3.1 Different populations

3.1.1 Vegetarians and vegans

There is no doubt that there is a trend for more people and also more players to become vegetarian or vegan. Plant-based diets represent a growing area of interest in the promotion of physical and environmental health (Lynch, Johnston, & Wharton, 2018). Without going into an environmental discussion, here we want to explore whether it is possible to perform at the highest level on such a diet.

The short answer to the question if elite football and plant-based diets are compatible is most likely "yes, it is possible, but it is going to be challenging". "These challenges include the digestibility and absorption of nutrients such as protein, calcium, iron and zinc, meaning that athletes might need to consume higher amounts of these foods compared to omnivores and other vegetarians"(Rogerson, 2017, https://bit.ly/2hwineX). For example, animal foods are good sources of protein and iron, and by excluding these sources, it will become more challenging to find replacements. Especially with respect to protein "replacement", this means not only the quantity but also the quality. It is known that animal protein is of higher quality than plant protein. Similarly, iron from animal sources is better absorbed than iron from plant sources. Therefore, it is not simply replacing 100 g of protein from animal sources with 100 g of protein from plants or 50 mg of iron from meat with 50 mg of iron from spinach. In order to get the same effects, far larger quantities of plant derived foods should be consumed. This may not be easy because plant-based foods produce more satiety. "Vegan diets (and probably vegetarian diets to a lesser degree) therefore tend to be lower in calories, protein, fat, vitamin B12, n-3 fats, calcium and iodine than omnivorous diets (Rogerson, 2017). On the other hand, plant-based diets tend to be higher in carbohydrates, fibre, micronutrients, phytochemicals and antioxidants." (Rogerson, 2017, https://bit.ly/2hwineX).

Protein quality

> Animal sources of protein appear more effective for muscle building than plant proteins or at least increasing muscle protein synthesis. Consistent with this idea, laboratory studies have reported a greater post workout response of muscle protein synthesis when strength-trained young

men consumed either skimmed milk or whey protein vs. a matched dose of soy protein (Tang, Moore, Kujbida, Tarnopolsky, & Phillips, 2009; Wilkinson et al., 2007). As further proof that animal proteins trump plant proteins, a study in middle-aged men revealed a greater stimulation of muscle protein synthesis at rest after ingesting a 100g lean beef steak vs. a soy protein marketed and sold as a bona-fide replacement for beef (Witard, 2018). Plus, in healthy older adults, ingesting 35 grams of micellar casein protein stimulated a greater MPS response compared with a matched dose of the cereal protein, wheat. (Jeukendrup, 2017, https://bit.ly/2mll1tn)

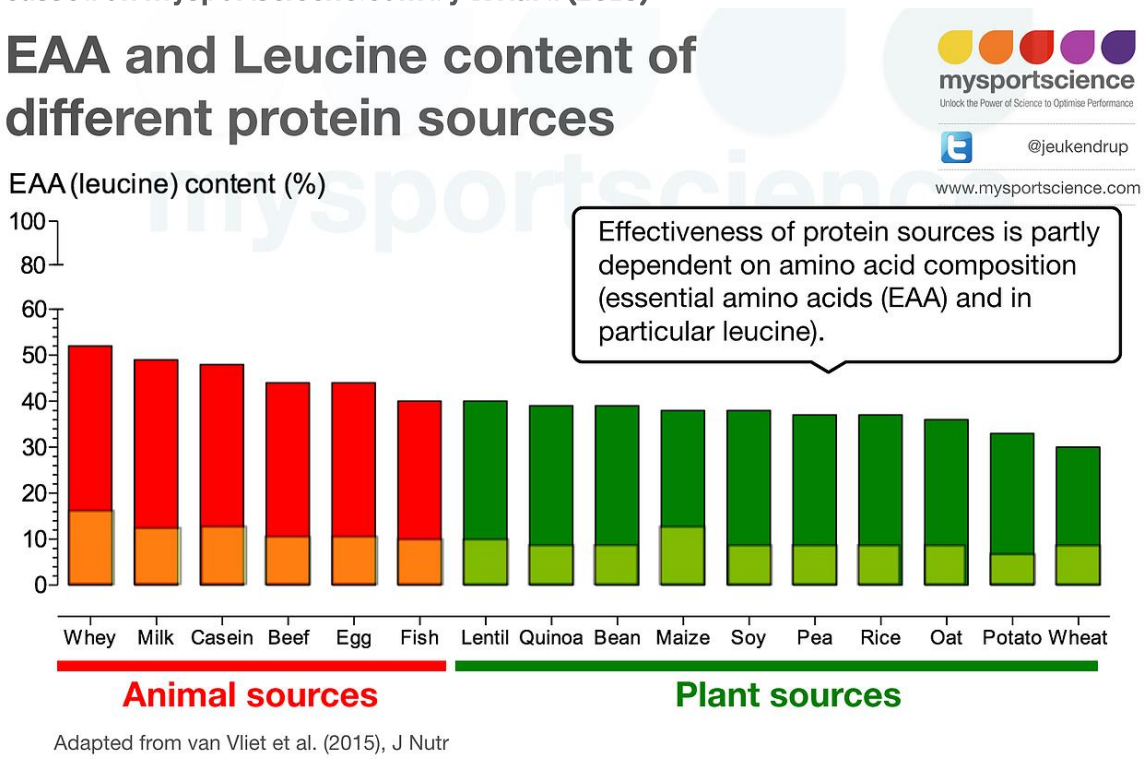
There are several more studies, reviewed in (Witard, Wardle, Macnaughton, Hodgson, & Tipton, 2016) that indicate that animal proteins are more effective in stimulating protein synthesis than plant-based proteins.

