corresponding to 6-8, 1.5-2.5 and 2 g·kg^{-1}·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 implemented. Indeed, whilst the present players appeared capable of consuming appropriate energy intake for the required TEE, it should be noted that the academy in which this research was conducted had a full-time nutrition practitioner (PhD candidate) and also provided numerous meals and snacks to their players on a daily basis. In those clubs where such 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.

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 players, TEE is comparable to or exceeds that previously reported in adult Premier League soccer players.

Chapter 7

Synthesis of findings

The aim of this Chapter is to provide a summary of the findings from this thesis in relation to the original aims and objectives outlined in Chapter 1. A general discussion is then presented, which focuses on how the data derived from this thesis has furthered our understanding of the energy requirements of academy soccer players. Finally, the practical implications, limitations and recommendations for future research will be outlined.

7.1 Achievement of thesis aims and objectives

The overall aim of this thesis was to determine the energy requirements of English Premier League (EPL) academy soccer players of different chronological and biological ages. It was hoped that the data derived from this thesis would assist towards the formulation of evidence-based nutritional guidelines that support growth, maturation and physical development in EPL academy soccer players. This aim was achieved through a series of both laboratory and field-based studies conducted in Chapters 4, 5 and 6. An overview of each specific objective is provided below.

Objective 1**: To assess body composition and resting metabolic rate in EPL academy soccer players of different chronological and biological ages. This objective was achieved through the completion of Study 1 (Chapter 4).**

Using a cross-sectional design, this study assessed the body composition (quantified using DXA) and RMR (quantified using indirect calorimetry) of 99 male soccer players from an EPL soccer academy. These data demonstrate that the largest difference in stature, body mass, FFM and RMR is between U12 and U16, suggesting this is a key period for growth, maturation and physical development during which energy requirements are increased. Further analysis also demonstrated that commonly used prediction equations significantly underestimate RMR in EPL academy soccer players and that FFM is the single best predictor of RMR in this population.

Objective 2**: To quantify external training and match load over a competitive season in EPL academy players of different chronological and biological ages. This objective was achieved through the completion of Study 2 (Chapter 5).**

The data presented in this chapter demonstrated that TML (both volume and intensity) in EPL academy soccer players differs between age-groups whereby U16-U18 players complete higher absolute loads than younger players. When considering these data alongside data from Study 1 (Chapter 4), it was hypothesised that total daily energy expenditure was likely increased accordingly. Additionally, periodisation of physical loading across the weekly micro-cycle (as evident in adult EPL players) was only evident in the U16-U18 age-groups.

***Objective 3*: To quantify energy expenditure and energy intake in EPL academy players of different chronological and biological ages during a typical 14-day in-season period. This objective was achieved through completion of Study 3 (Chapter 6).**

Having quantified the differences in resting energy requirements (Study 1, Chapter 4) and TML (Study 2, Chapter 5) of EPL academy soccer players across the entire academy age-range, the aim of this study was to quantify the typical TEE and energy intake of this population at three distinctly different stages of growth and maturation. Findings from this study demonstrate that the daily TEE of EPL academy soccer players progressively increases in accordance with increased FFM, RMR and TML. These data also indicate that the players observed in this study are matching their energy intake to their energy expenditure and are therefore achieving their daily energy requirements.

7.2 General discussion of findings

7.2.1 Body composition changes during growth, maturation and physical development

As an academy soccer player transitions through the academy pathway, they undergo rapid biological growth and maturation, resulting in many anatomical, physiological and metabolic changes (Malina, Bouchard and Bar-Or, 2004) that can subsequently influence the energy requirements of these players (Desbrow *et al.*, 2014). It is well documented that as an academy soccer player advances in biological and chronological age, they increase in both stature and body mass (Malina *et al.*, 2000; Deprez *et al.*, 2013; Lovell *et al.*, 2015; Malina, Figueiredo and Coelho-e-Silva, 2017). Age at PHV is generally between ~13-14 years in this population (Philippaerts *et al.*, 2006; Deprez *et al.*, 2013; Lovell *et al.*, 2015) with adult stature generally attained by ~16-17 years old (Milsom *et al.*, 2015; Patel *et al.*, 2019); further increases in body mass also continue into adulthood (Milsom *et al.*, 2015; Patel *et al.*, 2019). Prior to the completion of Study 1 (Chapter 4), limited research in academy soccer players suggested that increases in body mass are derived primarily from increases in FFM (Milsom *et al.*, 2015) and that the amount of body fat is not affected by growth and maturation (Figueiredo *et al.*, 2009; Nikolaidis and Vassilios Karydis, 2011; Buchheit and Mendez-Villanueva, 2013; Hammami *et al.*, 2013). However, inconsistencies in the methodologies and populations utilized in these studies makes comparisons difficult.

