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Nutrition on match day

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Abstract

What players should eat on match day is a frequently asked question in sports nutrition. The recommendation from the available evidence is that players should eat a high-carbohydrate meal about 3 h before the match. This may be breakfast when the matches are played around midday, lunch for late afternoon matches, and an early dinner when matches are played late in the evening. The combination of a high-carbohydrate pre-match meal and a sports drink, ingested during the match, results in a greater exercise capacity than a high-carbohydrate meal alone. There is evidence to suggest that there are benefits to a pre-match meal that is composed of low-glycaemic index (GI) carbohydrate foods rather than high-GI foods. A low-GI pre-match meal results in feelings of satiety for longer and produces a more stable blood glucose concentration than after a high-GI meal. There are also some reports of improved endurance capacity after low-GI carbohydrate pre-exercise meals. The physical demands of soccer training and match-play draw heavily on players' carbohydrate stores and so the benefits of good nutritional practices for performance and health should be an essential part of the education of players, coaches, and in particular the parents of young players.

Keywords: *Soccer, football, carbohydrates, glycaemic index, fatigue, exercise capacity*

Introduction

"Breakfast is the most important meal of the day" is such a well held belief that it has become a mantra repeated as much to our athletes as to our children. In general, the recommendation not to miss breakfast is sound because it helps replenish the carbohydrate stores that are lost from the liver during the overnight fast as well as replenishing other nutrients and fluid that are necessary for health (Casey *et al.*, 2000; Nilsson, Furst, & Hultman, 1973; Nilsson & Hultman, 1973). In addition, a high-carbohydrate breakfast also helps "top up" muscle glycogen stores within 3 – 4 h after the meal (Chryssanthopoulos, Williams, Nowitz, & Bogdanis, 2004; Wee, Williams, Tsintzas, & Boobis, 2005). When matches are played between late morning and early afternoon, breakfast may well be the pre-match meal for those players who are not early risers. Most matches are played in the afternoons on a Saturday or Sunday. However, there has been an increase in the number of matches played in the evenings, especially on weekdays (e.g. Champion's League games).

Planning a nutritional strategy for match day begins by first knowing the time and location of the match. Thereafter, the team nutritionist can work out how much time is available for meals and then recommend their composition bearing in mind the culinary likes and dislikes of the players. For example, when the match begins in the afternoon, players may have a light breakfast followed by a main meal around midday. When a match is played in the evening, players may have a late breakfast followed by a light lunch and their pre-match meal during the late afternoon, say about 15.00 – 16.00 h. To develop a successful nutritional strategy for players on match day, it is important to recognize that in many football clubs the pre-match meal is largely dictated by tradition and routine. For many players, a departure from their favourite pre-match meal is regarded as much a disadvantage as beginning a match with a physical injury. Therefore, any nutritional strategy must be developed in the context of what is custom and practice within a football club and supported by sound evidence.

The standard recommendation is that players should eat an easy-to-digest high-carbohydrate meal

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no later than about 3 h before a match. This recommendation has not changed since the publication of the last Consensus Statement on Nutrition and Soccer a decade ago (Ekblom & Williams, 1994). Since then there has been further progress in understanding the links between food intake and exercise performance but there have been few studies on football. Nevertheless, laboratory studies that have investigated the links between food intake and exercise performance have helped establish the principles, leaving team nutritionists to translate these principles into practice.

Our aim here is to provide an overview of those studies that have examined the influence of food intake on subsequent exercise performance in order to establish the bases for our recommendations for nutritional strategies on match day.

Pre-exercise meals

Most studies on exercise performance fall into two broad categories: whether the mode of exercise is cycling or running. Exercise tests that require participants to complete a fixed amount of work as quickly as possible or do as much work as possible in a set time, usually when cycling, may be regarded as assessing "exercise performance". Exercise tests that require participants to exercise as long as possible at a fixed power output (cycling) or at a set pace (running) may be regarded as assessing "endurance capacity".

In one of the early endurance performance studies, participants ate a breakfast consisting of bread, cereal, milk, and fruit juice (200 g carbohydrate) 4 h before cycling to exhaustion (Neufer *et al*., 1987). This meal increased pre-exercise muscle glycogen concentration by about 15% (though this was not statistically significant). The performance test required the participants to cycle for 45 min at 77% of maximal oxygen uptake ($\dot{V}O_{2max}$) and then to cycle as fast as possible for 15 min. The total work accomplished during the last 15 min of the test was greater (22%) after the pre-exercise meal than it was following the no-meal trial. However, not all performance studies have found such marked improvements in performance following the ingestion of a high-carbohydrate pre-exercise meal. In one cycling study, Whitley *et al*. (1998) found no difference in time-trial performance when participants were provided with a meal containing 215 g of carbohydrate, or no meal, 4 h before a 10 km time-trial. Their cyclists completed 90 min at 70% $\dot{V}O_{2max}$ and then the 10 km as fast as possible, but the 10 km times for the fed (878 s) and the fasted (874 s) trials were almost identical.

