2.2 Sports Nutrition

The origin of Nutrition as a science dates back to approximately the mid-XVIII century. However, if we trace the origin of **Sports Nutrition (SN)**, we can see that it dates back much further. The earliest existing records of the practice of training and diet date back to the Olympic Games of ancient Greece. In any case, these texts still remain half truth, half legend. It would be more adequate to see them as an example of how man's interest in discovering the effect that different types of food can have on our performance capability is age-old.

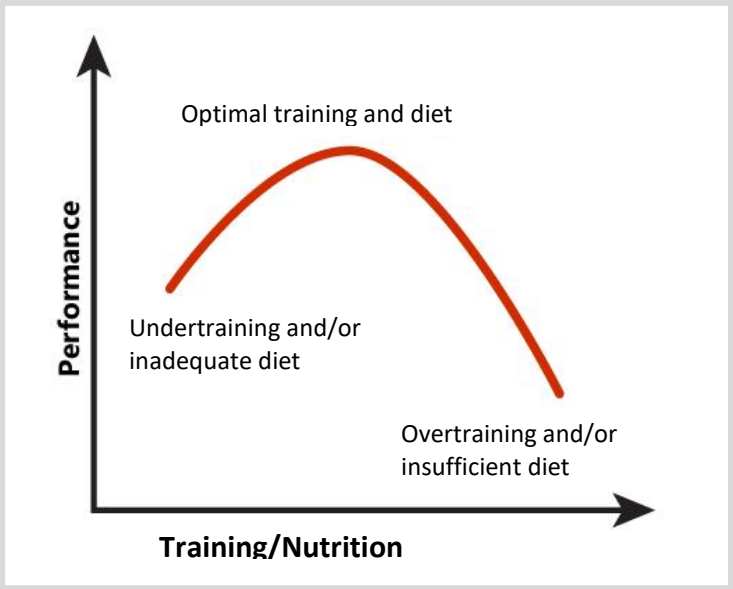
Even though scientific advances have enabled us to make huge advances in the field of nutrition, it is still considered a relatively young science. This is even more true in the case of SN. It could be claimed that, as a science in its own right, it still finds itself in the early stages of development. As an example of this, the earliest records of the eating habits of Olympic athletes began to surface around fifty years ago, and the majority of in-depth data available is the result of research conducted in the last fifteen to twenty years.

SN could be seen as an application of nutritional principles in order to maintain health and improve sports performance. That is, it is concerned with the aspects of nutritional science related to the interaction between nutrition and physical activity. In the last few decades, SN has made considerable progress, to the point that it has moved on from being based on empirical studies focused on the effects of dietary manipulations to involve direct research on the physiological basis of the nutritional demands specific to exercise.

Relationship between Training, Nutrition and Performance

The main factors that affect athletic performance ability are **genetic inheritance** and the **quality of the training process**. Beyond those factors, nutrition plays a critical role in optimizing performance capacity (American College of Sports Medicine, 2000; Leutholtz & Kreider, 2001). This means that for an athlete to perform to the best of his ability, training and nutrition should be both optimal and perfectly coordinated (Figure 2). What an athlete eats and drinks will without doubt affect their health, weight and body composition, the availability of energy substrates during exercise, recovery time after training or competition and, consequently, their performance (American College of Sports Medicine, 2000).

Figure 2. Relationship between Performance and Training/Nutrition



Source: adapted from Leutholtz &Kreider, 2001.

2.2.1 Principles and Objectives

Sports Nutrition Principles

The first principle to optimize the athlete's performance is make sure they consume enough energy, i.e., maintain their energetic balance (American College of Sports Medicine, 2000; Leutholtz & Kreider, 2001). Achieving an adequate energy intake is essential in order to maintain lean body mass, and immune and reproductive function, as well as an optimal athletic performance (American College of Sports Medicine, 2000). Additionally, a chronic deficit in energy intake has been considered one of the potential causal factors of overtraining (Leutholtz & Kreider, 2001).

The second principle in an athlete's diet is making sure they consume adequate quantities of macronutrients in their diet (Leutholtz & Kreider, 2001). Even though high-carbohydrate diets (that provide CHO >60% of the total caloric value) have been recommended for athletes (especially resistance athletes) in the past, there is no available information to suggest that athletes require a diet very different from that which is recommended for the general population to stay healthy (50 to 60% of the energy provided from CHO, 12 to 15% from protein and between 25 and 30% from fats), except for their increased need for energy and liquids (American College of Sports Medicine, 2000). In any case, the use of percentages to express the distribution of macronutrients in an athlete's diets could lead to misleading or confusing recommendations, which is why in this group it is best to express macronutrient requirements according to body size (American College of Sports Medicine, 2000).