“Different protein sources are characterized by unique digestive properties and amino acid profiles. Most animal-based protein sources, including dairy, meat and eggs are more digestible than plant proteins such as soy, wheat, rice and potato.” (Jeukendrup, 2017, https://bit.ly/2mll1tn)

There are a number of reasons for this. One of the reasons is the presence or absence of antinutritional factors, compounds that affect digestibility of the protein. Antinutritional factors naturally occur more often in vegetable foods and include glucosinolates, trypsin inhibitors, haemagglutinins, tannins, phytates, and gossypol. These factors, often found in plant foods such as beans, legumes, soybeans, and cereals all reduce the digestibility of protein but may work in different ways. One action mechanism includes the disruption of enzymes involved in protein digestion (trypsin inhibitors), Phytate, found in nuts, seeds, and grains, binds with proteins in the digestive tract, reducing their absorption. The digestibility can be improved by food preparation: soaking, fermentation, and germination will all help.

“A greater percentage of amino acids derived from animal protein sources successfully negotiate the small intestine and reach the circulation, rather than being extracted by the gut or taken up by the liver. As such, more amino acids (or building blocks) become available to the muscle for making new muscle protein, i.e. muscle protein synthesis, after ingesting most animal vs. plant protein sources.” (Jeukendrup, 2017, https://bit.ly/2mll1tn)

Figure 1: Proteins and their essential amino acid and leucine contents as discussed on mysportsciecne.com by Witard (2018)



Source: (Jeukendrup, 2017, https://bit.ly/2mll1tn) redrawn from van Vliet, Burd, and van Loon (2015).

As illustrated in Figure 1, plant and animal proteins also differ in terms of amino acid profile (Witard et al., 2016). The essential amino acids (EAA), i.e. those amino acids that must be supplied by the diet, —in particular the amino acid, leucine— are key to driving MPS. In addition to providing a building block for making new muscle proteins, leucine itself acts as a signal to switch on the process of muscle protein synthesis. Crucially, as a general rule, the leucine content of animal proteins (8-13%) exceeds plant proteins (6-8%). The same applies for EAA content. In fact, whey, milk and casein are the only protein sources with a higher constituent EAA content compared with human muscle itself. Plus, animal proteins typically boast a complete profile of all 9 EAA's, whereas plant proteins are deficient in at least 1 of the EAA's, usually lysine or methionine. So, it seems clear that the superior response of MPS to ingesting dairy and beef proteins compared with soy and wheat proteins stems from inherent differences in digestive properties and amino acid profiles between proteins.

However, there are exceptions to these rules that, as such, offer hope for alternative plant-based proteins and therefore vegetarian strength-based athletes. For instance, the plant protein maize boasts a leucine content of 12% that exceeds most animal proteins. Plus, quinoa consists of an unusually high lysine (7%) and methionine (3%) content and therefore contains a full complement of all EAA. So, it may be that other plant proteins, in addition to soy and wheat, such as maize and quinoa are equally effective as so-called "higher quality" animal proteins from dairy or meat sources. Moving forward, as is so often the case in Sport Nutrition, much more work is needed before we as sport scientists can definitely state what protein source is best for muscle building in strength athletes. (Jeukendrup, 2017, https://bit.ly/2mll1tn)

Iron

The iron status of vegetarians and vegans has received attention in the literature (Hunt, 2002; Waldmann, Koschizke, Leitzmann, & Hahn, 2004), and it appears that although both vegetarians and vegans consume similar amounts of iron as omnivores (Craig, 2009; Davey et al., 2003), there is a big difference in the bioavailability (Waldmann et al., 2004). The main source of iron in the vegan diet is found in the non-haem form, which is less bioavailable than the haem iron found in animal products (Waldmann et al., 2004). Vegan diets also commonly contain dietary inhibitors such as the polyphenols tannin (found in coffee, tea, and cocoa) and phytates (found in whole grains and legumes), which reduce the amount of iron absorbed from the diet.

It has been recommended that iron intakes for vegetarians be increased by 80%, so that adult males and females achieve a recommended intake of 14 mg/day and 33 mg/day (compared with the normal recommendations of 8 mg/day and 18 mg/day respectively) (Hunt, 2002). The Institute of Medicine (IOM) also suggests that iron requirements for vegetarians are 1.8 times greater than omnivores. This can also be achieved by supplementation. (Rogerson, 2017, https://bit.ly/2hwineX).

Maybe particularly relevant to football players, vegetarian and vegan athletes tend to have lower muscle creatine and carnosine concentrations. Higher muscle creatine as well as higher carnosine concentrations have been linked to better performance, especially

during repeated high intensity exercise, such as in football. Therefore, supplementation with creatine or beta-alanine may be particularly useful in this population. Vegan versions of these supplements are available.

Key points

- Digestibility and amino acid composition are key factors that determine the potential of a protein source to stimulate MPS.
- As a general rule, the leucine content of animal proteins (8-13%) exceeds plant proteins (6-8%)
- Based on currently available evidence, animal proteins such as dairy and beef confer an advantage over plant proteins such as soy and wheat with regards to stimulating MPS post workout.
- The potency of alternative plant proteins such as maize, lentil, quinoa and pea for stimulating MPS post workout remains unknown.
- It has been recommended that iron intake for vegetarians be increased by 80%. This can be achieved by supplementation.
- Vegetarian or vegan football players may benefit more from creatine or beta-alanine supplementation. (Jeukendrup, 2017, https://bit.ly/2mll1tn)

Conclusion

It is challenging to reach all nutrition targets with a plant-based diet. However, through careful selection and management of food choices, and with special attention being paid to the achievement of energy, macro and micronutrient recommendations, along with appropriate supplementation, a vegan diet can achieve the needs of most athletes satisfactorily. Supplementation with creatine and β-alanine might be of interest to vegan athletes as their performance-enhancing potential is greater than omnivorous athletes because of low pre-existing levels of these substances.

