2.1 Training low or training high?

2.1.1 Introduction

Athletes (including football players) have different goals on different days of the week and different parts of the year. Obtaining ideal body composition may be the pre-season goal; recovering as quickly as possible during periods with congested fixture schedules may be another goal. Recovering from a match on Sunday could be a main goal during a week in the season but, on other days, it may be about supporting high-intensity training or some other goal. In the last example, recovering from a match may require similar nutritional preparation to the one required for an intense day of training, but in the first example, the nutritional strategies may be completely different. Weight loss will require energy restriction, whereas rapid recovery will require high energy and high carbohydrate intake. Making sure that nutrition is adjusted to the goals is one important aspect of what we call periodised nutrition. The second important aspect of periodised nutrition is that it is planned. Often, we read (also in the scientific literature) that athletes periodise anyway because they eat differently on different days. The term nutrition periodisation is typically used to describe changes in nutritional intake in response to certain periods of training (Impey et al., 2018; Mujika, Halson, Burke, Balague, & Farrow, 2018; Mujika, Stellingwerff, & Tipton, 2014; Stellingwerff, Boit, Res, & International Association of Athletics, 2007). For example, they eat more on days of hard training. In our opinion, this is not necessarily periodised nutrition, as periodised nutrition means that the nutrition plan is strategically used and it is a planned process (Jeukendrup, 2017a). This is not too different from the concept of periodised training. The term periodisation in the context of exercise training refers to a long-term, progressive approach designed to improve athletic performance by systematically varying training throughout the year. It is obvious that training in off-season and in season is different and that it varies on different days of the week. However, it is not periodised training, unless the training is planned. With periodised nutrition it is not different, we need a macro (year) and micro (week or day) planning of the nutrition to make sure nutrition supports the training goals.

For example, during certain periods of training there is a focus on weight management and lower energy intake, whereas during other periods there is a focus on recovery and performance and higher carbohydrate intake. Mujika et al. (2014) conclude "Nutrition should be periodised and adapted to support changing individual goals, training levels, and requirements throughout a season and/or training cycle" (p. 12933). Hawley, Burke, Phillips, and Spriet (2011) discuss the importance of a long term periodised training-nutrition program as a way to enhance performance. The authors state it seems prudent to suggest that competitive athletes may wish to manipulate carbohydrate availability before, during, or after selected training sessions that form part of a long-term periodised training-nutrition plan to promote metabolic training adaptations that should, in theory, promote endurance-based performances.

In this statement, there is a strong focus on carbohydrate availability as a driver of training effects, and the training effects are mostly in the muscle and metabolic. For example, training the extension of the stomach wall as discussed in the section on training the gut would not be included in this definition of periodised nutrition. (Jeukendrup 2017a, https://bit.ly/2W08dX0)

Therefore, we proposed the following definition:

Periodised nutrition refers to the planned, purposeful and strategic use of specific nutrition interventions to enhance the adaptations targeted by individual exercise sessions or periodic training plans, or to obtain other effects that will enhance performance longer term (Jeukendrup, 2017a)

This definition of periodised nutrition (or nutritional training) includes all methods that use nutrition (in the presence or absence of training) to improve long term performance. These methods include manipulations of nutrient availability before, during and after training, but could also include practices that prepare other organs for competition through nutritional manipulation (for example improving stomach comfort by drinking large volumes regularly [Jeukendrup, 2017b]). The definition nutritional training is not restricted to adaptations of the muscle (and could relate to adaptations in all organs such as the intestine or the brain) but will always have long term performance improvements as the main goal. (Jeukendrup 2017a, https://bit.ly/2W08dX0).

Recently we have seen a number of additional training goals being used, such as "training twice a day", "training low", but also "training high" and "training the gut". These are the nutrition tools for a practitioner. The practitioner then works closely with the trainer/coach to understand the goals, so these goals and the training that is planned to achieve these goals can be supported as effectively as possible by a detailed nutrition plan. Generally, athletes evolve from just eating because they are hungry to eating according to a periodised nutrition plan that optimally supports their performance. This also means that sticking to one particular diet will remove the flexibility to periodise nutrition. The example we will discuss here is the example of low carb diets, a returning question in football.