In Study 1 (Chapter 4) we therefore assessed body composition assessed via DXA (for the first time) in a cohort of soccer players from a Category One EPL academy at different biological and chronological ages. Consistent with previous research (Philippaerts *et al.*, 2006; Deprez *et al.*, 2013; Lovell *et al.*, 2015), age at PHV was ~13-14 years old (U13 and U14 age-groups) with attainment of adult stature at ~17 years old (i.e. U18 age-group) (Milsom *et al.*, 2015; Patel *et al.*, 2019). Progressive increases in stature and body mass were observed until U16, with the largest increase in both measures coinciding with PHV (Table 9). Building upon the findings of Milsom *et al.* (2015), increases in body mass were primarily derived from increases in FFM (Figure 7). Absolute fat mass was similar between all age-groups (~10 kg), however there was a reduction in percent body fat from U12-U14 (Figure 7). Whilst there were no statistically significant differences in FFM, fat mass and percent body fat between the U16, U18 and U23 age-groups, Figure 7 clearly demonstrates the large within and between age-group differences. These data highlight the necessity to adopt an individualised approach to player development within professional soccer academies.

7.2.2 Resting metabolic rate

It has long been accepted that an increase in body size is associated with an increase in RMR (Harris and Benedict, 1918) and that FFM is the most metabolically active compartment (Müller *et al.*, 2018). Despite this, only one study to date had previously quantified RMR in youth soccer players of different chronological and biological ages. Data from Indian soccer players demonstrates that RMR increases by ~400 kcal·day^{-1} from the (chronological) ages of 10 to 13 in accordance with increases in stature, body and FFM (Cherian *et al.*, 2018). However, in this study participants were classified as recreationally active and the sample included both male and female participants (Cherian *et al.*, 2018). As such, prior to completion of Study 1 (Chapter 4), there was a lack of data quantifying RMR (alongside stature, body mass and FFM) across the chronological and biological age-range of male soccer players from an EPL academy.

In addition to the body composition assessments in Study 1 (Chapter 4) players also underwent an RMR assessment. In accordance with changes in stature, body mass and FFM, an increase in RMR was also observed between the U12-U14 age groups (U12: 1655 ± 195 kcal·day^{-1}; U13 1720 ± 205 kcal·day^{-1}; U14: 1846 ± 218 kcal·day^{-1}), thus highlighting the requirement to adjust total energy intake accordingly. Such data correspond with data from the Indian soccer players (discussed previously) where an increase in RMR of ~400 kcal·day^{-1} from the ages of 10 to 13 (Cherian *et al.*, 2018) was also reported. Once the influence of both stature and FFM were removed via allometric scaling (Figure 9), there was no significant relationship between either of these body size variables and RMR, i.e. when considering per cm of stature or per kg of

FFM, RMR was the same across all age groups. When considering the largest changes in body composition (particularly stature and FFM) and RMR typically occur between U12-U16 age-groups, this demonstrates that this is a key period for growth and maturation during which energy requirements are increased.

Considering the impracticalities of assessing RMR via indirect calorimetry in the applied environment, there are also a number of prediction equations that can be used to estimate RMR. However, these predication equations may be limited as they are derived from non-athletic populations (Cunningham, 1980; Henry, 2005) and may not take into account FFM which is an important component in athletic populations (Schofield, Thorpe and Sims, 2019). Thus, there was a definitive need to develop population specific predictive equations according to changes in stature, body mass and FFM (Herrmann *et al.*, 2017) and moreover, across the age-range that is representative of professional soccer academies.

