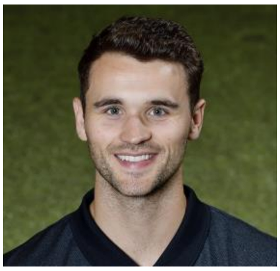
Energy and macronutrient considerations for young athletes

Marcus P Hannon[1], Prof Graeme L Close[1], Prof James P Morton[1]

[1] Research Institute for Sport and Exercise Sciences (RISES), Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF

Marcus Patrick Hannon,
BSc (Hons), MSc
PhD candidate
Liverpool John Moores University



Graeme Leonard Close
BSc (Hons), PhD
Professor of Human Physiology
Liverpool John Moores University

James Peter Morton
BSc (Hons), PhD
Professor of Exercise Metabolism
Liverpool John Moores University

Corresponding author: Marcus Hannon; Tom Reilly Building, Byrom Street, Liverpool, L3 3AF, England; m.p.hannon@2015.ljmu.ac.uk

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ABSTRACT
Young athletes undergo many anatomical and physiological changes during the first two decades of life as a result of growth and maturation. Such changes influence a young athlete's nutritional requirements and it is therefore inappropriate to apply nutritional guidelines for adult athletes to this population. Nutritional recommendations for young athletes should not only focus on sporting performance but should also meet the requirements to ensure optimal growth, maturation and physical development. This review

article provides an overview of the nutritional recommendations for young athletes based on the best available literature from a range of sports.

INTRODUCTION AND OVERVIEW OF YOUNG ATHLETES

Despite some young athletes competing against adults at the highest level, young athletes cannot simply be considered 'mini adults'. As a young athlete progresses from childhood (years up until the onset of adolescence) through adolescence (identified with the onset of sexual maturation / puberty) and into adulthood (achieved once fully mature, i.e. fully ossified skeletal system, a fully functioning reproductive system or the attainment of adult stature), they undergo many anatomical, physiological and metabolic changes as a result of biological growth and maturation (56). 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 (35). The primary focus for practitioners working with young athletes should be to ensure that the nutritional requirements for growth and maturation are met amongst their athletes (16). There are several differences in substrate storage and substrate metabolism in young athletes compared to adult athletes, with numerous physiological and metabolic changes accompanying growth and maturation in the young athlete. These changes in physiology and metabolism subsequently influence the nutritional requirements of the young athlete (**Table 1**).

<TABLE 1>

Table 1. The main anatomical, physiological and metabolic differences between young and adult athletes. Adapted from (26).

There are a number of inter-linked key factors that influence a young athlete's nutritional requirements: 1) their current anthropometric profile, rate of growth and maturity status / timing, 2) their current physiological and metabolic capabilities, and 3) their sport and exercise demands. Before developing sport specific nutritional requirements for young athletes, it is essential to gain a greater understanding of these factors and the inter-play between them. It should also be noted that mostly, any sex differences in nutritional requirements are primarily driven by differences in size between boys and girls, with the exception of iron which has been reviewed in detail elsewhere (3). Consequently, macronutrient (carbohydrate, fat and protein) requirements (particularly carbohydrate and protein) are prescribed per kilogram of body mass, to account for individual differences in body size.

ENERGY CONSIDERATIONS

A young athlete's energy intake is provided through the consumption of the macronutrients, carbohydrate, fat and protein. The energy intake of each young athlete should be dictated by their total energy expenditure (i.e. their energy requirements) to optimise not only growth and maturation but also stimulate training adaptations, promote recovery and of course, sporting performance. Therefore, before giving specific macronutrient recommendations, it is first essential to understand the typical energy expenditures experienced by young athletes from different sports but also those at different ages / stages of maturation (within a certain sport).

Total energy expenditure is comprised of three contributing factors: 1) basal metabolism (typically known as resting metabolic rate; the amount of energy required to maintain normal homeostatic physiological function in a rested, fasted and thermoneutral state); 2) thermic effect of food (also known as diet induced thermogenesis; the energy costs of digestion, transport and absorption and storage of food and drink), and 3) activity energy expenditure from planned sport and exercise and non-exercise activity thermogenesis (NEAT) (21).

During growth, energy is required to synthesise new tissue and also for deposition into this new tissue (61). The highly variable rates of growth and maturation between young athletes (36), particularly around peak height velocity (the maximum rate of growth in stature during adolescence), will influence an individual's energy requirements, particularly their resting metabolic rate (RMR). Whilst RMR is usually the largest component of energy expenditure in the general population (54), this is often not the case in athletic populations, particularly in young athletes with high training loads and subsequent high total energy expenditures (49). We have recently observed that basal energy requirements (resting metabolic rate) in Premier League academy soccer players (11-21 years old) range from 1347 – 2382 $kcal.day^{-1}$ (24). In this study, as players increased in age (until age 14), RMR also increased in a stepwise fashion, which coincided with increases in stature, body mass, fat-free mass and maturity status (**Figure 1**). However, once the influence of body size variable (both stature and fat-free mass) was removed (via allometric scaling), relative RMR (i.e. $kcal.kg\ FFM.day^{-1}$) was similar between players of all ages (24).