These two examples of exercise performance studies are typical of those reported in the early literature and, in general, the benefits of eating a high-carbohydrate meal before an exercise performance test are not as clear as before an exercise endurance capacity test.

In one endurance capacity study, Schabort, Bosch, Weltan and Noakes (1999) provided their participants with a commercially available breakfast cereal (100 g carbohydrate) and milk 3 h before they cycled to exhaustion at 70% $\dot{V}O_{2max}$. They also obtained muscle biopsy samples from the participants before each trial and then again at the end of exercise to assess the use of muscle glycogen. Endurance capacity was significantly greater after the carbohydrate breakfast than when the participants exercised to exhaustion after an overnight fast (136 vs. 109 min). There were no differences in the muscle glycogen concentrations at the end of exercise in the two trials, but a direct comparison of the respective rates of glycogenolysis cannot be undertaken because the final biopsy samples were obtained at different times.

The amount of carbohydrate ingested in a pre-exercise meal is also an important consideration. For example, Sherman *et al.* (1989) showed that although small amounts of carbohydrate (46 and 156 g) consumed 4 h before intermittent cycling improved endurance capacity, a greater amount (312 g) was even more effective. After this larger amount of carbohydrate, the exercise capacity was 15% greater (56 min) than after the water placebo (48 min) trial.

Footballers' breakfasts usually contain about 100 – 150 g of carbohydrate (C. Williams, unpublished observations) and so increasing this amount in one meal may lead to abdominal discomfort. Nevertheless, a compromise must be reached between eating sufficient carbohydrate to benefit performance without eating so much that it causes gastrointestinal disturbances during subsequent exercise. Sherman *et al.* (1989) avoided these potential gastrointestinal problems by liquidizing the pre-exercise meals given to their participants.

If eating a carbohydrate meal 3 – 4 h before exercise causes gastrointestinal discomfort, one alternative is to drink a carbohydrate solution before exercise. This nutritional strategy even allows athletes to take in carbohydrate to good effect as late as 1 h before exercise. Sherman, Peden and Wright (1991) showed that performance was improved during submaximal cycling lasting more than 90 min, when a solution containing the equivalent of 1.1 – 2.2 g · kg body mass^{-1} (BM) of carbohydrate was consumed 1 h before exercise. Wright, Sherman and Dernbach (1991) built on these observations by comparing the cycling time to exhaustion while their participants ingested carbohydrate before exercise, during exercise, undertook a combination of both, or exercised without carbohydrate. Endurance capacity increased to a greater extent when the cyclists drank a carbohydrate solution before and during exercise than when they exercised without carbohydrate (18% and 32% more, respectively). However, the greatest increase in endurance capacity (44%) was achieved when the cyclists ingested carbohydrate solutions both before and during exercise.

A similar result was reported when running rather than cycling was used to assess the influence of pre-exercise meals on endurance capacity (Chryssanthopoulos, Williams, Novitz, Kotsipoulou, & Vleck, 2002). When runners ate a high-carbohydrate breakfast (2.5 g carbohydrate · kg BM^{-1}) 3 h before exercise and drank a carbohydrate-electrolyte solution during a subsequent run to exhaustion, their endurance capacity was greater than when they ran after a high-carbohydrate breakfast alone. The pre-exercise carbohydrate meal and the carbohydrate-electrolyte solution increased running time by 9% (125 min) more than when only the meal was consumed (115 min) but 21% more (103 min) than when the runners completed the test without breakfast and had fasted overnight.

One obvious question is whether or not drinking a carbohydrate-electrolyte solution during prolonged running improves endurance capacity more than the combination of a high-carbohydrate pre-exercise meal and a carbohydrate-electrolyte solution during exercise. Chryssanthopoulos and Williams (1997) attempted to answer this question by comparing the endurance running capacity of ten runners who completed three trials. In one trial the participants ate a high-carbohydrate meal (2.5 g · kg BM^{-1}) 3 h before a treadmill run to exhaustion at 70% $\dot{V}O_{2max}$, and in another they consumed a placebo solution as the pre-exercise meal and drank a 6.9% carbohydrate-electrolyte solution throughout the run to exhaustion. In a third trial, they consumed a placebo solution as the pre-exercise meal and drank a placebo solution during the run to exhaustion. Again the most successful combination was the high-carbohydrate pre-exercise meal with a carbohydrate-electrolyte solution during the run. This combination of carbohydrates resulted in a run time to exhaustion of 147 min, whereas when the runners drank the carbohydrate-electrolyte solution during exercise they ran for 125 min. However, in both carbohydrate trials the run times were significantly longer than when the runners had a liquid placebo pre-exercise meal and drank a placebo solution during the run (115 min).