After comparison of measured and estimated RMR values, the prediction equations evaluated in Study 1 (Cunningham, 1980; De Lorenzo *et al.*, 1999; Henry, 2005; Wong *et al.*, 2012; Kim *et al.*, 2015) provide inaccurate estimations of RMR in EPL academy soccer players (Figures 10 & 11). As an extreme example, estimated RMR using the Kim equation (Kim *et al.*, 2015) underestimated RMR by ~850 kcal·day^{-1} in one individual, despite this equation being developed in a population most similar to those in Study 1 (Chapter 4; 16-year-old recreational soccer players). The use of inappropriate prediction equations could be potentially harmful to a player (or any athlete) if used to prescribe energy requirements, given the consequences of chronic low energy availability on growth and maturation (Mountjoy *et al.*, 2018). In this regard, the development of the novel prediction equation(s) generated in Study 1 (Chapter 4) [Equation one: $RMR\ (kcal \cdot day^{-1}) = 1315 + (11.1\ x\ FFM\ in\ kg)$; Equation two: *RMR (kcal·day*-

^{1}) = 1254 + (9.5 x body mass in kg)*] provide practitioners with an alternative population specific equation which can be used to estimate RMR in conditions where direct measurement is not possible (in U12-U23 age-groups).

7.2.3 Training and match load

Whilst the training and match loads experienced by adult Premier League players are well understood (Di Salvo *et al.*, 2009; Barnes *et al.*, 2014; Malone *et al.*, 2015; Anderson, Orme, Michele, *et al.*, 2016), the habitual training and match loads completed by academy soccer players are less well studied. Prior to completion of Study 2 (Chapter 6), reports were limited to quantifying the accumulative training and match load (TML) over a period of one-to-two weeks (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015) and were often confined to internal measures such as heart rate and RPE (Wrigley *et al.*, 2012) or single training metrics such as session duration (Brownlee *et al.*, 2018). As such, there was a definitive need to quantify the absolute loading patterns completed by academy players so as to ascertain when players are physically capable of achieving similar volumes (i.e. total distances) and intensities (i.e. distances attained within specific absolute speed thresholds) of work done that is associated with adult soccer. Additionally, understanding the periodisation of daily loading within the weekly micro-cycle across the different academy age-groups was important given the implications on energy expenditure and subsequent periodisation of energy intake (Anderson *et al.*, 2017).

In Study 2 (Chapter 5), seasonal physical loading (both training and match-play) was quantified using GPS technology in a cohort of EPL academy soccer players across the age-groups of the academy pathway. Weekly training and match duration and TD was lower in the younger age-groups compared to the older age-groups (Figure 12). Whilst these training and match volumes differ from previous reports in EPL academy soccer players (Wrigley *et al.*, 2012; Brownlee *et al.*, 2018), it is clear that EPL academies are not fulfilling the advised guidelines of ~720 mins for U12 players rising to ~920 mins for U21 (now U23) players, initially stated in the EPPP (Premier League, 2011). Typical weekly TD completed by the U15-U18 age-groups was similar to those experienced by adult EPL players during a one match week (~26 km; Anderson *et al.*, 2016) and during a "high" week was comparable to adult EPL players during a three match week (Anderson, Orme, Di Michele, *et al.*, 2016).

Weekly HSR and sprint distance (i.e. intensity) was higher in the older age-groups compared to the younger age-groups (Figure 12). The progressive increases in both HSR and sprint distance throughout the age-groups coincided with increases in both chronological and biological age, and is likely therefore simply a product of growth and maturation (Malina, Bouchard and Bar-Or, 2004). In the U16 and U18 age-groups, HSR distance was similar to that of adult EPL players during a two and a three match week, however sprint distance was significantly less than adult players for a two (~520 m) and three (~1000 m) match week (Anderson, Orme, Di Michele, *et al.*, 2016), demonstrating that academy players cannot physically achieve the absolute intensities required to play at senior level.

Similar to adult players (Anderson, Orme, Di Michele, *et al.*, 2016), players in all age-groups experienced the greatest physical load on a MD (Figures 14-17). Consequently, MD is likely to incur the largest daily energy expenditure for academy soccer players. The daily periodisation of loading that is typically observed in adult players (Anderson, Orme, Di Michele, *et al.*, 2016) only appears evident in the U16 and U18 age-groups, which is consistent with previous reports in both academy (Wrigley *et al.*, 2012; Coutinho *et al.*, 2015) and adult (Anderson, Orme, Di Michele, *et al.*, 2016) soccer players. Given the lack of periodisation of load within a weekly micro-cycle in the younger age-groups in combination with the fact these players are progressing through a period of rapid biological growth and maturation (i.e. through PHV, Table 12), periodisation of energy intake may not be necessary within these age-groups.