<FIGURE 1>

Figure 1. Adapted from (24): a comparison of (A) resting metabolic rate (RMR), (B) fat-free mass, (C) fat mass and (D) 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.

In young athletes, activity energy expenditure is often the greatest contributor to total energy expenditure (49). Activity energy expenditure is the most variable component of total energy expenditure and it is influenced by both anthropometric profile (i.e. body size) and locomotion. Thus, the type, duration and intensity of exercise all influence activity energy expenditure. This results in a large inter-individual variability in total energy expenditure between young athletes, even those within the same sport (**Table 2**). Therefore, the energy requirements for non-athletic children and adolescents nor the requirements of adult athletes are appropriate for young athletes.

Considering the many factors that contribute to a young athlete's total energy expenditure, this value will almost certainly vary day-to-day, making it difficult to prescribe exact energy requirements for young athletes. Research studies using gold standard methods (such as the doubly labelled water technique) to assess total energy expenditure, provide an insight into typical expenditures of the specific young athlete population that was assessed (**Table 2**). However, whilst it is difficult to prescribe exact energy requirements for young athletes, it is strongly recommended that young athletes are not in a negative energy balance and have sufficient energy availability (EA) for growth. Energy availability is the amount of energy left for homeostatic physiological functions and growth once activity energy expenditure has been deducted from energy intake and is relative to fat-free mass (FFM) [EA = (energy intake – AEE) / FFM] (34). 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, increased risk of stress fractures, increased risk of osteoporosis later in life, delayed sexual maturation, disruption or cessation of menstruation and a suppression of the immune system (34). Not only is this likely to have a negative effect on a young athlete's performance but also their long-term physical and psychological health. An energy availability of ≥45 kcal.kg FFM^{-1}.day^{-1} is recommended for adult athletes to maintain normal physiological function (34). Considering young athletes have greater relative energy demands than adults, ≥45 kcal.kg FFM^{-1}.day^{-1} is likely to be the *minimum* a young athlete would require, however further research is required. Due to the difficultly of accurately quantifying energy availability, few studies have report it in young athletes (11). Koehler and colleagues (32) reported a mean energy availability of 29 and 29 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. In English Premier League academy soccer players, assessed over a seven day period, we recently observed estimated energy availabilities of 69 ± 10 kcal.kg FFM^{-1}.day^{-1}, 51 ± 9 kcal.kg FFM^{-1}.day^{-1} and 41 ± 15 kcal.kg FFM^{-1}.day^{-1} in U12/13, U15 and U18 age-groups respectively (25). Whilst we acknowledge that under-reporting of energy intake does occur in young athletes (33,49), available data would still suggest that a negative energy balance is common in this population (**Table 2**); this is particularly apparent in young basketball players (49) and swimmers (62). In these sports, is it advised that these young athletes increase their energy (and therefore macronutrient) intake to prevent any detrimental consequences of low energy availability. Given the potential detrimental consequences of low energy availability in young athletes, more research in this area is required.

<TABLE 2>

Table 2. Energy intakes, expenditures and estimated energy balance of young athletes in different sports. Adapted from (26).

CARBOHYDRATE CONSIDERATIONS

The type of exercise, as well as exercise duration and intensity dictate a young athlete's carbohydrate requirements; as duration or intensity increases, so does an athlete's carbohydrate requirements (30). Given glycogen depletion is a major cause of fatigue in both endurance and high-intensity intermittent exercise, it is essential that young athletes consume sufficient carbohydrate in their diet for performance and recovery from training and competition. Considering young athletes do not have the same ability to store glycogen as adult athletes (20) and on the most part their competition is shorter in duration, classical carbohydrate loading protocols prior to competition are not likely necessary; though currently no data on young athletes exists.

There is also little information on glycogen utilization during exercise in young athletes, due to the invasive techniques used to assess muscle glycogen. Muscle biopsy studies undertaken in Scandinavia in the 1970's demonstrated that muscle glycogen concentrations decreased by ~52% (from ~304-146 mmol.kg^{-1}.dry weight) following a bout of incremental cycling exercise to volitional fatigue in 11 and 12 year old boys (19). A comparative study in adults reported decreases in muscle glycogen concentrations from ~280-90 $mmol.kg^{-1}$.dry weight (~68% decrease) following a similar cycling protocol to volitional fatigue (27). Glycogen depletion of ~36% (assessed via magnetic resonance spectroscopy) was observed in elite young soccer players (~17 year old males) during a time-to-exhaustion soccer specific running test (43).