The third element to take into account in an athlete's diets is making sure that they maintain an optimally hydrated state, since performance declines as the fluid balance changes and progressive dehydration occurs (American College of Sports Medicine, 2000).

Finally, it is important to develop a strategic diet plan, which means carefully planning the timing and most favorable composition of meals to ensure complete recovery after training and therefore optimize the adjustments generated by the training program. The idea of periodizing an athlete's diet can also be applied to the use of supplements and ergogenic aids.

Sports Nutrition Objectives

Essentially, an athlete's nutrition has two main objectives:

- Successfully develop an adequate training diet that allows the athlete to cope with the physical stress of training, providing all necessary substances to ensure optimal adaptation and facilitate a proper recovery between training sessions. An important characteristic of the training diet is that is can be easily manipulated to make it adapt to special situations that may arise, for example, marked changes in the training load, changes in the intended bodily composition, etc.

- Develop an optimal competition diet. The objective is to allow the athlete to arrive at the competition in favorable conditions so they can achieve their best performance. This basically involves three stages: pre-competition diet, diet during the competition and post-competition diet.

Nevertheless, the messages about health and food offered to people in general are still important goals for athletes to aim for (American College of Sports Medicine, 2000). They should be reminded that diet has an important psychological and social value, and that, beyond the immediate importance for their athletic performance, its importance is also long term because the food consumed today can have very important effect on their health in the future, especially once their athletic career is over.

2.2.2. Optimal Dietary Composition

Nutrition is one of the main factors that can affect an athlete's performance. However, some athletes are only concerned about their diet a few days before an important competition; but it is unlikely that this will improve their performance.

In the same way that athletes periodize their training (the components of their training plan, such as volume or intensity, vary throughout the year to achieve maximum performance), they should adapt their diet plan so it

supports their training plan. This means that every time their training plan enters into a new cycle or stage, their diet plan should be adapted to this change, so that they can cope with these new energetic and nutritional requirements. This is what is called **nutrition periodization (NP)**.

The **main goals** of NP are (Seebohar, 2011):

- Improve performance.
- Improve health.
- Optimize weight and bodily composition.

This same author notes that the **implementation principles** which NP is based on are:

- planning;
- developing;
- implementing;
- food quantity;
- food quality;
- meal timing.

Because of the differences that exist between different sports, and even within the same sport (between different specialties or between different positions), it is normal for there to be a wide range of macronutrients. In addition, each athlete's own individuality and the different objectives that each athlete has throughout the training seasons should also be taken into account. The result is that the recommendations given about consuming macronutrients should be taken as general references which should later be adapted to each particular case.

During the **preparation period (or "pre-season")** the following could be considered as general nutritional goals (Seebohar, 2011):

- Eating to optimize weight and bodily composition: If necessary, this is the period in which it is most recommendable to try to reduce body fat or gain muscle mass.
- Eating to train: The quantity of energy and nutrients is determined by the training load.
- Eating to learn: This could also be an excellent time to experiment with new foods and preparations, so you can better know the individual response. This information will prove very useful in later stages of the season.
- Eating to improve metabolic efficiency: During this stage, some strategies could be used to optimize the use of fat as a source of energy, and therefore preserve the limited bodily CHO reserves.

The general nutritional goals during the period of competition are:

- Continue experimenting to find out which foods and drinks are better tolerated before and during training and the competition.
- During training, rehearse the nutrition plan intended for competitions.
- Continue implementing the metabolic efficiency strategy. Keep in mind that this is not the same as recommending a low CHO diet.
- Practice and refine different nutrition plans, especially for hydration, according to the different conditions in which they may compete.
- Avoid straying from the nutrition plan, especially while traveling.

During transition period or off-season, the general nutritional goals are (Seebohar, 2011):

- Identifying the changes or necessary adjustments in the diet plan to account for the lower energetic requirement which characterizes this stage.
- In relation to the previous point, adequately managing emotions so that anxiety or other states do not lead to an over-intake of energy ("emotional eating"), which could result in weight and body fat gain.
- Discontinuing the use of sports supplements, especially those which could provide an important energy contribution (sports drinks, weight gainers, supplement bars, etc.), as this period is characterized by a reduced energetic need, which can be covered by common food and drinks.
- Prevent weight and body fat gain.

