1. The history and future of sports nutrition

1.1 History

1.1.1 Where it all started

Greeks and Romans

It could be argued that sports nutrition started in paradise when Eve gave the apple to Adam to make him as strong as God. Nutrition has always intrigued humans. As far back as ancient Greece, nutrition has been linked to performance and health. It was Hippocrates (460 BC - ca. 370 BC) who said "If we could give every individual the right amount of nourishment and exercise, not too little and not too much, we would have found the safest way to health". The diet of most Greeks and Romans was predominantly vegetarian and consisted of cereals, fruit, vegetables and legumes, and wine diluted with water. When meat was eaten, the most common source was goat for Greeks and pork for Romans.

It is believed that the first documented information about a special diet of a Greek athlete was Charmis of Sparta. He is said to have trained on dried figs. There are other reports of figs being used as sports nutrition. Running was a big part of army training and there were professional runners who were used to send [*sic*] messages sometimes over long distances. The most well known runner was perhaps Pheidipphides, who has been linked to the origin of the marathon. Pheidipphides is said to have run from Athens to Sparta (240km) to ask the Spartans for help when Persians were about to destroy Athens. When the Spartans replied that they were just celebrating an annual ceremony and their laws did not permit them go to Athens to help, Pheidippides had to run back to convey the bad news.

"If we could give every individual the right amount of nourishment and exercise, not too little and not too much, we would have found the safest way to health." Hippocrates (460 BC - ca. 370 BC).

So, he ran a total of 480km and he would have used figs as one of his main energy sources. It was estimated that with his 50 kg, he expended 28,000 kcal. (112,000 kJ). He also supposedly ran from Marathon to Athens (40km) which later became the marathon distance at modern Olympic Games. However, whether this run actually took place is still debated. (Saltin & Jeukendrup, 2010, p. 9).

Olympic Games

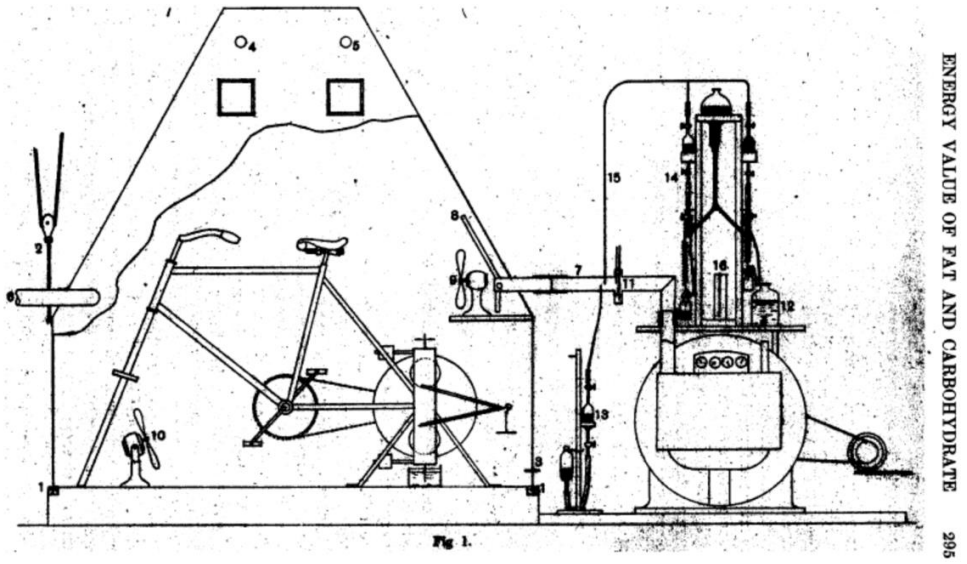
According to Galen and other authors, at the end of the third century B.C., athletes believed that drinking herbal teas and eating mushrooms could increase their performance during competition in the ancient Olympic Games. There is also a report that states that a meat diet was introduced about the middle of the fifth century by Dromeus of Stymphalos, an ex-long-distance runner. Another account by Diogenes Laertius reports that Eurymenes of Samos consumed a meat diet recommended by his trainer, Pythagoras of Croton. However, by far the best accounts of athletic diet to survive from antiquity are those of Milo of Croton, a wrestler whose feats of strength became legendary and won the wrestling event at five successive Olympics from 532 to 516 B.C. His diet supposedly consisted of 9 kg (20 pounds) of meat, 9 kg (20 pounds) of bread and 8.5 L (18 pints) of wine a day. The validity of these reports from antiquity, however, must be suspect. Although Milo was clearly a large and powerful man, who possessed a prodigious appetite, basic estimations reveal that if he trained on such a volume of food, Milo would have consumed approximately 57,000 kcal (238,500 kJ) per day.