2.1.2 More on terminology

Terminology is of utmost importance. If we have a conversation about a topic but we use different terminology, this leads to confusion or even conflict. Many stakeholders, including scientists, coaches, athletes, and practitioners, have tried to implement aspects of periodised nutrition. Similar concepts have been used, but because these concepts have been very poorly described at the onset, this has confused the whole sports nutrition area. For example, the term "low carbohydrate" could mean a low carbohydrate intake in grams per minute or it could mean that carbohydrate intake is low relative to other macro nutrients. It was common practice until about the early 2000s to express carbohydrate intake as a percentage. But, for example, a carbohydrate intake of 70% (normally considered high) can still be low in absolute terms if energy intake is low. A carbohydrate intake of 30% (normally considered low) can still be high in absolute terms if energy intake is very high. Therefore, recommendations are now usually in grams per day or in grams per kilogram per day. However, especially in the popular media (including many of the highly popular diet books), there is still reference to the percentages. This means that two people on social media can be having a discussion about a low carbohydrate diet and each could be referring to a completely different diet. Terms like "carboloading" also mean different things to different people because it has never been defined very well. Does it mean eating as much carbohydrate as possible? (This is how it is often interpreted.) Or does it mean that you are eating more carbohydrate than your requirement, but staying in energy balance by reducing fat and/or protein intake?

Even within the toolbox of such strategies, there is confusion over the names of the tools, how they should be used, and what they might achieve in reengineering the muscle (Burke et al., 2018). This arises because of the different nomenclature used in the original studies and the tweaking of both names and protocols in further research or real-world applications. In some cases, the same term may mean different things in the same literature but also have another meaning in an adjoining field for coaches/athletes. For example, the term “train low” has been used to describe a single acute training session in which the availability of muscle CHO and/or exogenous CHO has been manipulated to “lower” levels before and/or during the session by a variety of techniques that have different metabolic and cellular consequences (for reviews, see Bartlett, Hawley, & Morton [2015]; Burke & Hawley [2018]; Hawley, Lundby, Cotter, & Burke [2018]; Impey et al. [2018]). However, the term has also been used to describe a chronic training period in which such strategies were undertaken in differing combinations over many days to weeks (Hansen et al., 2005; Yeo et al., 2008). In addition to this, to many sports scientists and coaches, “train low” is more likely to be aligned with altitude/hypoxia exposure protocols.

Sometimes the reader is misinformed on purpose (to support a point an author is making) and this happens even in the scientific literature. Proponents of low-CHO high-fat dietary philosophies have repeatedly misinformed and mislead the reader that contemporary sports nutrition guidelines promote high carbohydrate intakes at all times for all athletes (Brukner, 2013; Noakes, Volek, & Phinney, 2014; Volek, Noakes, & Phinney, 2015). This is simply not the case. As far back as 2003, official recommendations from an International Olympic Committee expert panel noted that fuel demands differed between different types of events or training intensities and volumes, leading to a sliding scale of daily carbohydrate intake targets and the promotion of specific scenarios, rather than a universal recommendation for aggressive CHO fuelling strategies (Burke, 2004; Burke, Kiens, & Ivy, 2004). It is also too simplistic to think that one diet would be best for all athletes in all situations.

In a recent review we discussed a number of terms that are frequently used and called for a common definition. At least explaining the origin of the terms and what they mean in the eyes of different people is a first step towards removing the confusion. There is, however, a real need to agree on the definitions of these terms and to start using common terminology. Below we will discuss some of the most important terms (from Burke et al., 2018).

High carbohydrate diet
Lacks a single or clear definition. Is typically considered a static target. Various metrics for carbohydrate intake have included a ratio of energy intake (e.g., >50% or 60–70%), absolute amounts (e.g., 500–600 g/day), or amounts relative to BM as a proxy for the size of the exercising musculature (e.g., 7–10 g/kg).

Absolute targets (e.g., 500–600 g/day) or relative energy targets (e.g., >50% or 60–70%) should not be used since they do not correlate well with fuel needs for training (Burke et al., 2004).