This same high-carbohydrate pre-exercise meal (2.5 g · kg BM^{-1}) was subsequently shown to increase glycogen concentration in the vastus lateralis of runners by 11% just 3 h later (Chryssanthopoulos *et al.*, 2004). However, this increase in muscle glycogen storage could not account for all the carbohydrate consumed. Therefore, it is reasonable to assume that at the end of the 3 h postprandial period, some of the carbohydrate was still undergoing digestion and absorption and some would have been deposited in the liver as glycogen.

In contrast to the clear benefits of pre-exercise meals plus the ingestion of a carbohydrate-electrolyte solution during constant-paced running to exhaustion (i.e. endurance capacity), compared with ingesting only a carbohydrate-electrolyte solution during exercise, there may not be such clear differences between the nutritional interventions when endurance performance is the criterion of success.

Williams and Chryssanthopoulos (1996) compared the influences of a pre-exercise meal with no-meal on endurance running performance during a 30 km treadmill time-trial. The pre-exercise meal provided the runners with the equivalent of 2 g carbohydrate · kg BM^{-1} in the form of white bread, cereal, sugar, jam, and orange juice. During the time-trial, 4 h later, the runners ingested only water. In the no-meal trial the runners ingested 10 ml · kg BM^{-1} of a liquid placebo instead of breakfast, and immediately before the 30 km time-trial they drank 8 ml · kg BM^{-1} of a commercially available carbohydrate-electrolyte solution. They also drank 2 ml · kg BM^{-1} of this same solution every 5 km during the simulated race. In the fasting trial during which the runners drank the carbohydrate-electrolyte solution, they completed the 30 km in 121.7 min and in the fed trial their run time was an almost identical 121.8 min. Again this is an example of the point made earlier, that the choice of the exercise test has a profound influence on the outcome of studies on carbohydrate feedings and exercise performance.

Nevertheless, the weight of available evidence supports the recommendation that a high-carbohydrate meal before exercise is of greater benefit to performance than undertaking exercise in the fasting state. Thus in trying to optimize muscle and liver glycogen stores in preparation for the game, nutritional interventions should always try to match the individual needs of players by taking into account a player's position, physical characteristics, recent demands of training and competition, as well individual food preferences. The growing evidence in support of the beneficial role of high-carbohydrate diets for prolonged heavy exercise should be communicated to all players and coaches at all levels of the game through appropriate nutritional educational programmes. Education of young players and their parents, and older players as well as coaches, will help establish good nutritional practices that will not only help players realize their physical potential, as a result of a greater capacity to train hard, but also benefit their long-term health.

One of issues that a nutrition education programme should address is the demand of many coaches that their players become as lean as possible. Low-energy and low-carbohydrate diets are often recommended for players who are attempting to lose body fat. However, recommending that players train and compete in negative energy balance ignores the negative consequences for performance and health. A diet low in carbohydrate will fail to resynthesize muscle glycogen stores after training and matches (Bangsbo, Mohr, & Krustrup, 2006). Furthermore, low-carbohydrate diets that do not allow players to cover their daily energy expenditures appear to suppress the immune system and so make them more susceptible to viral infections (Nieman & Bishop, 2006). In summary, the more that players and coaches know about all the physical demands on players during the preparation for, and the participation in, football, the better able they will be to appreciate the needs for well-balanced diets that are high in carbohydrates and contain sufficient energy to cover daily energy expenditures.

Composition of pre-competition meals

Accepting that a high-carbohydrate pre-exercise meal is of benefit to performance, the next question to ask is whether there is an advantage in selecting one type of carbohydrate over another. The ingestion of different types of carbohydrates will produce markedly different changes in plasma glucose and insulin concentrations. These glycaemic and insulinaemic responses following the ingestion of different carbohydrates are the bases of a classification of carbohydrates that is more informative than describing them as simple or complex.

The changes in plasma glucose concentration following the ingestion of 50 g of available carbohydrate when compared with the glycaemic response following the ingestion of 50 g of glucose is used to describe the glycaemic index (GI) of that carbohydrate (Jenkins *et al.*, 1981). For example, white bread has a high value whereas lentils have a low value, reflecting the differences in the size of the glycaemic responses following the ingestion of these two carbohydrates (Foster-Powell & Brand Miller, 1995; Wolever, Jenkins, Jenkins, & Josse, 1991). Although the concept was developed to help prescribe diets for diabetics, it is now being used in studies of the influence of carbohydrate pre-exercise meals on performance (Burke, Collier, & Hargreaves, 1999). One of the potential attractions of consuming low- rather than high-GI carbohydrate foods before exercise is that the normal suppression of fatty acid mobilization is less and so there is a greater contribution of fat to energy metabolism (Wu, Nicholas, Williams, Took, & Hardy, 2003).