In South America, stimulants like mate tea, coffee and coca were used to increase performance. It has been reported that the Incas chewed coca leaves to cover the distance between Cuzco and Quito, in Ecuador (>1600km). (Saltin & Jeukendrup, 2010, p. 10).

1.1.2 The first experimental approach

> An experimental approach to the field of human muscle energy metabolism had its start in the middle of the 19th century. In 1842 Justus von Liebig stated that the primary fuel for muscular contraction was protein. However, within two decades this was proven wrong by von (von Pettenkofer & Voit, 1866). Subsequent laboratory experiments focused on whether carbohydrates and fat could be used directly by contracting skeletal muscle. After some initial studies by Chaveux, supporting the view that fat had to be converted to carbohydrates before it could be used by muscle, Zuntz (1901) claimed that both carbohydrates and fat were oxidized by skeletal muscle, not only at rest but also during exercise. This was confirmed in later studies by Krogh and Lindhard (1920). They also demonstrated that both fuels were used at the same time, in most instances, while protein normally did not play a role as a supplier of energy. (Saltin & Jeukendrup, 2010, p. 10).

Figure 1: Gas Analysis Jaquet Apparatus



Source: Krogh and Lindhard, 1920, p. 295.

This is the experimental Krogh and Lindhardt (1920) used to measure carbohydrate and fat utilisation during exercise. Oxygen consumption and carbon dioxide production were measured; and from this, carbohydrate and fat oxidation were calculated.

Carbohydrate can be converted and stored as fat, but fat cannot be converted or stored as carbohydrate (although some of the breakdown product (glycerol) can be used in gluconeogenesis to make glucose).

> Other researchers [in the early 20th century] had a more applied approach. They studied the diet of Arctic explorers crossing ice caps in the world. The Polar expeditions established that with an energy intake of up to 60-70% coming from fat, subjects could still maintain a relatively high daily high exercise output. The sledge dogs could, however, perform their heavy task with a diet containing up to 90% fat. (Saltin & Jeukendrup, 2010, p. 11).