When exogenous carbohydrate is consumed during exercise, the oxidation rate of exogenous carbohydrate, relative to body mass, is higher in greater in children and adolescents compared to adults (58). As a result, the relative contribution of exogenous carbohydrate towards total energy production is greater in young athletes compared to their adult counterparts (58). This appears to be more pronounced in less mature boys compared to boys that are more biologically advanced (59); although this is not the case in females (60). The authors of this study suggested that estrogen, glucocorticoids or perhaps differences in enzyme activity within the contracting muscle may result in differences in females of different levels of maturation, however these suggestions were speculative and require further exploration (60). However, absolute exogenous carbohydrate oxidation rates (i.e. $g.min^{-1}$) do not appear different between children and adults (30). It has been suggested that because (absolute) exercising energy expenditure is higher than in adults than children and adolescents (due to larger anthropometric profiles and higher absolute intensities), despite similar rates of absolute exogenous carbohydrate oxidation, adults will have a lesser contribution of exogenous carbohydrate towards energy expenditure (30). Therefore, during exercise, carbohydrate recommendations for young athletes are similar those for adult athletes. During moderate-to-high intensity exercise lasting longer than 60 minutes young athletes should consume 30 – 60 $grams.hr^{-1}$ and should not consume more than 1 $g.min^{-1}$ of carbohydrate (16). Liquid forms of high-GI carbohydrates are recommended due to the additional benefits on fluid consumption. This should be in the form of a 6% carbohydrate drink (i.e. a commercial sports drink), as drinks with a higher carbohydrate content (8%) have been shown to increase gastrointestinal discomfort in both male and female adolescents (48). Competition rules and regulations may dictate when carbohydrate (and fluid) consumption can occur. Athletes and practitioners should make both carbohydrates and fluids easily accessible (e.g. side of a pitch) for when competition rules allow.

In addition to sparing endogenous carbohydrate stores (44), exogenous carbohydrate consumption during exercise has also been shown to reduce the perception of effort (RPE) during exercise and benefit performance across different types of exercise. Research has shown that consumption of a 500 ml 6% carbohydrate solution (~35 $grams.hr^{-1}$ of carbohydrate) during intermittent high intensity exercise improved exercise capacity in 12 - 14 year old boys compared to a placebo (42). Improvements of 40% in a time to exhaustion test, performed on a cycle ergometer, have also been reported following consumption of a 6% glucose and fructose solution (25 $ml.kg^{-1}$) in 10-14 year old boys (45).

Following glycogen depleting exercise, post-exercise carbohydrate ingestion should be consumed to replenish glycogen stores. Data from adults have shown that the greatest rates of glycogen re-synthesis occur in the first hour after exercise, and by delaying carbohydrate intake by two hours, glycogen re-synthesis is attenuated (28); however no data in young athletes exists. Therefore, advice for young athletes is the same as adult athletes: 1.2 $g.kg^{-1}.h^{-1}$ of high-GI carbohydrate should be consumed in the two hours immediately post-exercise. High-GI carbohydrates rapidly elevate blood glucose and promote glycogen re-synthesis and are therefore preferred to low-GI carbohydrates during this timeframe (29). The precise amount of carbohydrate to be consumed post-exercise is dependent on the recovery period until the next training session/competition, and also the intensity and duration of that next training session. Short recovery periods will require a more aggressive approach (i.e. greater amounts of carbohydrate) whereas young athletes that compete once a week may not require such a high carbohydrate intake post-competition. Fructose (contained in fruit and fruit juices) and galactose (contained in dairy products) are more effective than glucose in promoting liver glycogen re-synthesis, and are therefore recommended post-exercise (15). The consumption of protein alongside suboptimal quantities of carbohydrate has also been shown to accentuate glycogen re-synthesis (6). A milk-based fruit smoothie is therefore a good option post-exercise, as it contains all of the aforementioned nutrients.

Data from adults has shown that consuming carbohydrate before, during and after an acute training session attenuated markers of bone resorption (i.e. bone break down), however the chronic implications of this are unclear (i.e. long-term morphological changes to bone) (23). Given the importance of maximising bone mineral accrual in young athletes to maximise peak bone mass and help reduce the risk of skeletal injuries and osteoporosis in adulthood, carbohydrate intake before, during and after exercise may be warranted to attenuate bone resorption (22,23). An example of suitable carbohydrate foods / drinks pre-, during and post-exercise would be a bowl of cereal, a commercially available sports drink and a glass of flavoured milk, respectively.