High carbohydrate availability
Dietary plan in which total daily carbohydrate intake, and its spread over the day, is targeted at optimizing muscle glycogen stores and additional exogenous carbohydrate supplies to meet the fuel demands of the day's training or event commitments. Total daily targets vary according to goals and are typically represented as g/kg as a proxy for the size of the exercising musculature; the daily range may vary from 3 to 12 g/kg according to the training load. In football players the likely range is 3-8 g/kg. This includes carbohydrate intake before, during, and/or between key sessions if needed for fuel support.

Periodised carbohydrate diet
Dietary plan in which carbohydrate availability for each workout is varied according to the type of session and its goals within a periodised training cycle (Jeukendrup, 2017a). This may include single sessions of variants of "train high" and "train low" as well as sequences of these strategies (as we will discuss in this course).

Low carbohydrate diet (LCHF diet - non-ketogenic)
Usually refers to a dietary plan in which carbohydrate availability is chronically (days/weeks/months) maintained below muscle carbohydrate needs to promote adaptations favouring fat oxidation, but with sufficient carbohydrate to avoid sustained ketosis. Typical intake = 15–20% energy from carbohydrate (<2.5 g/kg/day), 15–20% protein, 60–65% fat in combination with a moderate-endurance training volume (>5 hr/week).

Ketogenic diet
Dietary plan in which chronic ketosis is achieved by severely restricted carbohydrate intake and moderate

protein intake. Fats, principally saturated and monounsaturated, contribute the major energy source. Typical intake = <5% energy from carbohydrate (<50 g/day), 15–20% protein, and 75–80% fat.

Train high

Completion of a training session with muscle glycogen stores that are able to meet the demands of the workout. Achieved by combination of sufficient time and carbohydrate intake after prior training session to store targeted glycogen stores; total carbohydrate intake target typically ranges from 5-12 g/kg/day according to training load. Depending on glycogen depletion in last session, may require proactive refuelling after previous session and pre-session fuelling.

Recover high

Rapid refuelling undertaken after a training session, used usually to promote glycogen restoration for an upcoming session with <8-hr recovery. Carbohydrate targets: ~1 g/kg soon after completion of the session, with intake repeated hourly until daily carbohydrate targets are resumed.

Train low

Completion of a training session that commenced with, or achieves, suboptimal/low muscle glycogen stores in comparison with fuel demands. A common protocol to set up this scenario involves "two a day" training, in which the first session is undertaken to deplete muscle glycogen, and the second session is undertaken after a brief recovery period in which minimal carbohydrates are consumed.

Train fasted

Completion of a training session with low liver glycogen stores and low exogenous carbohydrate availability due to fasted conditions (overnight fast or >6 hr since last carbohydrate intake) and lack of carbohydrate intake during session. Sessions probably need to be at least 45–60 min in duration to exert a significant altered metabolic stress (significant changes in glucose and/or FFA, altering muscle fuel oxidation). When undertaken according to typical patterns (e.g., morning session undertaken before breakfast and with intake only of water [or, in the case of prolonged sessions; water for the first hour(s) followed by small amounts of CHO to allow session to be completed]). Muscle glycogen may be adequate for the session.

Recover low/sleep low
Deliberate restriction of carbohydrate in meals after an exercise session to delay restoration of muscle glycogen. May be undertaken as carbohydrate restriction after the morning training session, or as an overnight carbohydrate restriction following an evening workout. Post-exercise intake of protein supports adaptive processes without dampening the effects of the low carbohydrate availability. Burke, Hawlay et al., 2018, https://bit.ly/2QLrD35)

These different training methods, such as training low, training fasted, training twice a day, training high, training the gut, sleep low etc, are the tools of a performance nutritionist (Figure 1). After clearly understanding the goals and in collaboration with the coach/trainer, these tools can be used when appropriate to support the goals of the day or the week.

Figure 1: The toolbox of a sports nutritionist. The tool to use depends on the job to be done

Figure from Jeukendrup, 2018, mysportscience (www.mysportscience.com).