In one of the first studies on the influence of high- and low-GI carbohydrate foods on exercise capacity, the low-GI food appeared to improve endurance capacity to a greater extent than the high-GI food. In this study, Thomas, Brotherhood and Brand (1991) used lentils as the low-GI food and potatoes as the high-GI food, and compared the responses to those obtained after drinking a glucose solution or water. The meals and solutions were ingested 1 h before cycling to exhaustion at an exercise intensity of between 65 and 70% $\dot{V}O_{2max}$. The carbohydrate content of the meals and glucose solution was equivalent to $1\,g \cdot kg\ BM^{-1}$ and the volume was adjusted to 400 ml. The exercise times for the lentils, the potato, the glucose, and the water trials were 117, 97, 108, and 99 min, respectively. There was a clear difference in exercise time for the lentils trial, but there were no differences in performance times between the potato, the glucose, or the water trials. Thomas *et al.* (1991) did not address the different rates of digestion and absorption of the three carbohydrates within the hour before the start of exercise, or the fact that they had matched only the amount of carbohydrate ingested in these trials and did not account for the other nutrients in the lentils and potatoes, including protein.

A more recent study addressed the question of whether there are performance benefits to eating low-GI carbohydrate meals before exercise – that is, whether the amount of work done in a fixed time is increased. Febbraio and Stewart (1996) fed their participants instant mashed potatoes (made up in water) as the high-GI carbohydrate and lentils as the low-GI carbohydrate ($1\,g \cdot kg\ BM^{-1}$), and they used a low-energy jelly as the control meal. The three conditions were assigned in random order and the "meals" were consumed 45 min before exercise. The exercise test required the six participants to cycle at 70% $\dot{V}O_{2peak}$ for 2 h before they cycled to complete as much work as possible in 15 min. There was no difference in the muscle glycogen concentrations at the start or at the end of exercise on the three test occasions. The total amount of work accomplished during the last 15 min period was not different between the three conditions. Although these results do not confirm the benefits of a low-GI carbohydrate diet as reported by Thomas *et al.* (1991), a direct comparison cannot be made because different performance criteria were used in the two studies. Thomas *et al.* (1991) assessed endurance capacity, whereas Febbraio and Stewart (1996) assessed total work done in a fixed time (endurance performance).

Most of the subsequent studies on high- and low-GI carbohydrate pre-exercise foods have used similar cycling performance trials (DeMarco, Sucher, Cisar, & Butterfield, 1999; Febbraio, Keegan, Angus, Campbell, & Garnham, 2000; Goodpaster *et al.*, 1996; Paul, Rokusek, Dykstra, Boileau, & Layman, 1996; Sparks, Selig, & Febbraio, 1998; Stannard, Constantini, & Miller, 2000). In only one of these later studies was there a significant difference in performance times following the ingestion of a low-GI pre-exercise meal. DeMarco *et al.* (1999) reported an improvement in exercise time after their participants had eaten a low-GI meal 30 min before exercise that required them to cycle for 2 h at 70% $\dot{V}O_{2max}$ and then at 100% $\dot{V}O_{2max}$ to exhaustion. The times to exhaustion were 206, 130, and 120 s for the low-GI, high-GI, and water trials, respectively.

The most positive results have been reported when exercise capacity tests have been employed in cycling (Kirwan, O'Gorman, & Evans, 1998) and some (Stevenson, Williams, McComb, & Oram, 2005a; C.-L.Wu *et al.*, 2006) but not all (Wee, Williams, Gray, & Horabin, 1999) running studies.

In most of the studies on high- and low-GI carbohydrate pre-exercise meals, the foods were consumed within 2 h of the start of exercise. Therefore, it is likely that much of the food was in the gastrointestinal tract during exercise and glucose was released into the systemic circulation throughout exercise. In one of the first running studies on this topic, the pre-exercise meals were consumed 3 h before the participants completed a treadmill run to exhaustion at speeds equivalent to 69% $\dot{V}O_{2max}$ (Wee *et al.*, 1999). There were no differences in run times between the high-GI (113 min) and the low-GI (111min) trials, but the rate of fat oxidation was significantly greater in the low trial, both during the 3 h postprandial period and during the run to exhaustion.

In a more recent study, Wu (2003) repeated the running study of Wee *et al.* (1999) but used foods that are more commonly eaten at breakfast. In the earlier study (Wee *et al.*, 1999), the low-GI pre-exercise meal consisted entirely of lentils and this was matched for energy and carbohydrate by a selection of high-GI foods. In the more recent study (Wu & Williams, 2006), the pre-exercise meals were matched for energy, carbohydrate, and macronutrient composition (Table I). The run time to exhaustion at 70% $\dot{V}O_{2max}$ was significantly longer in the low-GI trial (109 min) than in the high-GI trial (101 min). Furthermore, the rate of fat oxidation during the run to exhaustion was greater, and plasma glucose concentrations were more stable, during the low-GI trial (Wu & Williams, 2006). A low-GI diet during recovery from prolonged running has also been shown to result in a greater endurance capacity during a subsequent run to exhaustion than a high-GI recovery diet (Stevenson *et al.*, 2005a).