7.2.4 Total energy expenditure

On the basis of findings from Study 1 (Chapter 4) and 2 (Chapter 5), it was hypothesised that daily TEE would also increase as players transition through the academy pathway. Previous studies have estimated TEE in both U18 (3618 ± 61 kcal·day^{-1}; Russell and Pennock, 2011) and U15 (2551 ± 245 kcal·day^{-1}; Briggs, Cockburn, *et al.*, 2015) academy soccer players. However, these studies estimated TEE from indirect measures such as RMR prediction equations, activity diaries and accelerometery. Accordingly, there was a definitive requirement to accurately quantify TEE in academy soccer players of different chronological and biological ages, using gold standard methods, in order to accurately prescribe population specific energy requirements.

In Study 3 (Chapter 6), TEE was therefore quantified using the doubly labelled water method, in three different age-groups of EPL academy soccer players. In agreement with our hypothesis, 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. Observed TEE values for the U18 players were comparable to previously published data on adult EPL players (3566 ± 585 kcal·day^{-1}), also assessed using the DLW method (Anderson *et al.*, 2017). Additionally, TEE was similar to that reported in U18 academy soccer players (3618 ± 61 kcal·day^{-1}; Russell and Pennock, 2011), despite the latter authors using indirect assessment methods. In the U15 age-group, mean daily TEE was ~500 kcal·day^{-1} higher than that previously reported in U15 EPL academy players (2551 ± 245 kcal·day^{-1}), though it is acknowledged that the latter authors estimated TEE from accelerometery (Briggs, Cockburn, *et al.*, 2015). The large inter-individual variation in TEE between players in all age-groups (Figure 19), again highlights the importance of adopting an individualised approach to energy prescription (i.e. energy intake based on energy expenditure) in academy soccer players.

7.2.5 Energy and macronutrient intake

To better understand whether or not academy soccer players are meeting their daily energy requirements, dietary intake was also assessed alongside measurements of TEE in Study 3 (Chapter 6). Whilst several studies have previously reported typical energy and macronutrient intakes in EPL academy soccer players (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016), none have done so in combination with accurate assessments of TEE. We observed that U18 players reported higher energy 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 previous observations on academy soccer players where similar values (~2000 kcal·day^{-1}) were observed in U18, U15/16 and U13/14 players (Naughton *et al.*, 2016).

When making inferences of energy balance, no differences between self-reported energy intake and energy expenditure within squads were observed, nor were there any significant changes in mean body mass. These findings differ from those of Russell and Pennock (Russell and Pennock, 2011) and Briggs and colleagues (Briggs, Cockburn, *et al.*, 2015), who both concluded that youth soccer players failed to achieve their daily energy requirements. However, our energy intake data are also ~500 kcal·day^{-1} greater than other researchers' observations on U18 (Russell and Pennock, 2011) and U15 (Briggs, Cockburn, *et al.*, 2015) 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 (RFPM) and 24-hour recall adopted here. Mean daily estimated energy availability was 69 ± 10, 51 ± 9 and 41 ± 15 kcal·kg FFM^{-1}·day^{-1} in the U12/13, U15 and U18 age-groups respectively. To the authors knowledge this is the first report of energy availability in male soccer players (in both youth or adult populations) and some of the first reports in male youth athletes. These observed energy availability values are greater than those previously reported (~28.5 kcal·kg FFM^{-1}.day^{-1}) in male youth athletes (11-25 years old), that competed in a range of sports (aesthetic, ball, endurance, racquet, water sports) at national or international level (Koehler *et al.*, 2013).