Owing to the lack of accurate data on the typical total energy expenditures, it is currently difficult to accurately recommend specific carbohydrate requirements for young athletes training and competing in different sports. Daily carbohydrate intake varies between different sports and age-groups, with most young athletes typically consuming anywhere between 3 - 8 $g.kg^{-1}$ (9,13,40,41,49). From the author's own practice, we would suggest daily carbohydrate intakes of 6 - 10 $g.kg^{-1}$ for young athletes. Whilst further research is required to confirm these suggestions, carbohydrate requirements will differ according to the type of exercise (and sport), exercise duration and intensity.

FIBRE CONSIDERATIONS

Fibre is the structural part of plant-based carbohydrates that is indigestible. Fibre consumption promotes normal laxation, modulates post-prandial hyperglycaemia and is associated with good cardiovascular health (51). Current UK fibre guidelines recommend a daily intake of ≥25 $g.day^{-1}$ for <16 year olds and ≥30 $g.day^{-1}$ for those >16 years old (46). However recent research from our group has shown that young soccer players (aged 12-17) consume less than the current recommendations (~19 $g.day^{-1}$) (39). Given the benefits of fibre consumption for health, young athletes should aim to achieve at least these current daily recommendations. Foods high in fibre include wholegrain breads and cereals, oats, legumes, certain fruits and vegetables, with refined foods (e.g. white bread) generally have a reduced fibre content. Consequently, young athletes should consume wholegrain alternatives (e.g. wholegrain bread) over these refined foods to ensure an adequate fibre intake.

FAT CONSIDERATIONS

Dietary fat is required to promote absorption of fat soluble vitamins and also to supply essential fatty acids (omega-3 and omega-6 fatty acids) which cannot be synthesised by the body and therefore must be obtained through the diet (50). Fat also contributes to energy production during exercise, particularly when exercise exceeds 60 - 90 minutes. Fats are generally classified as saturated or unsaturated, based on their chemical structure, with unsaturated fats being further subdivided into mono-unsaturated or poly-unsaturated.

Traditionally saturated fats have been classed as 'bad' fats whereas unsaturated fats have been classified as 'good' fats. Inclusion of unsaturated fats such as oily fish, avocados, nuts and seeds in the diet has been shown to have a number of health benefits. Furthermore, individual saturated fatty acids have differing effects on blood lipid levels depending on their composition. For example, lauric acid (found in high concentrations in coconut oil), actually decreases total-to-high density lipoprotein cholesterol ratio, due to an increase in high density lipoprotein cholesterol. Therefore, instead of recommending types of fat, recommending types of food is considered more appropriate (4). Young athletes should choose natural sources of fat, particularly those high in omega-3 (including oily fish, nuts and seeds). Processed sources of fat such as trans-fats (contained in processed foods such as fast food, margarine, pastry, cakes and biscuits) should be limited as they increase low density lipoprotein cholesterol and lower high density lipoprotein cholesterol, increasing risk of cardiovascular disease (4).

There is no evidence to suggest a young athlete's fat requirements should differ from their non-athletic peers, however as previously discussed, young athletes should maintain a slight energy surplus for optimal growth and maturation. Fat should provide ~35% of total energy intake, with no more than 11% coming from saturated fats in children and adolescents (10). Considering this, young athletes should have a greater absolute fat intake compared to their non-athletic peers because of their higher energy intake (which is a consequence of their higher energy expenditure). Research suggests that young male and female athletes across a range of different sports have a daily fat intake of ~1.5 $g.kg^{-1}$ equivalent to ~30-35 % of energy intake (9,13,41,49). Considering fat is the most energy dense macronutrient (~9 kcal per gram, compared to ~4 kcal per gram for both carbohydrate and protein), young athletes that compete in endurance, weight-making and aesthetic sports (where having a low body / fat mass are often seen as desirable) may choose to limit their fat intake. This should be avoided to prevent chronic negative energy availability and also deficiencies in certain fat-soluble vitamins (vitamins A, E and K), omega 3 and 6 fatty acids and potentially iron and calcium.

PROTEIN CONSIDERATIONS

Protein is an essential macronutrient that has a wide variety of functions in the body. It is required to support turnover of tissues and contribute to tissue growth in young athletes (61). Additionally, proteins provide the building blocks (amino acids) to make many thousands of enzymes that are required in order to provide energy from the breakdown of carbohydrate and fat. There are 20 amino acids that are required to synthesise new proteins, 8 of which are classified as essential (i.e. they must be obtained through the diet) and 12 of which are classified as non-essential (i.e. the body can synthesise these amino acids). The amino acids leucine, isoleucine and valine are essential amino acids collectively known as branched chain amino acids and are particularly important to facilitate muscle protein synthesis, especially leucine (57).