The metabolic common denominator in those studies that have shown a clear improvement in endurance capacity following the ingestion of a low-GI carbohydrate pre-exercise meal appears to be a combination of a greater rate of fat oxidation and more stable plasma glucose concentrations during exercise than after a high-GI carbohydrate meal. An increased fat oxidation is accompanied by a reduction in the rate of carbohydrate degradation. This might suggest a sparing of the limited glycogen store in skeletal muscles. Some support for this suggestion is provided in a recent study that examined the influences of high- and low-GI carbohydrate pre-exercise meals on glycogen storage and utilization. In this study (Wee *et al.*, 2005), muscle biopsy samples were obtained from seven male runners after an overnight fast, 3 h after high- and low-GI carbohydrate ($2\,g \cdot kg\,BM^{-1}$) meals, and again after a 30 min treadmill run at 70% $\dot{V}O_{2max}$. Muscle glycogen increased by 15% 3 h after the high-GI meal, but there was no increase after the low-GI meal. During the 30 min treadmill run, the amount of muscle glycogen used was significantly greater after the high- than after the low-GI meal. Again the rate of fat oxidation was greater in the low-GI trial and plasma glucose was more stable during exercise than was the case in the high-GI trial. An explanation for

Table I. Characteristics of the High and Low GI meals (for a 70 kg subject).

Meal	Description	Macronutrient content
High-GI breakfast	72 g Corn Flakes®, 300 ml skimmed milk, 93 g white bread, 12 g Flora spread, 23 g jam, 181 ml Lucozade Original®	852 kcal 162 g carbohydrate 12 g fat 23 g protein **GI = 78***
Low-GI breakfast	100 g muesli (without raisins), 300 ml skimmed milk, 78 g apple, 120 g tinned peaches, 149 g yoghurt, 300 ml apple juice	855 kcal 162 g carbohydrate 11 g fat 27 g protein **GI = 44***

*Calculated by the method of Wolever (1986). Glycaemic index values from Foster-Powell *et al.* (2002).
Registered trade marks: Corn Flakes® (Kellogg's Ltd, Manchester, UK); Lucozade Original® (GlaxoSmithKline, Brentford, UK).

the greater endurance capacity following low- rather than high-GI pre-exercise meals based on glycogen sparing alone would be too simplistic without considering the overall contribution of carbohydrate to energy balance. Although some studies have provided clear evidence of improved exercise capacity coinciding with glycogen sparing (Tsintzas & Williams, 1998), there are older (Coyle, Coggan, Hemmert, & Ivy, 1986) and more recent studies (Claassen *et al.*, 2005) that have reported improvements in endurance capacity that cannot be explained by differences in muscle glycogen at the point of fatigue. The additional exercise time may well be linked to the continued optimum rate of hepatic glucose output late in exercise, and so simply focusing only on differences in muscle glycogen may provide a limited understanding of the mechanisms underpinning these improvements in exercise duration.

Multiple-sprint studies

In most studies of pre-exercise feeding, the exercise used has been cycling or treadmill running, but these types of exercise are not directly applicable to football. In an attempt to fill this gap in exercise protocols, Nicholas, Nuttall and Williams (2000) designed a shuttle running test that includes activity patterns similar to those that routinely occur in football. The Loughborough Intermittent Shuttle Test (LIST) requires the participants to repeatedly run, walk, jog, and sprint between two lines 20 m apart for 15 min, and this is continued, with 3 min rest between blocks, for 90 min (i.e. six blocks; see Figure 1). During the 90 min test, participants perform 66 maximum sprints. The total distance covered while walking, jogging, running, and sprinting is approximately 12 km and participants expend about 1330 kcal, which is similar to the estimated distances (about 11 – 12 km) and energy expenditures (1360 kcal) in football matches (Nicholas *et al.*, 2000) (Table II). Theses performances are similar to those of midfield players who demonstrate high work rates during matches (Bangsbo *et al.*, 2006). Furthermore, this protocol involves turning, acceleration, and deceleration at speed and it is so demanding that all participants report some delayed-onset muscle soreness (Thompson, Nicholas, & Williams, 1999) with clear evidence of muscle damage and decreased function (Thompson *et al.*, 2004).