Comparable with previous findings in EPL academy soccer players (Naughton *et al.*, 2016), absolute carbohydrate intake in our population was similar across all three age-groups, however relative intake was higher in the younger compared to the older age-groups (Figures 20C & 20D). Fat intake, relative to body mass, differed between age-groups (Figures 20E & 20F), however fat intake, as a percentage of EI, was similar across all three age-groups (~37%). These values are considerably higher than those previously reported in academy soccer players (0.9-1.5 g·kg^{-1} / 29-31% of EI) (Russell and Pennock, 2011; Briggs, Cockburn, *et al.*, 2015; Naughton *et al.*, 2016), which also coincided with larger energy intake. Absolute protein intake was highest in the U18 players compared to the U15 and U12/13 age-groups, however relative to body mass all three age-groups consumed ~2 g·kg^{-1} (Figures 20G & 20H). These differences were mainly due to the U18 age-group consuming a higher protein breakfast compared to the younger age-groups, similar to previous observations in EPL academy soccer players

(Naughton *et al.*, 2016). Nonetheless, the protein intakes in all three age-groups surpassed the recommended daily amount of 1.6 g·kg^{-1} for youth soccer players (Boisseau *et al.*, 2002).

7.2.6 Summary

Growth and maturation is a complex process that is influenced by the interaction of genes, hormones, nutrients and the environments in which the individual lives (Malina, Bouchard and Bar-Or, 2004). Given the role of energy availability in supporting growth and maturation, we suggest that daily energy intake should be adjusted accordingly as players transition through the academy pathway. An academy soccer player's energy requirements are influenced by a number of factors including their anthropometric profile, RMR, TML and ultimately their daily TEE. On the basis of our findings and estimation of energy balance, it is suggested that relative intakes of carbohydrate, fat and protein corresponding to 6-8, 1.5-2.5 and 2 g.kg^{-1} body mass would provide a reasonable starting point for which to meet the daily energy requirements of academy soccer players. On the basis of the work conducted in this thesis, an overview of practical recommendations is provided in Figure 24 and an overview of the anthropometric profile and energy requirements of the academy player can be seen in Figure 25.