3.1.2 Young players

Young athletes may have different nutritional needs because they are in a phase of growth, and their physiology and metabolism is different from adults (Jeukendrup & Cronin, 2011).

Dietary Reference Values (DRVs) have been established for various ages but for the athletic or highly physically active child or adolescent these will need to be adjusted for the level of physical activity. In adolescents in particular, the onset of the growth spurt, which is a major reason for increased energy requirements, is unpredictable and it is very difficult to estimate energy requirements. It is well known though that prolonged inadequate energy intake will result in short stature, delayed puberty, poor bone health, increased risk of injuries, and menstrual irregularities or absence in girls (Jeukendrup & Cronin, 2011, https://bit.ly/2SZHHeK).

Children are less metabolically efficient during motor activities, resulting in higher energy requirements per kilogram body mass than adults during most forms of exercise. For example, it has been reported that children require 30% more energy during running (Krahenbuhl & Williams, 1992). This makes it impossible to make estimations of energy expenditure for children based on adult data. There are several explanations for the higher energy expenditures: children have a higher weight-specific resting metabolic rate, but they also have a disadvantageous stride rate and stride length (imposed by shorter limbs).

Exercise metabolism in children

In adults, the density of mitochondria in skeletal muscle is one of the main determinants of carbohydrate and fat metabolism. In general, the greater the number and size of mitochondria, the higher fat oxidation rates are during exercise. There also seems to be an association between muscle fibre type and substrate metabolism with higher percentage type I fibres favouring fat metabolism (Jeukendrup & Cronin, 2011). For obvious reasons, very few studies have investigated muscle fibre composition or mitochondrial density in children (Jeukendrup & Cronin, 2011). With growth and maturation, the large increases in muscle mass are paralleled by an increase in mitochondria within these fibres.

There appear to be some differences in substrate utilization between adults and children. Children have a lower glycolytic capacity, a higher oxidative capacity and higher rates of fat oxidation. During heavy exercise, muscle and

blood lactate levels are lower in children than in adults and there is a greater reliance on fat as fuel. Furthermore, prepubertal adolescents have relatively high rates of exogenous glucose oxidation, which may be because they have smaller endogenous carbohydrate reserves. These differences, however, seem to diminish throughout adolescence, especially in boys (Riddell, Jamnik, Iscoe, Timmons, & Gledhill, 2008), suggesting that the hormones associated with puberty (i.e. growth hormone, insulin-like growth factor, testosterone and catecholamines) play a role in regulating energy metabolism in children (Boisseau & Delamarche, 2000).

Protein

In order to support their growth and development, children and adolescents have protein requirements that are relatively high compared to adults. The Recommended Daily Allowances (RDAs) for protein in the United States and Canada are between 1.05 and 0.80 $g.kg^{-1}$, depending on age, with the highest recommendations for 1-3 year-olds and lowest for 18 year-olds. However, as for adults the protein requirements for young elite athletes are likely to be even higher. In a study of 14-year-old soccer players, who played 10-12 hours per week, nitrogen balance measurements revealed that the estimated daily protein needed to maintain nitrogen balance was 1.04 $g.kg^{-1}.day^{-1}$ (Boisseau, Vermorel, Rance, Duche, & Patureau-Mirand, 2007). It was suggested that the RDA for protein was 1.40 g/kg/day (or 75 g/day in this group), which would be well above the RDA (52 g/day) for children of this age in the general population. However, as is the case in adult athletes this requirement is quite easily met due to the higher daily energy intakes of highly active individuals. The study in young football players was performed in France and the suggested RDA of 1.40 g/kg/day is still well below the average protein intake of French children in age group (2.07 g/kg/day). In the United States and in Australia, protein intakes by children and adolescents are generally 2-3 times the RDA. Even in sports where young athletes were reported to restrict their energy intakes, protein intakes were still between 1.5-2.0 g/kg/day. Although, on the whole, protein requirements seem to be of no particular concern for young athletes, it is important to be aware that there may be some individuals who, perhaps due to intentional energy restriction for weight loss or a vegetarian diet, have protein intakes well below the

recommended amounts. It is possible that most gains come from timing of protein intake (spreading protein intake over 3-4 meals per day, each meal containing 0.3 g/kg protein).

Carbohydrate

It is well known that carbohydrate ingestion in adults both before and during exercise can delay fatigue and improve endurance performance. Unlike protein which has a quite general recommendation, recommendations for carbohydrate intake rate highly dependent on the intensity, duration and type of exercise that is performed by young athletes. Carbohydrate loading to increase muscle glycogen levels is not advised for children but since most of their events will be shorter and glycolytic capacity is limited, it must be questioned whether such a strategy would be beneficial at all (Jeukendrup & Cronin, 2011). A relatively high carbohydrate diet is advised, but there is no need to follow a dedicated glycogen loading regimen.

Numerous studies indicate that children will also benefit from carbohydrate intake during exercise, but just as in adults, this effect may only be obvious during prolonged exercise of high enough intensity. Many children will be physically active or engage in regular training but may not reach the level of physical activity that would warrant the use of carbohydrate beverages. However, those young athletes training hard and long enough will probably benefit. It has been found that in children under the age of 5 years, the efficiency of carbohydrate absorption is lower than in adults, but this gradually increases with age up until the fifth year. At this age, exercise will not be long enough with intensity high enough to need any carbohydrate intake.

Fat

Very few studies have investigated fat intake or fat requirements in physically active children. Although essential fatty acids are clearly important for growth and development, the link with performance is far less clear. The usual general recommendation is that 25-30% of energy should come from dietary fat, but absolute fat intakes in g/kg/day are highly dependent on the energy expenditure. As in adults the main priorities are adequate protein and carbohydrate intake and fat can make up the

remaining energy needs. Restricting fat intake in non-obese children has been suggested to impair growth and development, although it is not clear whether this is a direct effect of low fat intake or low energy intake. If weight loss is required in children who are involved in relatively hard physical training, it seems sensible to reduce the fat intake rather than protein or carbohydrate (see also the section on weight management).