This protocol and slightly modified versions of it have been used to assess the efficacy of various

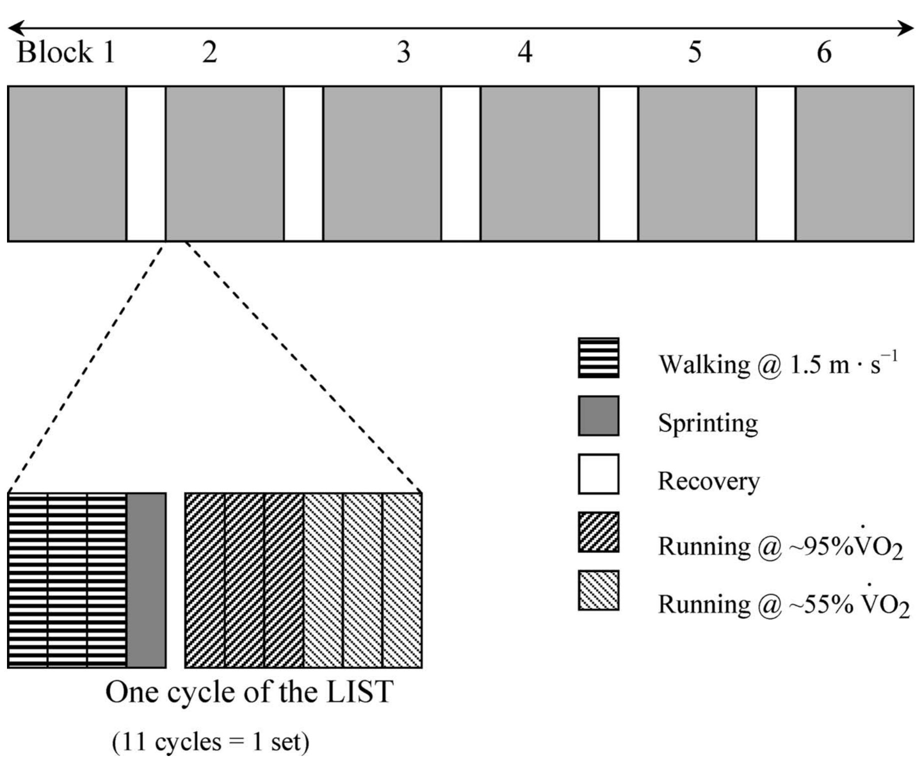

Figure 1. The Loughborough Intermittent Shuttle Test (LIST) is designed to reflect the activity pattern commonly associated with multiple-sprint sports such as soccer. The structure of the protocol is depicted. The LIST is performed in a sports hall on a marked 20 m track. The total exercise time of the LIST is 90 min, with a total rest time of 15 min. The varying running and walking speeds are dictated by an audio signal using a computer program developed at Loughborough University. Sprint times are recorded by a data logger using information from infrared photo-electric cells separated by 15 m. Over the course of the LIST, individuals cover a total distance of 12 km, sprinting approximately 1 km, and changing direction 624 times, with an estimated total energy expenditure of approximately 1330 kcal.

Table II. Activity pattern and typical physiological responses to the Loughborough Intermittent Shuttle Test.

Activity	Percent of time
Walking	49%
Jogging (55% $\dot{V}O_{2max}$)	24%
Running (95% $\dot{V}O_{2max}$)	19%
Sprinting	3%
Recovery	5%
Physiological characteristics	**Response**
Heart rate	165 – 170 beats min^{-1}
% $\dot{V}O_{2max}$	~70%
Energy expenditure	~1300 kcal
Rectal temperature	~38.7°C
Blood lactate concentration	~5 – 7 $mmol \cdot l^{-1}$
Distance covered	~10 – 12 km
Sprinting	~8% distance
Deceleration after sprints	~4%

nutritional interventions on exercise capacity (Davis, Jackson, Broadwell, Queary, & Lambert, 1997; Davis, Welsh, De Volve, & Alderson, 1999; McGregor, Nicholas, Lakomy, & Williams, 1999; Nicholas, Green, Hawkins, Williams, 1997; Nicholas, Williams, Boobis, & Little, 1999; Nicholas, Williams, Lakomy, Phillips, & Nowitz, 1995; Welsh, Davis, Burke, & Williams, 2002). In one study, Nicholas *et al.* (1997) reported that successful recovery of performance from this intermittent high-intensity running protocol was achieved when their participants increased their carbohydrate intake from about 4 to 9 $g \cdot kg\ BM^{-1}$ during the 24 h between exercise tests. When the participants ate their normal amount of carbohydrate during the recovery period, even though it matched the higher carbohydrate diet for energy, they were unable to repeat their performance of the previous day.

When this study was repeated using iso-energetic meals of either high- or low-GI carbohydrate foods as the 24 h recovery diet, there were no differences in endurance running capacity between trials when the LIST was performed again on the second day (S. Erith *et al.*, unpublished study).

The benefits of high- or low-GI carbohydrate pre-exercise meals on performance of a modified version of the LIST have also been explored in male games players (rugby and soccer) (J. Davis & M. Dombo, unpublished study) and elite female football players (S. Chamberlain *et al.*, unpublished study). In these two studies, the high- and low-GI meals contained the same amount of carbohydrate (2 $g \cdot kg\ BM^{-1}$) and consisted of the same quantities of macronutrients (Table I). Three hours after the high- or low-GI meal, the participants completed five blocks of the LIST (i.e. 75 min and then ran to fatigue alternating between sprinting and jogging between the 20 m lines that defined the test area. The time to exhaustion was not different between the high-GI (10.3 min) and the low-GI (12.0 min) trials for the elite female football players. Although there were no differences in the overall sprint times between the two dietary trials during the 75 min before the intermittent sprints to exhaustion, the mean sprint times in the first 15 min were faster after the low- than after the high-GI meal.