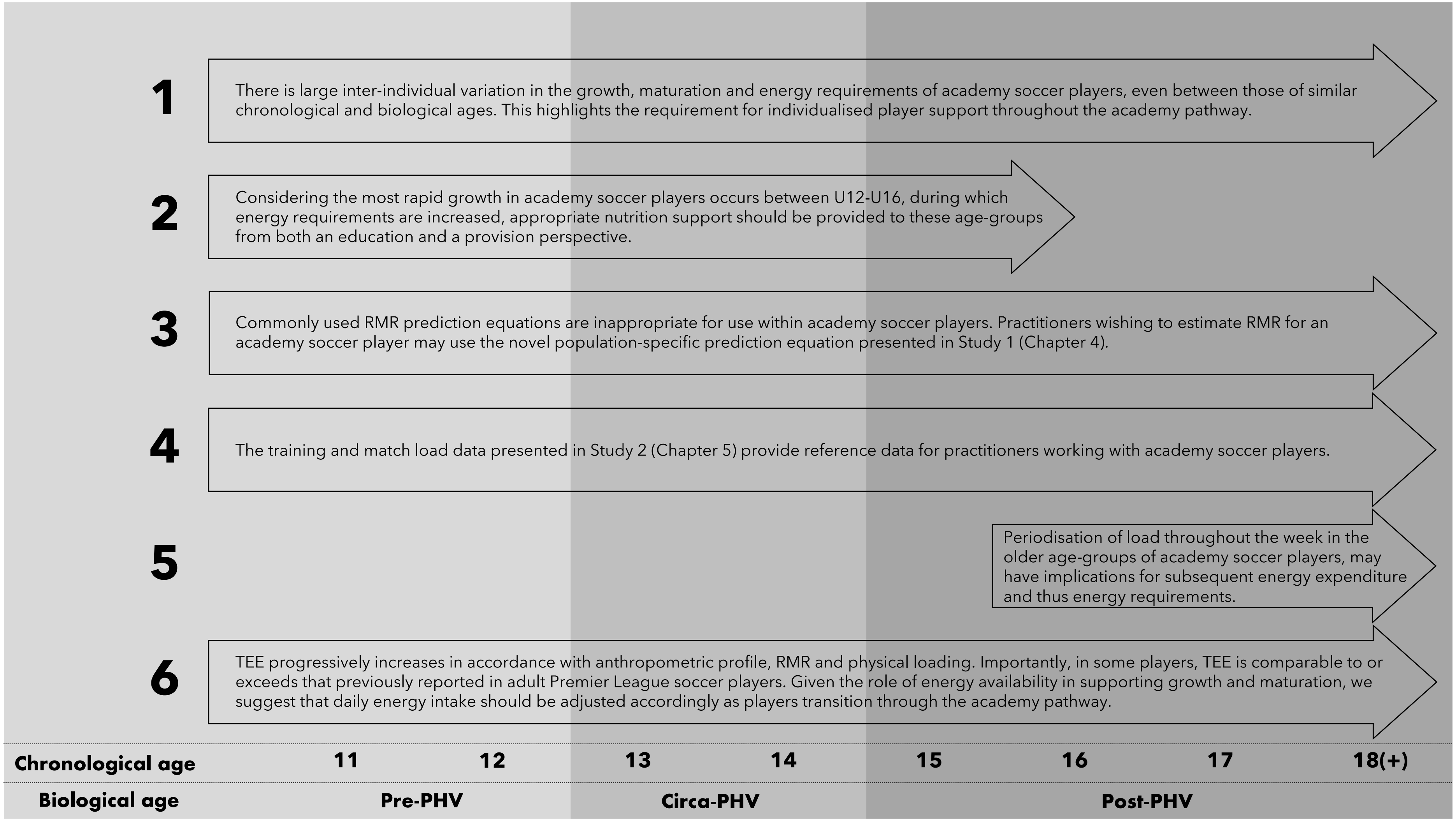

Figure 24. Practical implications of the main findings from this thesis.

Biological age	Pre-PHV	Circa-PHV		Post-PHV		
Chronological age-group	U12	U13	U14	U15	U16	U18(+)
Stature (cm)	156	163	169	176	178	182
PAS (%)	85	89	93	97	98	100
Body Mass (kg)	44	49	55	63	71	74
Fat-Free Mass (kg)	32	35	43	49	56	58
RMR ($kcal \cdot day^{-1}$)	1650	1725	1850	1975	2050	2000
TEE ($kcal \cdot day^{-1}$)		2900		3000		3600
Energy Intake ($kcal \cdot day^{-1}$)		2700		2800		3200

Figure 25. An overview of the of the anthropometric profile and energy requirements of the academy player based on the data presented in this thesis.

7.4 Limitations

Each of the studies conducted within this thesis have produced novel data that has advanced the body of knowledge and our understanding of the energy requirements of academy soccer players. Nevertheless, these studies are not without their limitations, some of which apply to all three studies. Firstly, due to the current landscape of professional EPL soccer academies, this research was only conducted in a male population. Consequently, extending the findings from this thesis to young female soccer players is not appropriate. Additionally, all data from this thesis was obtained from players from one EPL soccer academy, which may not be representative of other EPL academies or other professional soccer academies worldwide. Differences in philosophies (coaching, training, nutritional, player development etc), infrastructure and staffing, funding, resources and cultures between different clubs may influence how each club's academy operates, subsequently affecting both the training regimes and nutritional requirements of its players. There were also a number of limitations that were specific to each study within this thesis.

Study 1 (Chapter 4)

Although players presented to the laboratory under standardised conditions (≥8 hours overnight fast and ≥12 hours after exercise; Bone and Burke, 2018) and all scans were performed and analysed by the same trained operator (Nana *et al.*, 2016), both exercise (type, duration and intensity) and dietary intake in the preceding 24 hours was not standardised for each player. This may have influenced results, considering gastrointestinal tract and bladder contents and muscle glycogen can affect body composition (particularly FFM) results from DXA (Nana *et al.*, 2015).

Studies 2 & 3 (Chapters 5 & 6)

Whilst these studies used validated and widely accepted metrics to determine external load such as TD and different absolute speed thresholds (Malone *et al.*, 2015; Anderson, Orme, Di Michele, *et al.*, 2016; Beato *et al.*, 2018), no measure of internal load was quantified e.g. heart rate. Considering the large inter-individual variation in a player's internal response to an external load (Drust, Atkinson and Reilly, 2007), this may have had implications for an individual's energy expenditure (Ainslie, Reilly and Westerterp, 2003; Westerterp, 2013).