Thermoregulation and fluid requirements

As children have a higher ratio of body surface area to body mass (at the age of 8-years-old it is approximately 50% higher than that of an adult) it has been suggested that exercising children should be able to dissipate heat quicker than adults (Jeukendrup & Cronin, 2011). Children should therefore have an advantage in thermoregulation over that of exercising adults, at least up to the point at which ambient temperature exceeds skin temperature. After this, the advantage is supposedly reversed. In practice, however, this has not been found to be the case and instead adults and active children seem to experience similar core temperatures, even when exercising at high ambient temperatures (Inbar, Morris, Epstein, & Gass, 2004).

High sweat rates in hot conditions can result in large fluid and electrolyte losses. In adults, the dehydration caused by this fluid loss has been shown to impair both motor control and physical performance (see section on extreme environments), so adults are advised to balance any fluids lost from sweating, with fluid intake or to at least limit losses to no more than 2% of body mass. However, there are large differences in sweat rates between children and adults. In fact, 9 year-old boys exposed to hot and humid conditions (45°C and 97% relative humidity) had an average sweat rate that was only half of that of men. This muted response, (also observed in both young girls and adult females), is probably due to the underdevelopment of the peripheral sweating mechanism in younger boys. In fact, once male sex hormone production starts to increase during puberty, the sweat rate is seen to increase rapidly. If indeed the ability to sweat by young football players is lower than that of adults', then their risk of becoming dehydrated during exercise in the heat will also be reduced. However, as sweating is the main way of dissipating heat during exercise, it is possible that

children's thermoregulation is less effective, and their core body temperature could increase at a more rapid rate compared to that of an adult. This does not seem to be the case though, as studies indicate that the reduced sweat rate does not impair children's ability to lose heat during exercise (Inbar et al., 2004). Instead, it seems that children utilize different, but equally effective, thermoregulatory mechanisms (Falk & Dotan, 2008; Inbar et al., 2004) as discussed in more detail by Falk and Dotan (Falk & Dotan, 2011). Therefore, as the extent of dehydration and more importantly the risk of developing a heat-related illness seem to be similar between adults and younger athletes, then the recommendations regarding fluid replacement are likely to be similar too.

Young athletes have been reported to underestimate the amount of fluid they need to consume during prolonged exercise in order to stay hydrated, especially in hot and humid conditions and in particular when the only fluid available to them is water. As thirst is often reported to be a poor indicator of fluid needs, it is important to encourage drinking before, during and after exercise to prevent dehydration. Involuntary hypohydration can reach up to 1-2% of body mass loss in boys who are unacclimatized and untrained or acclimatized and trained. Whilst education for parents, coaches, teachers and indeed young athletes themselves can improve fluid intake in elite young athletes, studies have also shown that there are other ways to promote thirst, and therefore stimulate drinking. One of these is through the addition of small amounts of sodium chloride to water. This sensitizes the thirst mechanism through the maintenance of plasma osmolality and reduces the diuretic effect of ingested water (Bar-Or, 2001; Rivera-Brown, Gutierrez, Gutierrez, Frontera, & Bar-Or, 1999). Another way is through the addition of carbohydrate to the drink, as this increases the palatability of the beverage. This often becomes a discussion in young athletes, should they drink sugary drinks or not? In the vast majority of cases, neither dehydration or carbohydrate availability are critical in children, but when weather conditions are extreme, or the level at which young players perform is very high, sports drinks may be warranted. Finally, the addition of flavour is another important way to increase drinking and limit dehydration. The addition of flavour to a carbohydrate-electrolyte drink helped to reduce voluntary dehydration by 32% in heat-acclimatized, trained boys. This helped to maintain

euhydration over a 3 h period of moderate intensity intermittent cycling exercise in hot and humid conditions (30°C and 53-62% relative humidity) (Rivera-Brown et al., 1999).

Current recommendations for fluid replacement in children are scant. The 2007 American College of Sports Medicine (ACSM) position statement on 'Exercise and Fluid Replacement' makes very little mention of children's needs, only referring to the fact that pre-pubescent children have a lower sweat rate than adults (American College of Sports, Sawka, et al., 2007), whilst the 2009 and 2016 ACSM position statements on 'Nutrition and Athletic Performance' do not comment upon children's or adolescents' needs at all. In contrast, the policy statement re-issued by the American Academy of Pediatrics, regarding the fluid replacement guidelines for children during exercise in the heat state that a child who weighs 40 kg should drink 150 mL of cold water or flavoured salted beverage every 20 min and an adolescent who weighs 60 kg should drink 250 mL every 20 min, even if the child does not feel thirsty. Such guidelines, in contrast to those made available to adults, are far too general as they do not take into account important factors such as environmental conditions, exercise intensity, acclimatization and individual differences. With the current lack of studies investigating the impact of dehydration in children on their performance, it is very difficult to give balanced and objective guidelines. At an elite level it seems sensible to develop an individualized strategy that aims to reduce fluid losses in excess of 2-3% body mass. This can be done by measuring the body weight before and after training and correcting for fluid intake to obtain some estimate of sweat rates under different ambient conditions. This would eventually allow the prediction of sweat rates in similar conditions and provide a sound basis for fluid intake prescription.