The importance of carbohydrate feeding

> Important observations were also made by Levine and colleagues in the 1920s [Levine, Gordon, & Derick, 1924]. They measured blood glucose concentrations in some of the participants of the 1923 Boston Marathon… They observed that glucose concentrations markedly declined after the race in most runners. These investigators suggested that low blood glucose levels were a cause of fatigue. To test that hypothesis, they encouraged several participants of the same marathon the following year to consume carbohydrates (candy) during the race. This practice, in combination with a high-carbohydrate diet before the race, seemed to prevent hypoglycemia (low blood glucose) and significantly improved running performance (i.e., time to complete the race).
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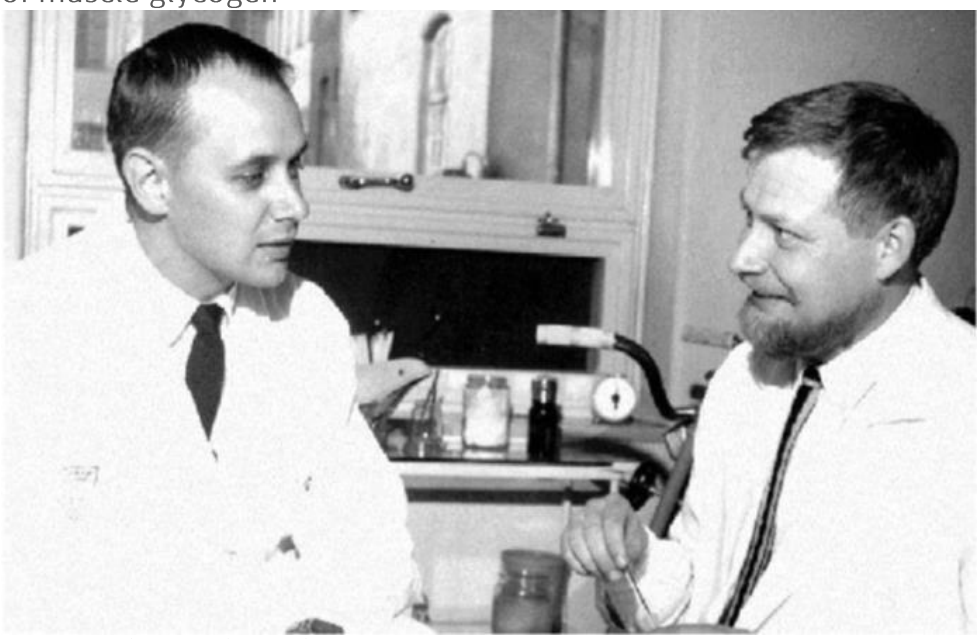
> The importance of carbohydrate for improving exercise capacity was further demonstrated by Dill, Edwards, and Talbott (1932). These investigators let their dogs, Joe and Sally, run without feeding them carbohydrates. The dogs became hypoglycemic and fatigued after 4 to 6 hours. When the test was repeated, with the only difference that the dogs were fed carbohydrates during exercise, the dogs ran for 17 to 23 hours. (Saltin & Jeukendrup, 2010, p.12)

1.1.3 Scandinavian studies

In the 1950-60s, methodologies improved and new techniques such as the use of isotopes were introduced; also, the biopsy needle was re-introduced to take muscle biopsies and measure muscle glycogen (by Jonas Bergström and Eric Hultman, 1967)

Figure 2: Jonas Bergström and Eric Hultman who performed muscle biopsies on each other and started ground breaking work on the role of muscle glycogen



Source: Hawley, Maughan and Hargreaves, 2015, p.14.

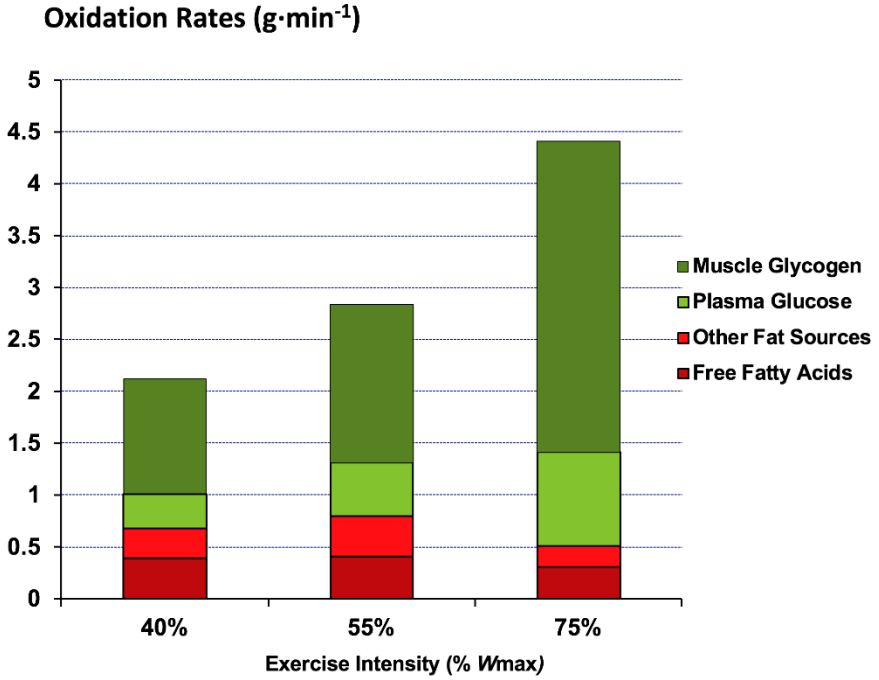
This provided new tools that allowed more detailed investigation of substrates used and metabolites produced by the muscle (Bergström, Hermansen, Hultman, & Saltin, 1967; Bergstrom & Hultman, 1967; Hultman & Bergstrom, 1967).