The protein requirements of young athletes are not further increased during periods of growth spurts (1). A number of nitrogen balance studies in adolescent sprinters and soccer players (1,7) have reported that a positive nitrogen balance was achieved with protein intakes between 1.4 - 1.6 $g.kg^{-1}.day^{-1}$ in both young male and female athletes. However, in one of the studies, it was reported that in two of the young athletes, a negative nitrogen balance still occurred despite a protein intake of 2 $g.kg^{-1}.day^{-1}$ (1). Based on this information, daily protein intakes of 1.4 - 2 $g.kg^{-1}$ are recommended for young athletes. For example, a young 50 kg athlete would require 70 – 100 grams of protein per day (50 x 1.4 – 2.0). Research suggests that young male and female athletes across a range of different sports are achieving these protein targets, with a daily intake of ~1.5-2.0 $g.kg^{-1}$ (9,13,41,49).

Similar to adults, studies in active children have also shown that timing of protein intake influences whole-body protein balance. Protein should be consumed at breakfast to shift whole-body protein balance from a negative into a positive state (31), and moderate doses of protein (0.22 - 0.33 $g.kg^{-1}$ per meal/snack) should be consumed every 3 - 4 hours throughout the day (64). For a young 50 kg athlete, this would equate to around 11 – 17 grams of protein (the amount typically found in two eggs or 500 ml of milk). Protein consumption is of particular importance pre-exercise (to increase amino acid availability) and also post-exercise. In the absence of post-exercise protein consumption, whole-body protein balance remains negative in active 9 - 13 year-olds (63). However, consumption of only 5 grams (0.12 $g.kg^{-1}$) post-exercise promotes a positive whole-body protein balance, suggesting that children have an increased sensitivity (relatively) to protein feeding in the 3-hours post-exercise compared to adults. Further increases in a positive whole-body protein balance have been reported following intakes of 10 and 15 grams (0.22 and 0.33 $g.kg^{-1}$) in the 6 hours post-exercise, in a dose-dependent manner (64). Protein should also be consumed prior to sleep to provide a supply of amino acids to the muscle overnight and promote increases in muscle mass and strength (53). A recent study has demonstrated that daily protein distribution is skewed in young soccer players, with lower intakes at breakfast and higher intakes consumed during the evening meal (40). Adding a glass of milk at breakfast is an inexpensive, quick and effective way to increase protein intake at this meal.

It is recommended that leucine rich sources of protein including dairy products (milk, yogurts and cheese), eggs, meat, poultry and fish are consumed by young athletes, given their importance in facilitating muscle protein synthesis. It is also recommended that young athletes consume non-animal sources of protein include beans, pulses, lentils, nuts and seeds, however it should be noted that these sources lack a number of essential amino acids including leucine. Soy beans are one of the only plant based sources of protein that contains all essential amino acids (37). Practitioners working with young vegetarian athletes should closely monitor their protein intake to ensure they are consuming enough in their diet. A young athlete is more than capable of meeting their daily protein requirements through food and drink sources (given their smaller size), so consumption of protein supplements (e.g. protein shakes) are not necessary or advised for this population.

PRACTICAL APPLICATION

Interpreting the science and putting the current energy and macronutrient recommendations into practice is imperative for the success of a young athlete. A guide of how to devise an individualised nutrition plan for a young athlete is presented in **Figure 2**. This guide provides a step-by-step practical outline, which may be used by key stakeholders working with young athletes (e.g. sports science and medicine staff, parents etc). Whilst it is obviously essential to understand the training and competition demands of each sport in addition to a young athlete's energy expenditure and dietary intake, other objective (e.g. growth rate) and subjective (e.g. feelings of fatigue) assessments can also assist in determining whether or not a youth athlete is achieving appropriate energy and macronutrient requirements.

<FIGURE 2>

Figure 2. A guide of how to devise an individualised nutrition plan for a young athlete.

Table 3 also provides an example of a young soccer players daily energy and macronutrient intake. In this example, this young soccer player is achieving an appropriate energy and macronutrient intake (energy availability - 53 kcal.kg FFM^{-1}.day^{-1}; carbohydrate - 9.3 g.kg^{-1}; fat - 30% of energy intake; protein intake - 2.3 g.kg^{-1}) to support optimal growth, maturation, physical development and sporting performance. In addition to the total amounts of macronutrients, timing of consumption is also particularly important (especially carbohydrate and protein), young athletes should carefully plan when they are going to eat and drink. Young athletes should aim to eat regularly throughout the day (every 3 to 4 hours) which should be planned around their busy school and training / competition schedules. This will help ensure young athletes are fuelling appropriately for training and competition, promoting recovery post-exercise, stimulating training adaptations as well as optimising their growth and maturation.

<TABLE 3>

An example of a young soccer players daily energy and macronutrient intake. This player attends school, has 90 minutes of soccer training and is aiming to achieve >3300 kcal.day^{-1}. 15 year old male; maturity offset = 1.0 years; stature = 176 cm; body mass = 50 kg; fat-free mass = 39 kg; fat mass = 11 kg; resting metabolic rate = 2000 kcal.day^{-1}; estimated energy availability (based on a total energy expenditure of 3500 kcal.day^{-1}) = 53 kcal.kg FFM^{-1}.day^{-1}. Adapted from (26).