Nutrition supplements

Just as in adults, supplement use amongst young athletes is common. In a study of 32 track and field junior athletes selected for Team Great Britain at the World Junior Championships, it was found that 62% currently were using supplements (Nieper, 2005). A higher percentage of females (75%) were found to use supplements than males (55%) although this difference was not statistically

significant. This trend may be attributed to a greater awareness among females, greater genuine need for supplementation (e.g. because of menstrual loss) or possibly because advertising campaigns have had a greater influence on females (Nieper, 2005). The most commonly used supplements were those related to health such as multivitamins, vitamin C and iron rather than those related to performance enhancement (Nieper, 2005). In a review, McDowall (2007) concluded that the prevalence of supplement use was between 22 and 71% in young athletes (aged 13–19 years). The most frequently cited reasons for using a supplement were: health benefits, illness prevention, enhancing performance, taste, rectifying a perceived poor diet and increasing energy which is not unlike similar reports in adult athletes.

Regardless of whether supplements have the effects they are claimed to have, it is clear that young elite athletes perceive a need for nutritional supplementation. However, there must be reservations about most supplements regarding long term use, combinations and appropriate dosages in an elite young athlete. These reservations concern both the potential for increased health risk to an otherwise healthy population and the possibility of positive doping tests caused by supplements containing banned substances. To minimize these potential risks arising from potentially inappropriate supplement use, an increased involvement of nutritionists and health professionals is desirable.

Although we don't want to engage in detailed discussions of a long list of supplements, one supplement that has received substantial attention recently is caffeine. Caffeine is one of the most widely used drugs and energy drinks containing caffeine are now marketed specifically to young adults and children. It is therefore important to understand the effects of caffeine in this population. Energy drinks containing high concentrations of sugars and caffeine represent the fastest growing segment of the beverage industry. Very few studies have examined the physiological and cognitive effects of caffeine in children, and therefore, it is difficult to give sound advice on caffeine use for young athletes. However, there is evidence that children and adolescents, although receiving similar benefits to adults, may be particularly vulnerable to the negative effects of caffeine. Therefore, caffeine should be used with caution. In general, due to health concerns and

lack of evidence of efficacy, supplements for younger athletes are not recommended (Meyer, O'Connor, Shirreffs, & International Association of Athletics, 2007). (Jeukendrup & Gleeson, 2018, https://bit.ly/2LC9XB7)

It is important to educate children as early as possible to eat a “healthy and balanced” diet and to encourage good eating habits. For the aspiring young athlete, this should also include specific sports nutrition guidance with performance goals, in addition to health goals. This can reinforce lifelong eating habits that contribute to the overall well-being of children and may enhance sport performance. On the other hand, any bad habits developed in childhood and adolescence may be difficult to eradicate later in an athlete’s sporting career and should therefore be avoided. There is an important role for parents, coach and support staff to encourage appropriate eating behaviours, but also to avoid bad habits such as too much attention to body shape and body weight. (jeukendrup & Chiampas, https://bit.ly/2TVJWQ5)

3.1.3 The older player

An increasing number of older adults choose to achieve physical fitness or health and well-being by participating in recreational or competitive football. In this subgroup of athletes, one of the goals is often performance although it is not always the most important goal. Because of the link between nutrition and these health and performance goals, older players should pay attention to their nutrition. Unfortunately, there are not many studies and very few nutrition guidelines for these older individuals who are looking to improve their performance.

Changes in metabolism with age

One of the main changes with ageing is the loss of muscle mass. This already starts from the age of approximately 30 years: there will be loss of muscle mass and function. The cause is age-related sarcopenia. Physically inactive people can lose as much as 3% to 5% of their muscle mass each decade after age 30. Muscle strength declines already at an earlier age (probably around 25 years old), whereas peak performance in endurance sports may be seen around the age of 40. Sarcopenia is characterized by losses in muscle mass, strength, and endurance: this will affect

performance but also contributes to other functional consequences of aging. Ageing causes changes in muscle fibres, protein synthesis, and mitochondrial function. Training can significantly delay this process and nutrition may have a role to play as well.

Energy, carbohydrate and fluids

With increasing age there are changes in energy expenditure (decreases) and individuals often comment that it is more difficult to maintain their body weight. Energy expenditure is mostly determined by resting metabolic rate and energy expended during exercise. Since muscle is the most metabolically active tissue, a loss of muscle mass will also result in a decrease in energy expenditure. This means that daily energy intake will have to be reduced as well to avoid weight gain. The loss of muscle mass is a slow and gradual process, and thus these changes will not happen overnight, but unless a high level of physical activity is maintained or there is a reduction in energy intake, weight gain will be the logical consequence. There are plenty of examples of athletes that struggle with this at later age, but there also plenty of examples of very lean older athletes.

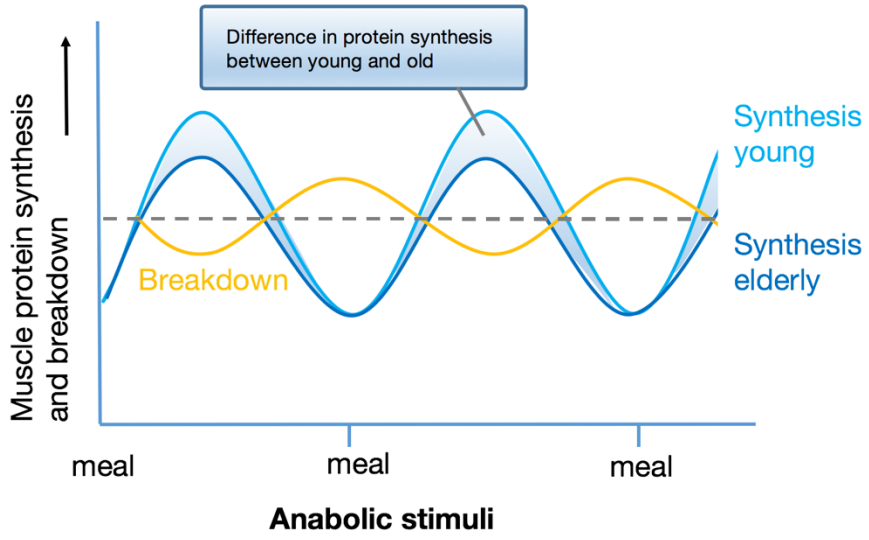
Many guidelines are exactly the same for all adult football players regardless of their age. For example, there are no reasons for the carbohydrate or fluid intake guidelines to be different for older adults. Carbohydrate requirements are determined primarily by the goals, the intensity and the duration of exercise. Older athletes may perform at lower absolute intensities and this will reduce the requirements. However, this is also true for the younger plater where carbohydrate needs also must be established on an individual basis. Fluid losses are a result of metabolic rate (intensity) and therefore the same advice would be appropriate. We would recommend measuring weight loss during training and/or competition and drink to prevent significant dehydration, keeping weight loss to within 3% of body mass. No different from the recommendations for younger individuals. Jeukendrup & Gleeson, 2018, https://bit.ly/2LC9XB7