The storage and use of muscle glycogen (Bergström et al., 1967; Bergstrom & Hultman, 1967; Hultman & Bergstrom, 1967) was extensively investigated. But also fat as a fuel received some attention. Fatty acids (FA) became recognized as key players in exercise metabolism (Havel, Pernow, & Jones, 1967).

Since then, many exercise studies have investigated the role of fat and carbohydrate during exercise and their relative contributions to energy expenditure. Many discoveries were made with regards to the factors that limit the use of these substrates and the mechanisms that regulate the use of these substrates. It is clear that carbohydrates are needed for high intensity exercise and that during exercise of 80%VO_2max or more fat oxidation is significantly reduced or even negligible (Randell et al., 2017;

van Loon, Greenhaff, Constantin-Teodosiu, Saris, & Wagenmakers, 2001; Venables, Achten, & Jeukendrup, 2005). Fat oxidation is increased significantly after several weeks (usually 10-12 weeks) of endurance training (Holloszy & Coyle, 1984).

Figure 3: Substrate use as a function of exercise intensity

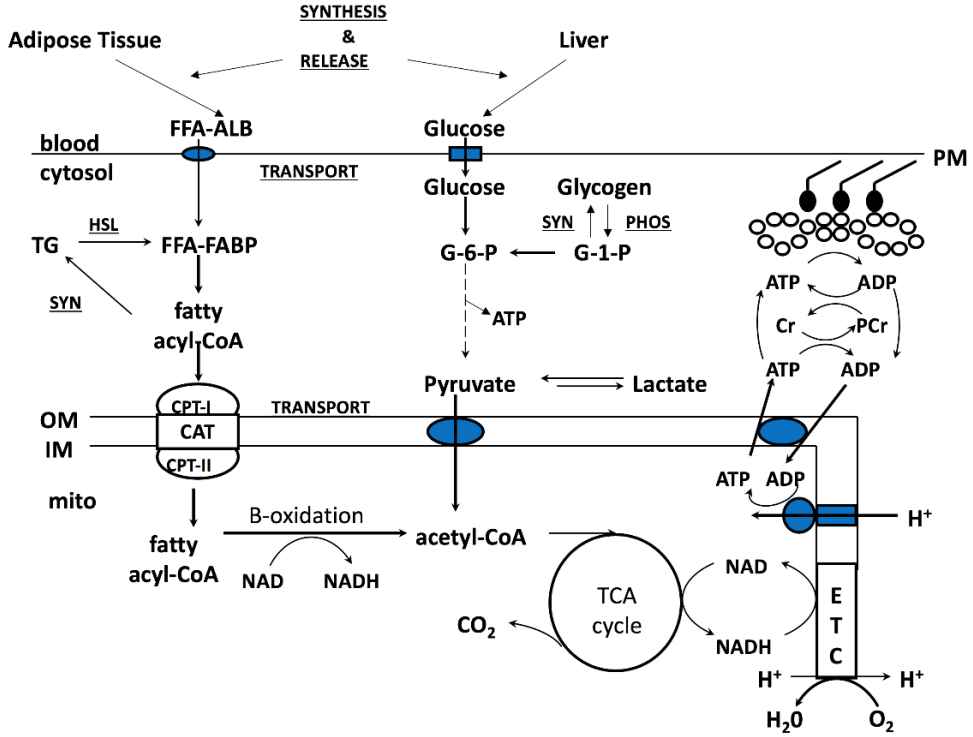


Source: adapted from Romijn, Coyle, Sidossis, Gastaldelli, Horowitz, Endert and Wolfe 1993, p. 385.

Figure 3. Fat oxidation is in red. It can be seen that fat oxidation increases from low to moderate intensity but decreases at higher intensities. This is true for both fat substrates (plasma derived and muscle derived). Carbohydrate oxidation on the other hand increases with increasing exercise intensity mostly as a result of muscle glycogen use. It is clear that at high intensities (>75%VO_2max) carbohydrate is the dominant fuel.