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Table 1

Table 1. The main anatomical, physiological and metabolic differences between young and adult athletes. Adapted from (26).

Summary of main anatomical, physiological and metabolic differences between young 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 young athletes. Whilst fat mass does not appear to significantly change throughout growth and maturation in young athletes, increases in body mass are primarily derived from an increase in fat-free mass (24). 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) (5). Changes in fat-free mass and stature are significantly influenced by the energy and macronutrient intake of a young athlete during childhood and adolescence (16).
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 (38).
Higher rates of aerobic metabolism It is well documented that higher rates of aerobic metabolism exist in young 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 (58).
Reduced glycogen storage capacity Young athletes, particularly those that are pre-pubertal have lower endogenous glycogen storage capacity compared to older, more mature young athletes and adult athletes (20).
Reduced glycolytic capabilities Young athletes have reduced glycolytic capabilities, with full anaerobic capabilities developing towards the end of puberty (55). Consequently, young athletes have lower levels of lactate production than their adult counterparts during high intensity exercise of the same relative intensity (19,20).
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 greater in children and adolescents compared to adults (58). Relative exogenous carbohydrate oxidation rates are higher in less mature boys compared to more mature boys of the same chronological age (59); although this is not the case in girls (60).

Figure 1

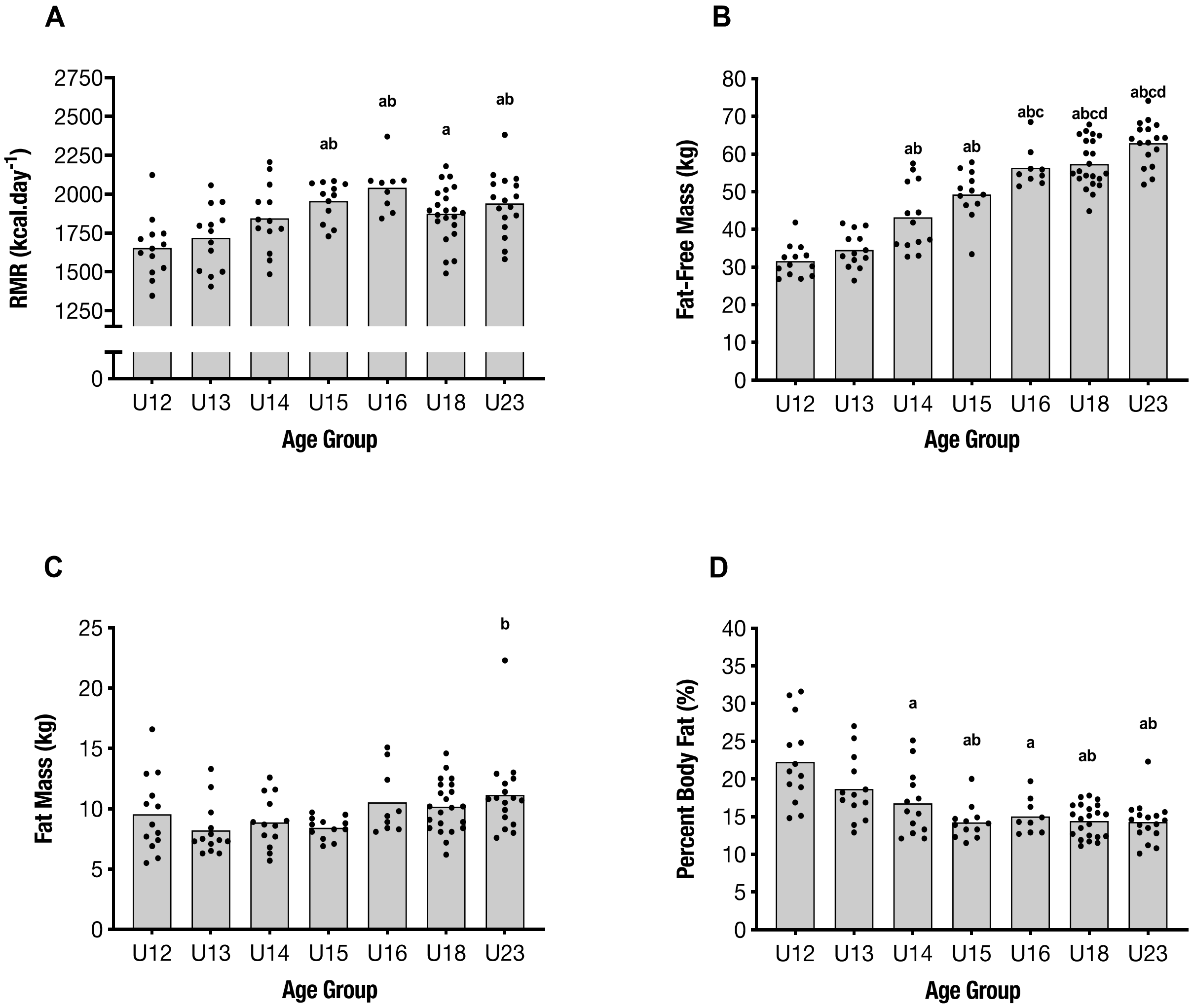

Figure 1. Adapted from (24): a comparison of (A) resting metabolic rate (RMR), (B) fat-free mass, (C) fat mass and (D) percent body fat between youth soccer players (U12-U23 age groups; n = 99) from a Category One English Premier League academy. [a] denotes significant difference from U12 age group, 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.

Table 2

Table 2. Energy intakes, expenditures and estimated energy balance of young athletes in different sports. Adapted from (26).

Sport	Training & Competition Load	Age (years)	Sex	EI Method	EI (kcal.day^{-1})	EE Method	EE (kcal.day^{-1})	EEB (kcal.day^{-1})
Active Adolescents (8)	-	~15	M & F	-	-	DLW 7 days	M: 3361 ± 557 F: 2546 ± 392	-
Team Sports								
Basketball (49)	>10 hours per week	~17	M & F	24-hour recall 7 days	M: 2895 ± 479 F: 1807 ± 46	DLW 7 days	M: 4626 ± 682 F: 3497 ± 242	M: -1731 F: -1690
Rugby (52)	-	~15	M	-	-	DLW 14 days	4010 ± 744	-