2.1.3 Train low

Our understanding of the underlying mechanisms of training adaptation has expanded enormously the last few years and this gives opportunities to optimise parts of the signalling processes or gene transcription processes in order to optimise training adaptations. Training low has been talked about a lot as a way to do this, but there may be other ways as well, including some phytonutrients or supplements. It is also possible to blunt adaptations by providing too much of a nutrient at the wrong times (see section on antioxidants). It is not only the muscle that adapts but also the brain, the gut and other tissues, and those adaptations can be targeted with nutrition as well. For example, if a player cannot tolerate drinks or gels very well on match days, this is trainable. The gut can be trained to absorb nutrients better and stomach comfort can be trained by regularly practicing intake during training. The science behind this will be discussed in more detail in one of the following sections.

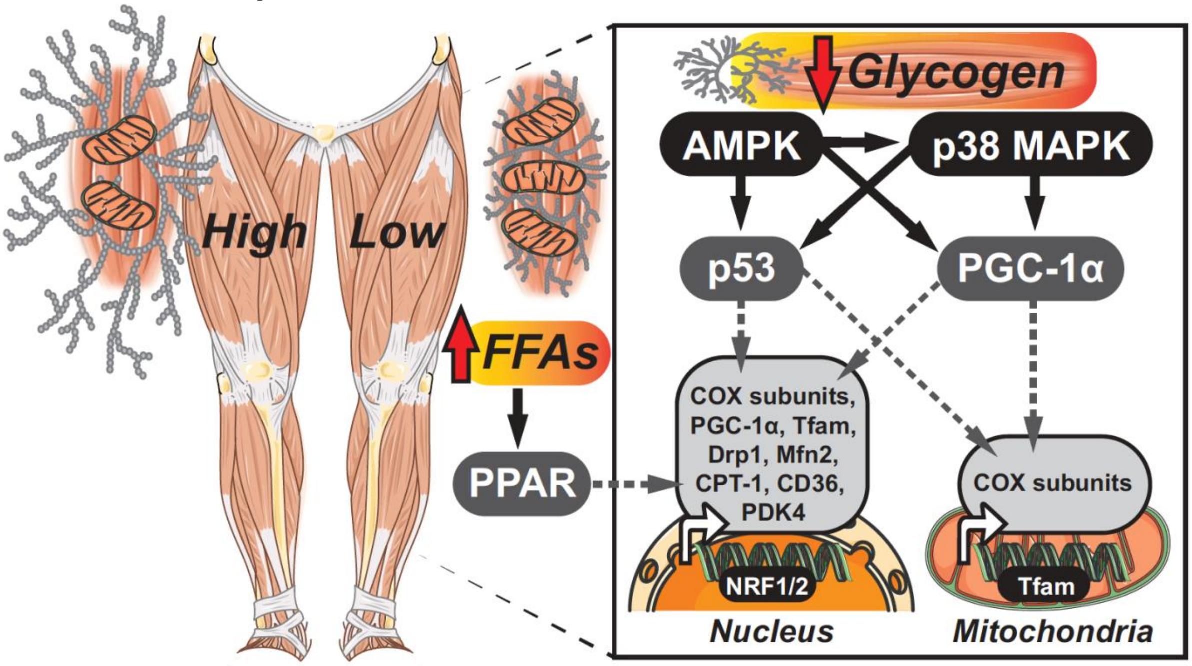
In the section on training adaptation, we discuss in detail how adaptation to training occurs. In brief, muscle contraction initiates a cascade of reactions (primary signals, secondary signals, gene transcription) that can result in the formation of proteins. The accumulation of these proteins is responsible for the training adaptation and improved function. “It is generally believed that training adaptations are the result of accumulated small changes in protein synthesis that result in an altered phenotype and improved performance”. (Jeukendrup 2017a, https://bit.ly/2W08dX0)

In order for this protein synthesis to occur, it is important that there is a stress signal, transcription or translation, that messenger RNA (mRNA) remains stable and that sufficient amino acids are available for protein synthesis. This process is slow and requires repeated exercise stimuli as well as appropriate nutrition. However, studies have also demonstrated that certain nutrition interventions or manipulation of endogenous fuel stores can exaggerate some of the signalling responses and increase gene expression, potentially resulting in the formation of proteins that will benefit the adaptations we are targeting with training. Training with low carbohydrate availability (or train low) is one of the most studied methods.