The roles of plasma and muscle triglycerides (TG) are less clear and continue to be intensely debated. There is also much discussion about the reasons why fat oxidation is limited during high intensity exercise. During high intensity exercise there is an increased demand for energy, yet it is not possible to use fat, even though it is available in abundance. It has been suggested that the transport of FA into the muscle is the rate-limiting step, but there is also strong evidence of an important role for the mitochondrial respiratory capacity. Another theory evolved around the regulation of the FA uptake into the mitochondria.

Figure 4: Schematic overview of energy production in skeletal muscle.



Source: adapted from Spriet 2002, p.1478.

Figure 4. Glucose and fat entering the cell and taken up as pyruvate or fatty acyl-CoA into the mitochondria where they are both converted to acetyl CoA before being used for ATP production through the TCA cycle. When pyruvate cannot be taken up and used by the TCA cycle fast enough by the mitochondria, lactate will be formed.

Early studies also focused on lactate metabolism. This intermediate product of carbohydrate metabolism is produced especially during high intensity exercise. In the 1970s, the theory developed that lactic acid was strongly related to fatigue. In sports, lactate became the most measured blood parameter and it was (and still is) often used to monitor training intensity. It was thought that lactate was formed as a result of insufficient oxygen supply to the working muscle. However, now we know that lactate is not the cause of fatigue, it is a great fuel for the muscle and it is also formed in the presence of oxygen. Lactate is simply a product of carbohydrate metabolism that is formed when the rate of glycolysis exceeds the capacity of tricarboxylic (TCA or Krebs) cycle activity. Glycolysis is stimulated during high intensity exercise and allows the adenosine tri phosphate (ATP) production required to sustain that intensity. If the TCA cycle activity cannot keep up with the high rates of glycolysis, pyruvate will accumulate and this could shut down glycolysis (through feedback inhibition). Of course this means that the intensity cannot be maintained. So to prevent pyruvate from accumulating, it is converted to lactate. This is a good thing and the fact that we can form lactate means that: 1. Rates of glycolysis can be high and we can continue

to generate energy; 2. Pyruvate accumulation is prevented. So whereas lactate, (especially in football) is still thought of as something that needs to be prevented, it is simply a byproduct of carbohydrate metabolism. It would be more of a problem if players could not produce lactate. Diet also affects lactate production. For example, if glycogen concentrations are low, lactate production will be low, but exercise capacity will be lower as well. So, although for many years lactate was thought of as a "bad thing" we now think of lactate as a "good thing" and a good fuel for the working muscle (Brooks, 1991, 2018).

> Although many questions are still unanswered, despite many years of intensive research, it is clear dietary carbohydrates are essential for optimal performance. Equally clear is that a high capacity for lipid oxidation in the active muscles of an endurance athlete is a requirement for optimal endurance performance. (Saltin & Jeukendrup, 2010, p. 12).

Hydration

> In the 80s, there were a number of studies showing that dehydration could reduce performance and extreme dehydration could result in heat stroke and adverse health effects. These studies were soon followed up by work to optimize fluid delivery during exercise. Sports drinks appeared on the shelves of sports shops and supermarkets and were marketed toward a growing number of long distance runners and other athletes.
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> There was clearly a trend towards drinking more and more during endurance events as evidenced by the IAAF (International Association of Athletics Federation) drinking guidelines and regulations for feed stations during marathon races. In 1953, the IAAF handbook for race organizers indicated that feed stations had to be provided only for marathon aces and only at 15 and 30 km. The 2009 guidelines indicate that water should be available at the start and finish of all events, for events up to 10 km drinking should be provided every 2-3 km and for longer events refreshment stations have to be provided every 5km. In addition, water should be supplied midway between these refreshment stations. Effectively the total number of drinking opportunities during a marathon may be 17! [versus just 2 in 1953!] Over the years the drinking messages got a bit clouded and some runners interpreted the

> guidelines as a directive to drink as much as possible. However, [the guidelines never actually stated this,] it is clear that drinking too much water can result in hyponatremia [Hew-Butler et al., 2008], and more recently the drinking advice has stressed that overdrinking can be dangerous [American College of Sports et al., 2007; Baker & Jeukendrup, 2014; McDermott et al., 2017]. (Saltin & Jeukendrup, 2010, p. 13).