The general macronutrient recommendations for different periods of the training season can be found summarized in Table 6.

Table 6. Macronutrient Recommendations (in g/kg/day and g/lb/day) during Different Periods of the Sports Season

Training Period	CHO	Proteins	Fats
Preparatory (without weight/fat loss)	5-7 g/kg/day (2.4-3.2 g/lb/day)	1.2-2 g/kg/day (2.4-3.2 g/lb/day)	0.9-1.3 g/kg/day (2.4-3.2 g/lb/day)
Preparatory (with weight/fat loss)	3-4 g/kg/day (2.4-3.2 g/lb/day)	2-2.5 g/kg/day (2.4-3.2 g/lb/day)	0.8-1 g/kg/day (2.4-3.2 g/lb/day)
Competitive	5-12g/kg/day (2.4-3.2 g/lb/day)	1.4-2 g/kg/day (2.4-3.2 g/lb/day)	1-1.5 g/kg/day (2.4-3.2 g/lb/day)
Off-season	3-4 g/kg/day (2.4-3.2 g/lb/day)	1.5-2.3 g/kg/day (2.4-3.2 g/lb/day)	1-1.2 g/kg/day (2.4-3.2 g/lb/day)

Source: Adapted from Seebohar, 2011.

2.2.3 Gastrointestinal Function and Exercise

The **gastrointestinal function (GI)** has the potential to influence both health and athletic performance. In fact, knowledge of the GI function allows to establish the basis for developing and applying optimal nutritional strategies to boost performance.

Sports performance and the environment in which it occurs could compromise the integrity and/or functionality of the digestive tract. GI disorder can reduce the availability of nutrients and the associated symptoms may cause weakness. Both conditions can reduce performance capacity.

Effects of Exercise and Subjects' Characteristics on GI Function

The **intensity** of the exercise can have an important effect on the **gastric emptying rate**. Low intensity exercise (e.g. walking) increases the gastric emptying rate. Across different investigations, no clear effect has been found regarding moderate-intensity exercise but, in general, the effect would not be too different from low-intensity exercise. Whereas, intense exercise (e.g. 80-90% VO_2 max) or intermittent exercise (e.g. varied intensity exercises, in which there is an alteration of moderate exercise, short high-intensity exercise with breaks or low-intensity periods) reduces the gastric emptying rate (Leiper, Broad, and Maughan, 2001; Leiper, Prentice, Wrightson, and Maughan, 2001; Rehrer, McLaughlin, and Wasse, 2014).

Even though intense exercise produces a significant reduction in the gastric emptying rate, this is not sufficient reason to discourage fluid consumption when losses are expected that could compromise performance capacity (Rehrer et al., 2014).

Exercise mode does not seem to have a very elevated impact on the rate of gastric emptying because, when the same individuals exert the same effort running or pedaling, similar rates of gastric emptying are observed (Houmard et al., 1991).

Similarly, the **training level** does not seem to affect the gastric emptying rate because, when the exercise remains at the same relative intensity level (e.g., VO_2 max %), no significant differences between the trained subjects compared to untrained subjects are observed (Rehrer et al., 2014).

While **age** has not been demonstrated to have a clear affect on the gastric emptying rate across different studies (Rehrer et al., 2014), it seems that the rate reduces in old age, since 70-year-old subjects empty fluids with CHO more slowly than 20-year-old-subjects(O'Donovan et al., 2005).

There are not many studies that have analyzed the effect of sex on gastric emptying, although it seems men have somewhat higher emptying rates than women, both in the case of solid foods and liquids (Datz, Christian, & Moore, 1987).

The combined effect that exercising in hot conditions and hypohydration has on thermal stress also reduces the gastric emptying rate (Neufer, Young, & Sawka, 1989), although it seems that hypohydration alone does not significantly reduce the gastric emptying rate (Ryan et al., 1998).

Beyond the fact that all these factors can allow us to conduct a better analysis of gastric function during exercise, it is very important to keep in mind that great differences exist between individuals in terms of the gastric emptying rate (Rehrer et al., 2014).