When the men consumed the high- and the low-GI carbohydrate pre-exercise meals, the mean sprint times for the five blocks of the LIST were faster after the low-GI (2.61 s) than after the high-GI meal (2.66 s). However, there was no difference between the run times to fatigue for the high-GI (11.2 min) and the low-GI trials (10.0 min). It is difficult to offer an explanation for these differences in the responses to the high- and low-GI meals during this prolonged intermittent high-intensity shuttle running test. One consistent and common observation by all the participants in these pre-exercise feeding studies is that they never felt hungry after the low-GI pre-exercise meal during the 3 h postprandial period or during the 90 min of exercise. In contrast, most participants in the studies mentioned above reported that they felt hungry towards the end of the 3 h postprandial period and during prolonged exercise after the high-GI meal.

Therefore, when preparing for a match, ingesting enough carbohydrate in the pre-match meals is probably the most important strategy, because with the present rules the opportunities to consume carbohydrate during the game are limited to the half-time break. The stress of the game and other circumstances during the 10 – 15 min break may limit the amount of carbohydrate that can be consumed by players. It therefore becomes even more important that the pre-match meal should contain low-GI carbohydrate foods because they result in long-term stable blood glucose concentrations and general feelings of satiety (Stevenson *et al.*, 2005b). Furthermore, stable blood glucose concentrations may delay the onset of fatigue not only by providing substrate for muscle metabolism, but also as a result of positive influences on the central nervous system in general and the brain in particular (Meeussen, Watson, & Dvorak, 2006).

Carbohydrate intake within the hour before exercise

Earlier studies on the influence of ingesting carbohydrate within the hour before exercise suggested that this practice would have a detrimental influence on performance (Costill *et al.*, 1977; Foster, Costill, & Fink, 1979).These studies showed that there was a greater rate of glycogen degradation during exercise after ingesting a concentrated carbohydrate solution (25% w/v) (Costill *et al.*, 1977), and that fatigue occurred sooner (19%) during cycling to exhaustion at 80% $\dot{V}O_{2max}$ (Foster *et al.*, 1979). However, this highly publicised recommendation has not been supported by subsequent studies (Burke, Claassen, Hawley, & Noakes, 1998; Chryssanthopoulos, Hennessy, & Williams, 1994).

These early studies also showed a sharp peak in blood glucose concentrations following the ingestion of the concentrated glucose solution and then a rapid fall at the onset of exercise. For most people, the transient fall in blood glucose concentrations during the first few minutes of exercise appears to go unnoticed and has little influence on subsequent exercise capacity (Chryssanthopoulos *et al.*, 1994). During a match, the half-time interval is an opportunity to replenish some of the fluid lost and also an ideal opportunity to consume some carbohydrate. Therefore, it is unsurprising that well-formulated sports drinks are recommended because they are an effective and convenient way of providing fluid, carbohydrate, and electrolytes during the limited time available.

Carbohydrate intake during exercise

The influence of drinking carbohydrate solutions during exercise on subsequent performance has been extensively studied (for reviews, see Coyle, 2004; Maughan & Murray, 2000). There have also been some field studies on football players during match-play (Kirkendall, 1993). For example, when players were given glucose polymer solutions to ingest before and during matches, they had higher work rates than players who consumed placebo solutions (Kirkendall, Foster, Dean, Grogan, & Thompson, 1988). Furthermore, there was also evidence that those players who were given the glucose polymer solution used less muscle glycogen during match-play (Leatt & Jacobs, 1989).

The LIST protocol has been used in several recent studies of the effects of drinking carbohydrate-electrolyte solutions on performance during prolonged intermittent high-intensity exercise under controlled conditions (Davis *et al.*, 1997, 1999; Davis, Welsh, & Alderson, 2000; McGregor *et al.*, 1999; Nicholas *et al.*, 1995; Welsh *et al.*, 2002). In the study of Nicholas *et al.* (1995), a group of recreational football players completed five blocks of the LIST and then they began sprinting and jogging back and forth over the 20 m course to the point of fatigue. They found that the distance covered was 33% greater when the football players drank a carbohydrate-electrolyte solution (6.5%) than when they drank a flavoured placebo solution. In a subsequent study, Nicholas *et al.* (1999) examined the amount of glycogen used during the completion of six blocks of the LIST (90 min) and reported that less glycogen was used when their participants consumed the carbohydrate-electrolyte solution than when they consumed flavoured water placebo. Welsh *et al.* (2002) used a similar protocol but gave their participants higher amounts of carbohydrate and found even greater improvements in endurance capacity (50%) than when the participants drank a placebo solution during the test.