Micronutrients

> Micronutrients have received some attention too. Since their discovery, vitamins have been more or less synonymous with good health because it was clear that a lack of these essential nutrients resulted in illness. Since the 40s and 50s it became common practice for sports people to supplement with vitamins in order to perform better. [Research was mostly focused on the general populations and guidelines aimed to prevent deficiencies]. However, research also consistently indicated that as long as there were no deficiencies, vitamin intakes over and above the daily recommended amounts did not enhance performance. Nevertheless, the use of vitamins and minerals, and antioxidants in particular, is still very popular. More recently, however, studies pointed out that large amounts of antioxidants could actually prevent (or at least reduce) normal training adaptations. It has also become clear that large doses of certain vitamins and minerals can have detrimental health effects. (Saltin & Jeukendrup, 2010, p. 13).

So, although vitamins and minerals are needed, more is not always better and sometimes more is worse.

1.1.4 Football studies

Science arrived relatively late in football and Tom Reilly (Liverpool John Moores University) was certainly one of the pioneers. Some of the earliest studies in football were performed by him and his team. In 1976, they reported that English First division players had about 100 changes in playing activities during a match with each activity having a mean duration of 5-6s. Reilly and Thomas also estimated that on average the intensity of match play was around 75%VO_2max (Reilly & Thomas, 1979).

In the 1960s, it was demonstrated that muscle glycogen concentration was related to fatigue. A higher carbohydrate intake resulted in increased muscle glycogen and increased endurance capacity. It was shown that during a football match muscle glycogen concentration declined to very low levels at the end of the match. On average, muscle glycogen concentrations were 96 mmol/kg ww, 32 mmol/kg ww at halftime and 9 mmol/kg ww at the end. It was also observed that in some players muscle glycogen was already very low after 45 min. The players who started the match with low muscle glycogen (45 mmol/kg ww) had almost depleted stores by half-time. Another important observation was that muscle glycogen concentration was correlated with parameters of running performance. For example, the players with lower muscle glycogen concentrations covered less distance. More importantly, they spent less time completing high-intensity runs (15% versus 27% of total time). (Bangsbo 2014)

In 1982, Ira Jacobs and colleagues took muscle biopsies in 15 Malmo players (Jacobs, Westlin, Karlsson, Rasmusson, & Houghton, 1982). They measured muscle glycogen and found that these concentrations dropped to very low levels after a real match. 24 hours later and 48 hours later muscle biopsies were collected and muscle glycogen was measured again. The main conclusion was that even 48 hours later muscle glycogen concentrations were not back to normal. This happened despite a relatively high carbohydrate intake. It could be speculated that even 72 hours after a match, glycogen would not be back to normal concentrations, which is when players would have to be ready to play again on a 2 matches per week schedule.