“Training-low is a general term to describe training with low carbohydrate availability. This low carbohydrate availability could be low muscle glycogen, low liver glycogen, low carbohydrate intake during or after exercise or combinations thereof” (Jeukendrup, 2017a, https://bit.ly/2QLrD35). Early studies observed links between carbohydrate availability (muscle glycogen) and gene expression (Pilegaard et al., 2002): lower muscle glycogen was associated with greater gene expression, especially of genes involved with fat metabolism.

For example, the metabolic changes that occur as a result of muscle contraction, including a rise in AMP-activated protein kinase (AMPK) are important factors in regulating gene transcription. A single bout of endurance exercise will increase AMPK and transcription and/or mRNA content for various metabolic and stress-related genes. Typically, transcriptional activity peaks within the first few hours of recovery, returning to baseline within 24 hours. These findings have led to the overall hypothesis that training adaptations in skeletal muscle may be generated by the cumulative effects of transient increases in gene transcription during recovery from repeated bouts of exercise (Pilegaard, Ordway, Saltin, & Neufer, 2000). Although it is clear that gene transcription alone is not a guarantee that protein synthesis will occur, it is a step necessary for protein synthesis to occur. Studies have also demonstrated a link between muscle glycogen and AMPK expression (Wojtaszewski et al., 2003) with lower muscle glycogen resulting in greater AMPK expression (Wojtaszewski et al., 2003). Theories have developed that suggest that muscle glycogen directly influences AMPK since the beta-subunit of AMPK binds to specific glycogen binding sides which prevents it from being phosphorylated by upstream kinases (McBride, Ghilagaber, Nikolaev, & Hardie, 2009; McBride & Hardie, 2009). (Jeukendrup 2017a, https://bit.ly/2W08dX0)