On the other hand, studies that analyze the effect of physical exercise on the rate of intestinal absorption are partly inconsistent and reflect great variation between individuals. In any case, it seems that the intestinal absorption rate is reduced during exercise only when the intensity of the effort or the environmental conditions are such that the blood flow to the GI tract is reduced to the point that it compromises oxygen (Rehrer et al., 2014).

GI motility is responsible for controlling GI transit. Similar to what happens with gastric emptying, moderate-intensity exercise increases motility and GI transit, while high-intensity exercise reduces them (Brown et al., 1994). As with other variables of the GI function, a great variability in GI motility is observed between individuals (Degen & Phillips, 1996; Rehrer et al., 2014) and GI transit tends to be, on average, a little higher in men compared to in women (Degen & Phillips, 1996).

Physical exercise also reduces the splanchnic blood flow (e.g. irrigation of visceral organs) and this becomes more evident as intensity increases. Even the combined effect of exercise with hyperthermia and dehydration can reduce blood flow to a greater degree (Rehrer et al., 2014).

Effects of the Nutrient Type and Drink/Food Characteristics on GI Function

One of the main factors that regulates gastric emptying is CHO concentration. As concentration increases, emptying slows down (Rehrer, Beckers, Brouns, Hoorten, and Saris, 1989; Rehrer et al., 2014; Vist and Maughan, 1994). The CHO type also modifies the gastric emptying rate because it affects osmolality and viscosity (Rehrer et al., 2014). Although, this is perhaps only relevant for drinks with high osmolality (>500 mOsm/L) because the osmolality does not seem to be a factor of high importance when it is found in the range of 200 to 400 mOsm/L (Brouns, Senden, Beckers, and Saris, 1995). Another factor that has a great

influence on gastric emptying is the **fluid volume** consumed (Noakes, Rehrer, & Maughan, 1991). The increase in volume, whether through a single gulp or repeated intake, increases the gastric emptying rate. While individual tolerance is quite variable among different individuals, the fluid intake rate which tends to provoke gastric distress hovers between 1000-1200 ml/hour (Mitchell & Voss, 1991; Rehrer et al., 2014).

The addition of other nutrients, such as proteins and fats, cause a reduction of the gastric emptying rate, in direct relation with the *energetic density* (Calbet & MacLean, 1997). This reduces the water availability rate and the CHOs contained in the drink. The consumed *food's physical state* affects the gastric emptying rate because liquid foods evacuate more quickly than solid foods (Rehrer et al., 2014), while the temperature of the drink does not seem to have a great influence on the gastric emptying rate.

Similarly, the osmolality of a drink with CHO (6%) when found within a range of 200 to 400 mOsm/L does not seem to affect **intestinal absorption** of fluids (Gisolfi, Summers, Lambert, and Xia, 1998). However, if the concentration of CHO increases to such a degree that it raises the osmolality over 400 mOsm/L, this can cause a flow of water towards the intestinal lumen, which causes reduced intestinal absorption of water (Ryan et al., 1998).

The use of *caffeine*, as well as being an effective ergogenic aid and very popular in sports (Burke, 2008), has proven to increase glucose absorption in the intestine, without producing adverse effects on the GI function (Van Nieuwenhoven, Brummer, & Brouns, 2000).

GI Distress During Exercise

GI disorders during exercise are experienced both by recreational athletes and elite athletes, but their causes are not completely understood.

The prevalence of GI symptoms varies greatly between athletes. Both their frequency and severity normally depend on the intensity and duration of the effort and, in general, they are more frequent in hot environments (Rehrer et al., 2014).

A recent study reported a similar quantity of subjects suffering GI distress during cycling and running trials (Pfeiffer et al., 2012), although some reports tend to mention that these types of problems are more frequent while running (Rehrer et al., 2014).

In general, GI symptoms tend to be classified as upper (e.g. gastroesophageal) and lower (intestinal) (Table 7). The mode in which the exercise is practiced could be an important factor in determining the place in which the distress is experienced. While running, inferior symptoms tend to be more frequent, but while cycling, upper symptoms tend to be more frequent. In general, upper symptoms tend to be minor and more transitory.

The underlying mechanisms of these problems are, in general, speculative, as a result of difficulties in taking physiological measures during exercise, and the transitory and likely multifactorial nature of these problems.