It is clear from studies that simulate the demands of match-play that those players who do not eat before a match or eat very little will benefit from drinking a carbohydrate-electrolyte solution during the match (Nicholas *et al.*, 1995; Welsh *et al.*, 2002). For example, players who completed the LIST after an overnight fast but drank a carbohydrate-electrolyte solution during exercise tended to maintain their sprinting ability for longer than if they had ingested water alone (A. Ali *et al.*, unpublished study).

Drinking a carbohydrate-electrolyte solution also appears to improve endurance capacity during intermittent exercise even when players have high pre-exercise muscle glycogen stores. Foskett, Williams, Boobis and Tsintzas (2002) studied the influence of drinking a carbohydrate-electrolyte solution on endurance capacity during intermittent shuttle running after participants had increased their pre-exercise muscle glycogen concentrations by carbohydrate loading in the previous 48 h. Six male recreational footballers were required to continue running repeated 15 min blocks of the LIST to the point of fatigue. On one occasion they drank a flavoured placebo and on another they drank a 6.4% carbohydrate-electrolyte solution throughout the exercise test. Muscle biopsy samples were obtained from the participants after an overnight fast (i.e. before exercise), after 90 min of the LIST, and again at the point of fatigue. All six participants ran for longer when they drank the carbohydrate-electrolyte solution (158 min) than when they drank the flavoured placebo solution (131 min). However, there were no differences in the muscle glycogen concentrations after 90 min of running during the two trials, endorsing the important role of blood glucose during the later stages of prolonged exercise (Claassen *et al.*, 2005; Coggan & Coyle, 1989; Coyle *et al.*, 1983, 1986). Of note is that these run times were much longer than when similar participants completed the same exercise protocol in the fasting state but without the prior carbohydrate loading (approximately 105 min, i.e. 90 min of the LIST plus one 15 min block: A. Foskett, unpublished observations). Therefore, it would appear that carbohydrate loading before a match plus drinking a carbohydrate-electrolyte solution during the match may be a worthwhile strategy, especially in the event of the game going into extra time. This strategy might also include a low-GI pre-exercise meal because the sensations of satiety are maintained for longer than after a high-GI meal. However, there is some evidence to suggest that the greater fat metabolism during exercise after a low-GI than after a high-GI meal is abolished when a carbohydrate solution is ingested during subsequent exercise (Burke *et al.*, 1998). Nevertheless, not feeling hungry during a match may have a beneficial influence on a player's performance even though the metabolic differences between low- and high-GI meals are minimized as a consequence of ingesting carbohydrate solutions at suitable breaks during a match.

Carbohydrate intake and skill performance

Unfortunately, too few studies have been conducted on the effects of ingesting carbohydrate on the ability to sustain soccer-specific skills during match-play. Some studies examining soccer-specific skills during match-play have found no differences following the ingestion of a carbohydrate-electrolyte solution (Zeederberg *et al.*, 1996), an improvement (Ostojic & Mazic, 2002), or at least maintenance of skill (Northcott, Kenward, Purnell, McMorris, 1999). However, in attempting to make the soccer skill tests as real as possible, these studies had to compromise their control of confounding variables. Therefore, it is difficult to obtain a clear consensus on the influence of carbohydrate ingestion on soccer-specific skills from these studies.

In a series of studies on soccer-specific skills, fatigue, and the influence of carbohydrate nutrition, Ali *et al.* (2002) tested the skills of soccer players before, during, and after they had performed the 90 min LIST. The LIST was used to simulate the activity patterns common to soccer in a controlled environment and so focus on the performance of the skills, which is not possible in soccer matches *per se*. They found that the performances of a soccer passing test and a goal shooting test were significantly poorer after the 90 min LIST. However, the decrease in these skills was less when the players ingested a carbohydrate-electrolyte solution immediately before and at 15 min intervals throughout the test than when they ingested a placebo solution. Furthermore, not only were the two soccer-specific skills better maintained during the carbohydrate-electrolyte trial, the accumulated sprint times of the players were also faster than in the placebo trial (Ali *et al.*, 2002). Clearly, more research is required on the effects of carbohydrates (or lack of them) on cognitive performance in general and sports skills in particular before we can formulate more precise nutritional strategies for players.

In summary, the evidence to support the recommendation that players should eat a high-carbohydrate pre-exercise meal has increased since the 1994 Consensus Conference on Nutrition and Soccer. This evidence comes from studies on pre-exercise meals containing high- and low-GI carbohydrate foods that are provided as palatable meals. It would appears that low-GI carbohydrate meals may be of some benefit as pre-match meals if only because they may make players feel ''better'', which in itself is often the basis of better performance. Therefore, while progress has been made in studying the influences of real foods on performance, there is still a need for more ecologically valid exercise tests that are well controlled and use footballers as their participants.

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