Figure 2: Turning up the Signal: Training with Low Carbohydrate Availability

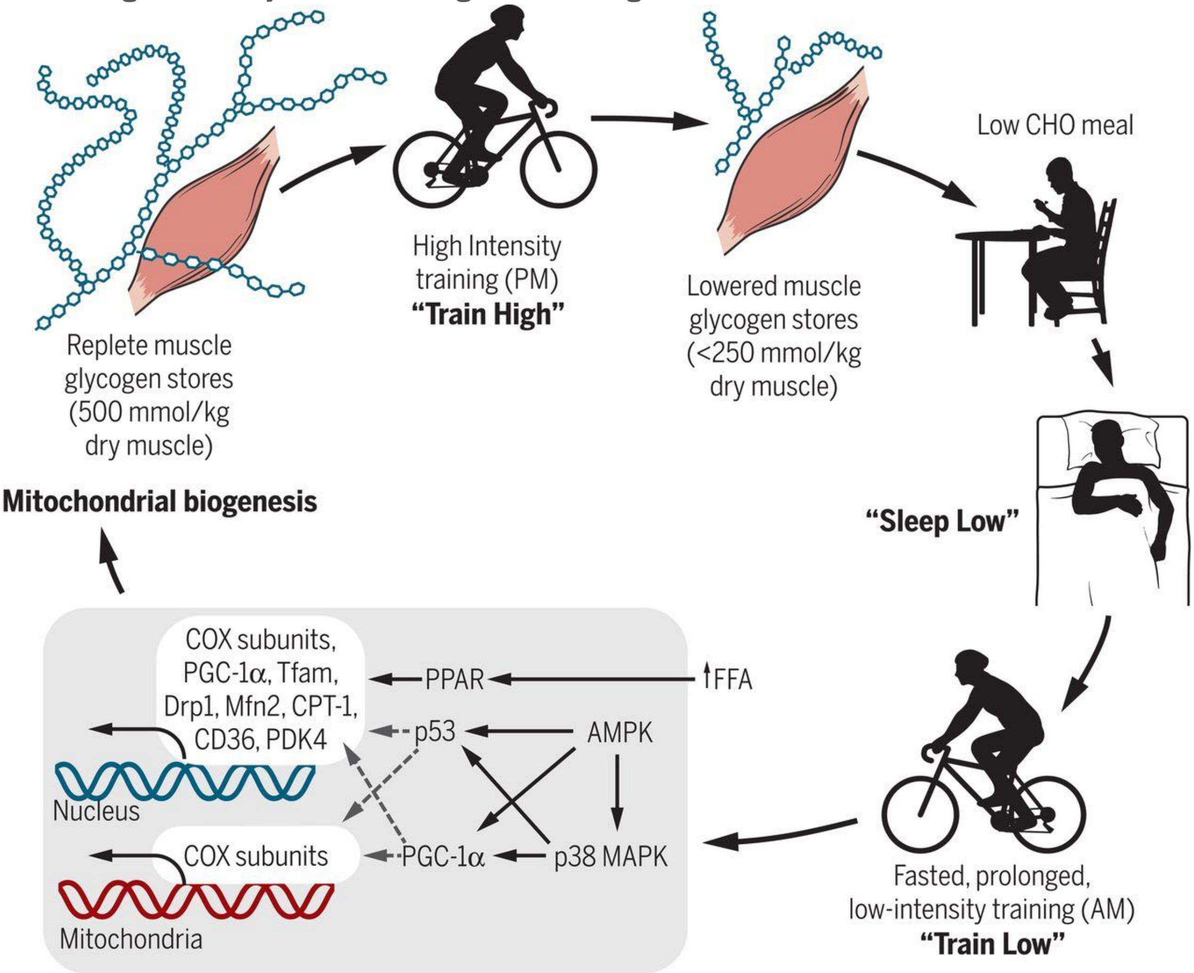


Source: Hawley 2018, https://bit.ly/2FHEmgH.

Skeletal muscle signalling responses after a single bout of endurance exercise are amplified in the face of low glycogen availability. The precise mechanisms responsible for this augmented activation are not resolved, but they likely involve the peroxisome proliferator-activated receptor g coactivator 1a (PGC-1a) and downstream targets. In this regard, the classical role of the AMP-activated protein kinase (AMPK) is to act as a sensor of the immediate energy status of the cell by monitoring the concentrations of AMP and ATP**.** However, the discovery and characterization of glycogen-binding sites within the carbohydrate-binding domain (CBD) on the AMPK beta-subunits indicate that this regulatory domain may also allow AMPK to act as a sensor of endogenous glycogen stores. In this case, the CBMs act as sensors enabling AMPK to gauge the state of cellular glycogen, increasing AMPK activity when stores are low and decreasing activity when stores are replete. As such, exercise sessions repeated over weeks and months in the face of low glycogen availability have the potential to modulate numerous adaptive processes in skeletal muscle, ultimately driving enhanced adaptation and the phenotype-specific characteristics observed in highly trained individuals.

> When glycogen is broken down this AMPK becomes available (McBride et al., 2009; McBride & Hardie, 2009) and therefore with low concentrations of glycogen high activity of AMPK is observed (Wojtaszewski et al., 2003; Yeo et al., 2010) (Figure 2). Other signalling molecules such as p38 mitogen-activated protein kinase (MAPK) (Cochran, Little, Tarnopolsky, & Gibala, 2010) and p53 (Bartlett et al., 2012), as well as the expression of peroxisome proliferator-activated receptor-γ coactivator 1-alpha (PGC-1α) (Sanders et al., 2007) may be enhanced to a greater extent when exercise is performed under conditions of carbohydrate restriction. It has also been demonstrated in rats that peroxisome proliferator-activated receptor gamma (PPAR-∂) transcriptional activity is sensitive to the combined effect of skeletal muscle contraction and glycogen depletion (Philp et al., 2013). Glycogen plays an important role in the regulation of gene transcription in the muscle. This in turn can alter protein synthesis and ultimately the training adaptation and function. Manipulating glycogen stores may therefore be a tool to optimize training adaptation and this has led to the development of a range of train low methods (Figure 3). (Jeukendrup 2017a, https://bit.ly/2W08dX0)

Figure 3: A cycle of training low and high



Source: Burke and Hawley, 2018, https://goo.gl/MRjqFM

In the next module, we will discuss a couple of these methods in more detail, but the reader is referred to several excellent recent review papers for a more in-depth discussion of train low strategies (Bartlett et al., 2015; Burke, Hawley, Wong, & Jeukendrup, 2011; Coffey & Hawley, 2007; Cox et al., 2010; Hawley et al., 2011; Perez-Schindler, Hamilton, Moore, Baar, & Philp, 2015; Philp et al., 2013).