Protein

Protein is the ingredient of interest for the ageing football player. Clearly loss of muscle mass is one of the main concerns for the ageing athlete,

protein is one area where requirements are higher. "A common observation is that many older individuals seem to lose muscle mass and do not seem to respond as well to resistance training. It may be that different responses to resistance exercise may be due to the fact that the older athletes generally lift lower volume of weights than the young." Jeukendrup & Gleeson, 2018, https://bit.ly/2LC9XB7. However, there is another explanation. If the same amount of protein is ingested and protein synthesis rates are stimulated a little less with all meals this can explain why over time muscle mass decreases (Figure 2). No differences in protein breakdown have been reported. "Indeed, it has been suggested that a reduced anabolic responsiveness to hypertrophic exercise may be a key factor in mediating the muscle adaptive remodelling in the older athlete (Figure 3)." Jeukendrup & Gleeson, 2018, https://bit.ly/2LC9XB7

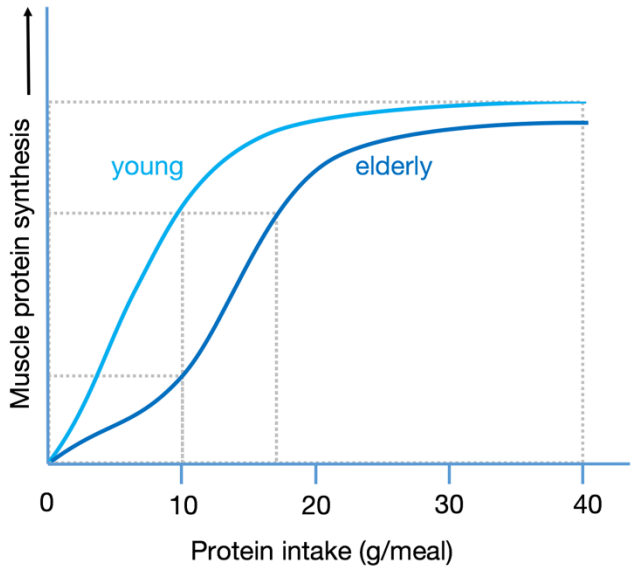
Figure 2: Anabolic resistance in the older football player.



Source: Jeukendrup & Gleeson, 2018, https://bit.ly/2LC9XB7. For the same exercise and nutrition stimulus, the protein synthetic response is blunted in the older athlete. This is referred to as anabolic resistance

It has been demonstrated that protein synthesis is lower and there appears to be some anabolic resistance (although it must be noted that studies have generally been performed with subjects aged 70 or older).

Figure 3: Schematic depiction of the concept of anabolic resistance in older individuals.



Source: Jeukendrup and Gleeson (2018). https://bit.ly/2LC9XB7. At low protein intakes, muscle protein synthesis is stimulated less in the elderly. In order to obtain similar effects of protein synthesis, larger amounts of protein need to be ingested. At very high protein intakes per meal (40 g) differences between young and old disappear

> In other words, for a given amount of protein in the diet, protein synthesis is stimulated less. This is especially true at low protein intakes. At an intake of 10 g, young adults respond with significantly increased protein synthesis, elderly do not respond. When the intake of protein (including leucine is increased), the difference between old and young becomes smaller and at very high intakes the difference may be negligible. This means that protein intake recommendations for older athletes should be higher than those for young athletes. Some questions, however, remain unanswered. For example, at what age do these increased requirements start? As mentioned above, most studies have been performed in non-athletes of over 70 years old, often the frail elderly. But decreases in muscle mass can be observed much earlier in life. (Jeukendrup and Gleeson, 2018, https://bit.ly/2LC9XB7.)

3.1.4 The female athlete

A number of differences in the physiology and metabolism of males and females have been consistently reported, and it needs to be explored whether female football players have different nutrition requirements. One of these findings is that there are differences in the relative contribution of type I and type II fibres. It has certainly been reported that

women have higher circulating levels of 17-β estradiol and this can influence fat, carbohydrate and protein metabolism. It has also been suggested that women have a greater capacity to oxidize fat (Venables, Achten, & Jeukendrup, 2005), that perhaps glycogen synthesis is impaired in women and that there are differences in hydration. There may also be different micronutrients needs (in particular iron).