Soccer (25)	U12: ~330 min per week U15: ~435 min per week U18: ~423 min per week U12: ~19 km per week U15: ~27 km per week U18: ~27 km per week	~12 ~15 ~18	M	RFPM 24-hour recall 7 days	U12: 2673 ± 203 U15: 2821 ± 338 U18: 3176 ± 282	DLW 14 days	U12: 2859 ± 265 (range: 2738 – 3726) U15: 3029 ± 262 (range: 2275 – 3903) U18: 3586 ± 488 (range: 2806 – 5172)	U12: -29 ± 277 U15: -134 ± 327 U18: -243 ± 724
Soccer (9)	~85 minutes per day	13-17	F	Food diary 7 days	2262 ± 368 (range: 1702 – 3194)	Activity diary 7 days	2403 ± 195 (range: 1946 – 2753)	-141
Strength & Power Sports								
Speed Skating (18)	-	~18	M	-	-	DLW 10 days	4013 ± 908 (range: 3057 – 5971)	-
Sprinters (2)	-	13-19	M & F	Food diary 7 days	2569 ± 508	Activity diary SenseWear armband 7 days	3196 ± 590	-627
Aesthetic Sports								
Gymnastics (14)	4 hours per day	6-8	M & F	Weighed food diary 4 days	1744 ± 444	DLW 10 days	2004 ± 258	-260
Endurance Sports								
Endurance Runners (17)	>30-40 weeks per year	10-19	M & F	-	-	Activity diary 3 days	M: 3609 ± 928 F: 2467 ± 426	-
Swimmers (62)	~5-6 hours per day	~19	F	Food diary 2 days	3129 ± 239	DLW 5 days	5589 ± 502	-2460
Miscellaneous Sports								
Table Tennis (47)	~3 hours per day	~19	M	Food diary RFPM 14 days	3211 ± 566	DLW 14 days	3695 ± 449	-484
Young athletes* (12)	≤ 5 times per week	~15	M & F	-	-	Activity diary 7 days	M: 3635 ± 828 F: 3100 ± 715	-

* Those engaged in either athletics, soccer, handball, rowing, canoeing, swimming or triathlon. M = males. F = females. EI = energy intake. RFPM = remote food photographic method. EE = energy expenditure. DLW = doubly labelled water. EEB = estimated energy balance.

Figure 2

1. Understand the training and competition demands

Consult the relevant scientific literature to assess the energetic requirements of training and competition. E.g. the training and competition schedule of an elite youth football player will be very different to that of an elite youth track and field athlete. Do not extrapolate results from adult studies and apply to young athletes!

2. Assessment of anthropometry

Conduct regular assessments of height, seated height and body mass to determine maturation status. These assessments should be made (every 8-12 weeks) to determine changes in maturation status and rates of growth (26). Rates of growth can be compared against population normative growth curves or against data in the scientific literature. Assess body composition using the most appropriate method for the specific population, e.g. ISAK skinfolds, dual-energy x-ray absorptiometry (DXA), Bod Pod etc. Standardize all assessment procedures for time of day, hydration status, prior exercise dietary intake as failure to do so may reduce measurement accuracy. Each team should establish their own levels of reliability.