Figure 5: Muscle Glycogen % in a two matches per Week Schedule

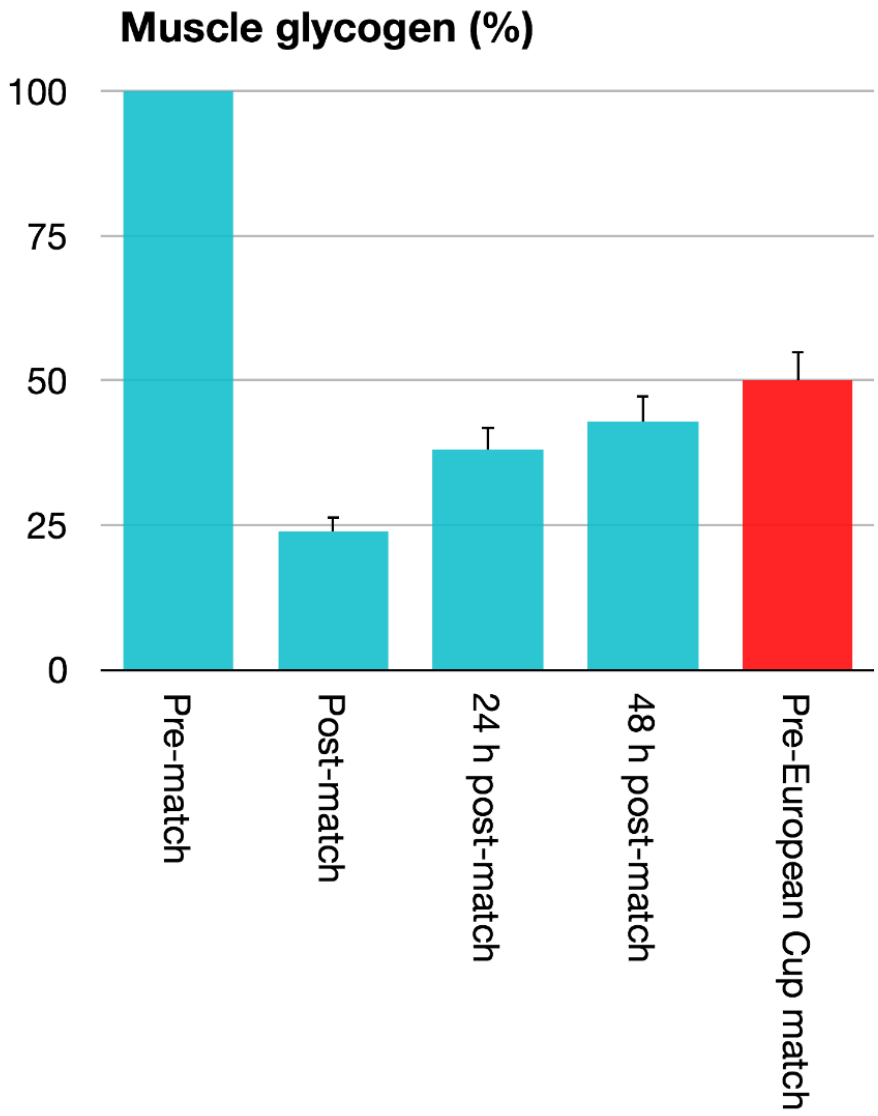

Figure 5. In blue, the muscle glycogen measurements performed in a Swedish football team. The players consumed their normal diet and this was not sufficient to restore muscle glycogen to pre-match levels. In red, the fictive muscle glycogen concentration on a European Cup match 4 days after the first match. It is clear that it is unlikely that muscle glycogen can be completely restored on that day. Source: based on Jacobs et al., 1982.

In the 1980s, studies started to appear demonstrating the benefits of carbohydrate ingestion during endurance exercise. Consistently greater endurance capacity was reported in these studies, especially when the exercise duration was greater than about 2 hours.

Studies in football soon followed. The effects of carbohydrate ingestion and player performance during "live" matches were investigated. For example, in a study (by Kirkendall, Foster, Dean, Grogan, & Thompson, 1988) 10 players were captured on video on two separate occasions, separated by one day. For each match, players drank either a carbohydrate solution or sweetened placebo before the game and at

halftime. Players who drank the carbohydrate solution ran approximately 40% greater distance during the second half of the game, in comparison to when the placebo beverage was consumed. Interestingly, a similar study in which players consumed 0.5 L of a 7% glucose solution 10 min before a practice match and the same volume again at halftime, reported a 39% reduction in muscle glycogen use compared to players drinking a sweetened placebo (Leatt & Jacobs, 1989).

As a returning theme in this course, it is important to note that it is not easy to measure performance in football. There are many aspects to performance and most of these are difficult to measure. This, in turn, results in greater variation which means that it becomes harder to detect small differences. Such differences, however small, could be important for a player's future performance and the team's performance. Therefore, we encourage researchers to report the reliability of their measurements so that interpretation of the data becomes more meaningful. Many studies are using exercise protocols that are inadequate, have poor reliability or have no resemblance to actual football performance. It is essential that we are able to critically read research papers so we can judge them better and interpret the data with more caution when needed.