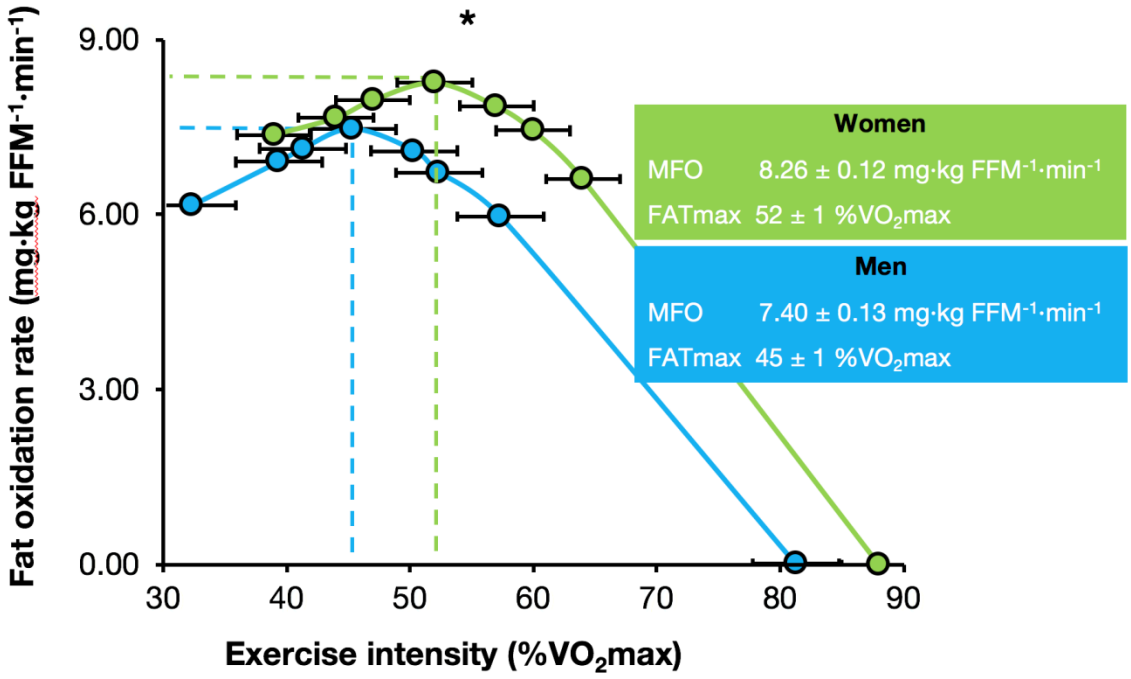
Energy

Female athletes are generally smaller, with less muscle mass than men, and have therefore also lower (resting) energy expenditures. Exercise related energy expenditure in football players will be an important component that determines the overall energy expenditure. A female player who trains harder and longer, may have a higher energy expenditure than a male player. It is very difficult to determine energy expenditure accurately in order to calculate energy intake (see the section on energy balance). There are various tools (heart rate monitors, global positioning systems and accelerometers that help us to estimate energy expenditure, but this will never be very accurate. Although it is important to keep this in mind, often it is still worth trying to estimate the energy availability: the energy intake minus the energy expended during exercise. The remaining energy is what is available for basic body functions and the target for a healthy female athlete should be about 45 kcal/kg fat free mass (FFM). For example: for a 60 kg (132 lb) female athlete with 20 % body fat and a FFM of 48 kg the energy availability should be above 45 x 48 = 2160 kcal. Any energy spent during training should be added to this number to get the daily energy intake.

Fat and carbohydrate

Although some studies show that female athletes oxidize more fat than their male counterparts during exercise, it must be noted that these conclusions may be rather academic. In most studies, such conclusions are based on data expressed per kg FFM. If expressed in this way, very small differences can be found in some studies, but not in others. For example, we observed in a very large sample of 300 subjects, half male and half female, that fat oxidation was higher in females when expressed per kg FFM (Venables et al., 2005). This difference, however, was small (Figure 4) and probably negligible when we translate this to dietary advice. When a group of male and female cyclists was carefully matched for training status, the male cyclists had higher power outputs, and thus, higher energy expenditures. As a logical result, both their carbohydrate and fat oxidation were higher at the same relative intensity of exercise. Therefore, in reality, men will oxidize more fat even though the oxidative capacity of the muscle may favour fat oxidation slightly more in females. The practical importance of the higher rates of fat oxidation that is reported for women is therefore questionable.

Figure 4: Fat oxidation in men and women as a function of exercise intensity.



Source: Venables et al. (20. 05). https://bit.ly/2ATcsL8Fat oxidation is expressed in g/kg FFM, and when expressed in this way, women tend to have higher maximal fat oxidation rates (MFO) that occur at higher exercise intensities (Fatmax). * indicates significantly different fat oxidation rates (Jeukendrup, 2017)

Carbohydrate loading

Carbohydrate loading has been shown to result in high muscle glycogen concentrations and can in some situations help performance. However, the majority of studies examining the response of muscle glycogen to an increase in the consumption of dietary carbohydrates have been conducted with predominantly male subjects. Given the attenuation in glycogen utilization during exercise seen in rodents with 17-β-estradiol administration, and the attenuation observed during exercise with the muscle biopsy method, it had been suggested that women would not be able to supercompensate as well as men.

In one study, muscle glycogen concentration was measured in response to a modified carbohydrate loading protocol whereby exercise intensity was tapered for 4 days and dietary carbohydrate intake was either 57% or 75% of total energy intake (Tarnopolsky, Atkinson, Phillips, & MacDougall, 1995). After the higher carbohydrate intake, the male subjects demonstrated a 41% increase in muscle

glycogen and a 45% improvement in performance time in an exhaustive exercise bout following 1 h of cycling at 75% of VO_2max, whereas the females showed no increase in muscle glycogen and no effect on performance. It was hypothesized that the inability of females to carbohydrate load may have been due to a difference in the enzymatic and/or transport capacity for glycogen resynthesis and glucose uptake, respectively. The explanation for the difference, however, is likely much more straightforward. Clearly the men received a larger amount of carbohydrate than the women even when expressed per kg body weight. In this study, carbohydrate intake was 4.8 g/kg/day and 6.4 g/kg/day for females and 6.6 g/kg/day and 8.2 g/kg/day for males, respectively, on the low and high carbohydrate diet. In most of the previous studies of carbohydrate loading in males, the dietary carbohydrate intake was greater than 8 g/kg/day. When another study was performed and carbohydrate intake of men and women was given as equal amounts per kg per day, there was no difference in glycogen synthesis between men and women. So, there is no physiological difference but there may still be a practical difference as we will illustrate with an example.