It is also accepted that the use of absolute speed thresholds within academy soccer players (of different chronological and biological ages) has its limitations. Notably, this approach does not consider the inter-individual variation in a player's sprinting 'capacity'; i.e. for a given absolute speed, a quicker player will be running at a lower percentage of their maximum speed (relatively) compared to a slower player, and vice versa (Gabbett, 2015). However, individualisation of speed thresholds was not deemed appropriate (particularly for Study 2, Chapter 6) because of the requirement to regularly update speed thresholds due to increases in speed associated with growth and maturation (Philippaerts *et al.*, 2006; Vaeyens *et al.*, 2006). Given the large inter-individual variation in the level (magnitude of change), timing (onset of change) and tempo (rate of change) of biological growth and maturation between players (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al.*, 2014, 2016), in addition to the large sample size, this approach was considered unfeasible.

Study 3 (Chapter 6)

Despite being considered the gold standard method to assess TEE in free-living conditions, the DLW technique only enables quantification of mean daily TEE over a period of time, and cannot therefore provide information on the AEE of a specific exercise bout (e.g. a training session) or TEE for a specific day (FAO/WHO/UNU, 2001; Ainslie, Reilly and Westerterp, 2003). 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) (Torun, 2005; Longland *et al.*, 2016). Additionally, we were not able to differentiate (AEE) between soccer and non-soccer related activity (i.e. away from the club). Consequently, we were not able to further determine the sub-components of AEE, e.g. NEAT or soccer related energy expenditure. Finally, whilst it is acknowledged that under-reporting is common when self-reporting dietary intake, particularly in adolescent athletes (Russell and Pennock, 2011; Silva *et al.*, 2013; Briggs, Cockburn, *et al.*, 2015), efforts were made to limit this through the use of two different methods (both prospective and retrospective) (Capling *et al.*, 2017).

7.5 Recommendations for further research

Building upon the findings from this thesis, further research is required to advance our knowledge and understanding of how we can better support the development of academy soccer players from a sports science and nutrition perspective. Some of the questions that remain unanswered may be addressed via the following research recommendations:

1. Replicating all three studies in a cohort of young female academy soccer players given the anthropometric, physiological and metabolic differences between males and females (Malina, Bouchard and Bar-Or, 2004; Timmons, Bar-Or and Riddell, 2007a; Lloyd *et al.*, 2014).

2. Monitoring longitudinal changes in body composition and RMR, particularly through PHV (i.e. pre-, circa- and post-PHV).

3. Validation of the novel RMR prediction equation(s) presented in Study 1 (Chapter 4), particularly in cohorts of academy soccer players of different ethnicities and larger sample sizes from different clubs.

4. Determine longitudinal TML in different clubs, including those in different countries, with different philosophies. Further research should aim to include internal load metrics and other validated metrics of external load, e.g. accelerations and decelerations, perhaps quantified using inertial sensors.

5. Begin to determine optimal loading patterns for academy players across the academy age-range. This would need to be done in combination with other information including physical testing data and injury data.

6. Determine whether or not different academies are providing the opportunity for their players to achieve their daily energy requirements from a nutrition provision standpoint.

7. Quantify TEE of academy soccer players during a period of high TML e.g. over the course of a tournament or during a congested fixture schedule.

8. Validation of a GPS derived equation/algorithm to determine the AEE of a single session.

7.6 Summary

In summary, the research undertaken in this thesis provides novel data on the body composition and resting metabolic rates, the typical training and match loads and energy expenditures and intakes of academy soccer players from a Category One English Premier League academy. The largest changes in body composition, particularly FFM, and RMR typically occur between U12-U16, suggesting this is a key period for physical development during which energy requirements are increased. Weekly training and match load is progressive in nature as players progress through the academy pathway, with U15-U18 players experiencing absolute loading patterns that are comparable to adult players. Periodisation of loading across the weekly micro-cycle only becomes apparent in the older age-groups (U16-U18) which may have implications for energy periodisation. TEE progressively increases in accordance with anthropometric profile, RMR and physical loading. In some players TEE is comparable to or exceeds that previously reported in adult Premier League soccer players. When taken together, these data enhance our understanding of the energy requirements of academy soccer players and will assist in the formulation of population specific sports nutrition guidelines.

Chapter 8

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