3. Assessment of energy expenditure

Conduct an assessment of exercise and daily energy expenditure across multiple days (including training, competition and rest days) using the most appropriate method, e.g. GPS, heart rate monitors, accelerometers, ActiHeart, Sense Wear armbands, doubly labelled water (DLW) etc. It is also important to account for the energy expenditure of growth (particularly circa peak height velocity). Also assess resting metabolic rate (RMR) via indirect calorimetry or use population specific prediction equations available in the scientific literature (24).

4. Assessment of dietary intake

Conduct an assessment of dietary intake using the most appropriate method for the specific nutritional problem, e.g. food frequency questionnaire, 24-hour recall, 3-7 day food diary, remote food photographic method etc. Ensure relevant education is provided prior to assessment and that a suitable dietary analysis software is used.

5. Assessment of subjective wellness

Assessment of daily wellness scores (e.g. sleep, fatigue, muscle soreness, mood etc) may help inform assessment of under-fuelling, poor recovery, over-training and symptoms of low energy availability.

6. Determine any symptoms of low energy availability

Under-fueling can lead to a number of detrimental performance and health implications including:

- decreased cardiovascular fitness, strength and power output
- impaired coordination and decision making / judgement
- reduced ability to concentrate alongside increased irritability
- increased feelings of fatigue and reduced ability to recover properly
- impaired immune system (may lead to increased frequency and/or severity of illness)
- reduced bone mineral density (increasing risk of fractures)

In combination with the data obtained from assessments of energy expenditure and intake, determine any signs and symptoms of low energy availability.

7. Formulation of dietary plan

Develop a tailored nutritional plan with the athlete and relevant stakeholders (parents/guardians, coaches and wider members of the sports science and medicine team). Ensure the plan has clear targets and timescales and that all interventions have been documented and monitored throughout the support period.

8. Evaluate and refine

Once the intervention is completed self-evaluate and evaluate with others (the athlete, parent/guardian, sports science and medical staff) the the positives and negatives of the process and outcome and implement any lessons into future practice.

Figure 2. A guide of how to devise an individualised nutrition plan for a young athlete.

Table 3

Table 3. An example of a young soccer players daily energy and macronutrient intake. This player attends school, has 90 minutes of soccer training and is aiming to achieve >3300 $kcal.day^{-1}$. 15 year old male; maturity offset = 1.0 years; stature = 176 cm; body mass = 50 kg; fat-free mass = 39 kg; fat mass = 11 kg; resting metabolic rate = 2000 $kcal.day^{-1}$; estimated energy availability (based on a total energy expenditure of 3500 $kcal.day^{-1}$) = 53 $kcal.kg\ FFM^{-1}.day^{-1}$. Adapted from (26).

Type of meal/snack and time	Food / Fluids	Nutritional content
Breakfast 07:00	Large bowl of muesli with 250 ml of full-fat milk, honey and a banana	**Kcal:** 778 **Carbohydrate:** 109 g **Fat:** 30 g **Protein:** 18 g
Mid-morning snack 10:00	1 large full-fat Greek yogurt pot 1 cereal bar 1 apple 300 ml water with squash	**Kcal:** 437 **Carbohydrate:** 57 g **Fat:** 15 g **Protein:** 18 g
Lunch 13:00	Spaghetti bolognaise (minced beef, onion, canned tomatoes, garlic, mixed herbs) with whole-wheat spaghetti 300 ml carton of orange juice	**Kcal:** 620 **Carbohydrate:** 96 g **Fat:** 14 g **Protein:** 28 g
Pre-training snack 16:00	Sandwich (2 slices of wholegrain bread with butter, 2 slices of ham, cheese and lettuce) 300 ml water with squash	**Kcal:** 368 **Carbohydrate:** 35 g **Fat:** 17 g **Protein:** 19 g
During training 17:00 – 18:30	500 ml sports drink	**Kcal:** 140 **Carbohydrate:** 33 g **Fat:** 0 g **Protein:** 0 g
Dinner (post-training) 19:00	300 ml of pineapple juice 1 small salmon fillet with pesto, medium portion of white rice and green beans 1 fruit yogurt	**Kcal:** 786 **Carbohydrate:** 119 g **Fat:** 24 g **Protein:** 24 g

Pre-bed 21:00	300 ml of full-fat milk	**Kcal:** 198 **Carbohydrate:** 14 g **Fat:** 11 g **Protein:** 11 g
		DAILY TOTAL **Kcal:** 3327 **Carbohydrate:** 463 g / 9.3 $g.kg^{-1}$ **Fat:** 111 g / 2.2 $g.kg^{-1}$ / 30 % of energy intake **Protein:** 118 g / 2.3 $g.kg^{-1}$