Table 7. Common Gastrointestinal Symptoms Associated with Exercise

Symptoms	Possible Contributing Factors
Upper gastrointestinal • Nausea • Acid reflux • Vomiting • Epigastric pain • Abdominal bloating • Belches Lower gastrointestinal • Constipation • Diarrhea • Rectal blood loss • Flatulence • Abdominal cramps • Sudden urge to defecate	• Dehydration • Altered gastrointestinal blood flow • Altered gastrointestinal permeability • Disturbances in gastrointestinal motility • Psychological influences • Pharmacological agents

Source: Adapted from Rehrer &Gerrard, 2000.

The mechanical factors could explain, at least in part, the difference between running and cycling. The movement of the intestine while running could be one of the reasons why lower symptoms are more common during this type of exercise, while the posture maintained during cycling could be one of the reasons why upper symptoms are reported to a greater degree during this type of exercise.

Among the physiological factors, blood flow has most often been related to GI problems. During exercise the blood flow towards the digestive tract reduces, which is why GI symptoms could be a consequence of ischemia (Rehrer et al., 2014). Even during prolonged resistance exercises, especially in hot conditions, it is likely for there to be some level of dehydration, which can increase the risk of suffering GI ischemia.

The increased consumption of CHO during exercise has been related to GI problems, mainly nausea, burps and flatulence, although symptoms tend to be mild to moderate. The use of multiple transportable CHO (i.e. different types of CHO that are absorbed by different transporters at an intestinal level) during exercise enables higher rates of CHO oxidation (Jentjens, Achten, & Jeukendrup, 2004). This, in turn, improves performance (Currell & Jeukendrup, 2008) and helps improve gastric

emptying and the intestinal availability of fluids and CHO (A. E. Jeukendrup & Moseley, 2010), which reduces GI symptoms.

The timing and composition of the meal before exercise is also an important factor to take into account, especially for longer events. For example, in a study conducted with triathletes, those who ate 30 minutes before starting, vomited during the swimming stage. In addition, the vomiting episodes or need to vomit were more frequent among those who ingested a greater quantity of fats and proteins in the pre-exercise meal, and drank hypertonic drinks. While all those who experienced intestinal cramps had eaten fiber-rich foods in the pre-race meal (Rehrer, van Kemenade, Meester, Brouns, and Saris, 1992).

The use of bicarbonate can increase athletic performance, but it can also cause GI problems, such as nausea, vomiting and diarrhea (Burke & Pyne, 2007).

In summary, while many factors related to the mechanisms of GI distress during exercise cannot be modified, others can be adapted to minimize these problems. Athletes should implement an proper training process for the competition, as well as developing an acclimatization process to the environmental conditions in which they will compete. They should also have an individualized and previously practiced nutrition plan that will help them to identify the most proper nutritional strategy in each case.

2.2.4 Nutrition, Exercise and the Immune System

Strenuous exercise, particularly if it is prolonged or intense, causes a temporary depression in various aspects in the immune function that can last between three to twenty four hours, depending on the intensity and duration of the exercise, and what parameter of the immune function is analyzed (Gleeson, 2007; Nieman, 1997). Therefore, exercise could be considered as a factor which puts stress on the immune system and may cause **immunosuppression**, similar to other stress factors (surgery, traumatic injury, acute myocardial infarction).

During this **post-exercise window period**, in which the immune system function is depressed, it is more likely that viruses and bacteria can enter the body and, therefore, increase the risk of infection. In fact, immune system disturbances caused by exercise are associated with an increased risk of **upper respiratory tract infection (URIs)**, in particular during intense training periods and for one to two weeks after endurance races (Nieman, 2000, 2014).

Various nutritional factors have been evaluated for their potential effects on reducing immune response, oxidative stress and inflammation caused by exercise. However, the majority have not been effective, except **CHO** and some **polyphenol** supplements (a group of chemical substances found in fruit and vegetables), such as quercetin, β-glucans, etc. (Nieman, 2008, Nieman, 2014).

Athletes with a strict training regime, and particularly endurance athletes, are interested in maintaining a strong immune system. This can be achieved by using CHO-based drinks and mixtures of bioactive substances (e.g. polyphenols) which aim to reduce the risk of infection, alleviate oxidative stress and inflammation caused by exercise (Nieman, 2014). Likewise, this strategy could be combined with others that help to maintain optimal immunity and health, such as following a healthy diet, avoiding overtraining, sleeping well, avoiding rapid weight loss, etc. (Nieman, 2008).

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