In football, training low may be a method used during pre-season. It may be a good way to help aerobic capacity. However, as soon as high quality of raining is required, it is recommended to move more towards training high methods. Therefore, there may not be many weeks in a year where train low is appropriate for a football player. When returning from an injury, when high-quality training is not possible yet, there may be a value in training low.

2.1.4 Train high

Training high is the opposite approach of training with low glycogen availability and is close to the traditional approach of training. With “training high”, there is a focus on making sure recovery, especially of glycogen stores, is optimal. Clearly, avoiding muscle glycogen depletion is important for the maintenance of high-intensity exercise performance and, thus, for the quality of football training. Glycogen restorations after glycogen depleting exercise (match or hard training) is critical to subsequent performance. The idea behind training high is that every training session can be completed at maximal intensity and this over time should give the greatest training effects.

The methods to achieve high glycogen are described on the sections on recovery, but typically involve eating carbohydrate rich foods before and after training. To rapidly replenish glycogen, it is recommended to take 1-1.2 g/kg carbohydrate within the hour post exercise and repeat this for the 4 hours post exercise (at least if this is possible within the energy budget for this day: on days with lower energy expenditure, this intake could be too high). Daily carbohydrate intake during “train high” days is typically 5-8 g/kg for football players.

The advantage of a relatively high carbohydrate intake approach may be to maintain high-intensity exercise performance, whereas, when training low, this is likely compromised (Hawley & Leckey, 2015). So, “training high” could be a method that is used on days of hard training and days where the quality of training is critical. “Training low” could be used on days where training quality is less important than training the mitochondrial capacity of the muscle as well as the capacity to oxidize fat.

Of course, “training high” can also mean simulating match day in terms of carbohydrate intake. A relatively high carbohydrate intake before training, as well as carbohydrate intake just before and 45 minutes into a harder training session, could be part of a train high and “training the gut” session. It will get players used to a higher carbohydrate intake on match days and it will help to develop routines. It is recommended to perform this type of training once a week to ensure adaptations at the level of the intestinal tract (see the sections on training the gut).

With repeated days of hard training it seems preferred to train high. Although no football-specific studies are available, studies in rowers, runners and cyclists have shown superior adaptations with a higher carbohydrate intake. For example, Simonsen et al. (1991) showed that performance in rowers improved more when they consumed a higher carbohydrate diet compared to a normal carbohydrate diet. In the section on overtraining we discuss several studies that showed reduced symptoms of overreaching when repeated days of extremely hard training were performed in runners and cyclists (Achten et al., 2004; Halson et al., 2002; Halson, Lancaster, Achten, Gleeson, & Jeukendrup, 2004; Jeukendrup, Hesselink, Snyder, Kuipers, & Keizer, 1992).

This means that sleep quality and mood state may be better maintained, and that players may find it easier to complete the training. There are other advantages of training with high muscle glycogen as well. In the section on immune system, we also discussed studies that showed better maintenance of immune function with a higher carbohydrate intake during periods of intense training (Halson, Lancaster, Jeukendrup, & Gleeson, 2003; Lancaster, Jentjens, Moseley, Jeukendrup, & Gleeson, 2003; Svendsen et al., 2016). In the section on injuries, we discussed that a higher carbohydrate intake is likely to reduce the risk of injury.

In football, “training high” may be the most appropriate form of training most of the year. It is often about recovering quickly from matches or from a hard training session to make sure that the quality of sessions is maintained, the risk of injury or of developing overreaching is minimized and the immune system is supported. However, in reality, football players may not actually achieve the nutrition goals that are required to “train high”. Several reports have suggested lower intakes of carbohydrate by football players compared with the recommendations (Anderson et al., 2017; Garcia-Roves, Garcia-Zapico, Patterson, & Iglesias-Gutierrez, 2014).

Thus, the challenge is to get players to “train high”, but to do it in a way that it actually restores muscle glycogen. If this is achieved, training according to the principles of “train high” is possible.