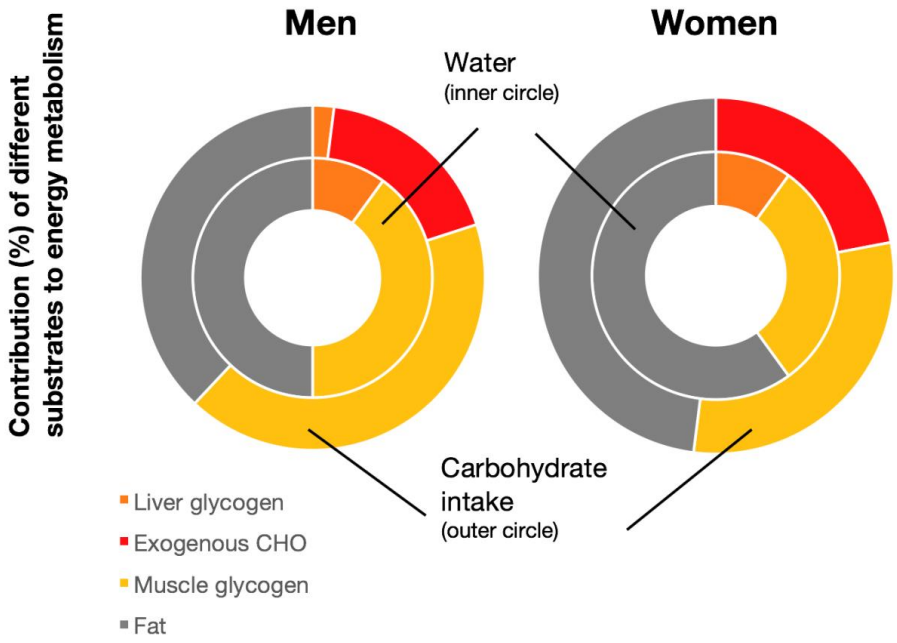
Consider a 50 kg female athlete consuming 2000 kcal/day. This female athlete who may consume a habitual 250 grams of carbohydrate per day (or 5 g/kg/day) may have to increase her intake by around 60% to bring it up to 8 g/kg/day. Now carbohydrate makes up 1600 kcal of her total daily energy intake meaning that there would only be 400 kcal left for protein and fat. Although not impossible this is not a practical scenario. The reality is probably that the female athlete will increase her carbohydrate intake slightly but perhaps not to the levels of 8 g/kg/day as in the studies and thus glycogen synthesis may not be quite optimal.

Carbohydrate intake during exercise

The effects of carbohydrate intake during exercise have been studied mainly in men. However, there are a couple of studies that specifically compared female and male athletes and observed no differences. In this study, 8 moderately endurance-trained men and 8 carefully matched women performed 2 h of cycling at 67 % VO_2max and ingested carbohydrate at regular intervals (Wallis, Dawson, Achten, Webber, & Jeukendrup, 2006). The total amount of carbohydrate in the men and women was the

same (and was as high as 90 g/h). Ingested carbohydrate was oxidized at similar rates in men and women during exercise. This was expected as the main limiting factor for exogenous carbohydrate oxidation is absorption and there is no reason to expect women who eat a similar diet than men to have different absorptive capacity of the gut. Thus, recommendations for carbohydrate intake during exercise are no different for women. (Jeukendrup and Gleeson, 2018, https://bit.ly/2LC9XB7.)

Figure 5: The contribution (% to total energy expenditure) of different substrates to energy expenditure in men and women, with ingestion of water during exercise or carbohydrate.



Source: (From (A. E. Jeukendrup & Gleeson, 2018 https://bit.ly/2LC9XB7) with data from (Wallis et al., 2006). Overall there are no major differences in substrate use between men and women

Protein

Few studies have looked into protein requirements for female athletes. Generally, it is assumed that these requirements are similar as for men. Protein intake guidelines usually don't specifically mention female athletes. One study, measured nitrogen turnover in female endurance athletes and concluded that to maintain nitrogen balance an intake of 1.63 g protein /kg/d should be ingested (Houltham & Rowlands, 2014). This is 25-30 % higher than as previously thought, but similar to what

would be expected for male athletes who perform similar training. Although, there is a lot more research to be done, these data suggest that protein intake requirements may increase with exercise training in a similar manner to the requirements in men.

Iron

Iron recommendations for the general population are significantly higher for premenopausal women than for men (18 mg/day versus 8 mg/day), mainly due to regular losses of iron through menstrual bleeding. Female athletes may struggle with the intake of adequate iron, especially if their energy intakes are low and if they are vegetarian. In female athletes, it is therefore important to pay extra attention to iron intake and to monitor iron status. Supplementation may in some cases be appropriate, but it is recommended to do this under supervision of a professional and to use iron sources that have relatively good bioavailability such as iron sulfate, iron gluconate and iron fumarate.

Other key nutrients that may be low in the diet of the female athlete are zinc, vitamin B12 and folate. For the female athletes, micronutrients are most likely to be low if energy is low, food groups are eliminated, or highly processed foods make up a large part of the diet. Conversely, active women with adequate energy intakes or those who use fortified/enriched foods or supplements appear to have little to worry about (Woolf, Hahn, Christensen, Carlson-Phillips, & Hansen, 2017).