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DOES A HIGH-CARBOHYDRATE BREAKFAST IMPROVE PERFORMANCE?

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KEY POINTS

- Fatigue during prolonged heavy exercise is often associated with low or depleted muscle glycogen stores and with lowered blood glucose.
- Eating a high-carbohydrate meal 2-4 h before constant-pace exercise can improve endurance capacity (time to exhaustion) but may not be advantageous in time-trials, especially if sports drinks are consumed during the trials.
- Contrary to earlier reports, there appear to be no adverse effects on endurance capacity of consuming well-formulated carbohydrate solutions within the hour before exercise.

INTRODUCTION

RATIONALE FOR PRE-EXERCISE CARBOHYDRATE FEEDINGS

The familiar recommendation that athletes should eat an easily digestible high-carbohydrate meal in the hours before endurance competition to increase muscle and liver glycogen stores and improve performance is supported by many laboratory and field studies published over the last two decades. This recommendation is based on the facts that (i) after an overnight fast the liver glycogen store—the source of blood glucose—is reduced to low values, and (ii) eating a high-carbohydrate meal helps replenish the supply of liver glycogen and may also help top off the limited muscle glycogen stores. As is well established, a severe reduction of muscle glycogen (Bergstrom et al., 1967) and/or of blood glucose derived from liver glycogen (Coyle & Coggan, 1984) is often associated with the early onset of fatigue. Therefore, it is not surprising that increasing muscle and liver glycogen stores confers an advantage by delaying the onset of glycogen depletion and hence fatigue during prolonged exercise. The previous issue of *Sports Science Exchange* (Williams & Lamb, SSE #107, 2008) reviewed how high-carbohydrate diets, including carbohydrate-loading protocols, can enhance glycogen stores and performance of certain types of endurance exercise. Research has also confirmed that eating a high-carbohydrate meal (2.5 g/kg body mass) 3 h before exercise will increase muscle glycogen concentrations by 11-17% (Chryssanthopoulos et al., 2004; Wee et al., 2005). Using data from two different experiments, Figure 1 shows the concentrations of muscle glycogen before and after eating high-carbohydrate meals. Because subjects in both studies ate the same amount of carbohydrate in similar meals, the differences in the concentrations of muscle glycogen at rest and 3 h after meal consumption that are shown in Figure 1 may be the result of using trained runners in one experiment (Wee et al., 2005) and less well-trained runners in the other (Chryssanthopoulos et al., 2004).

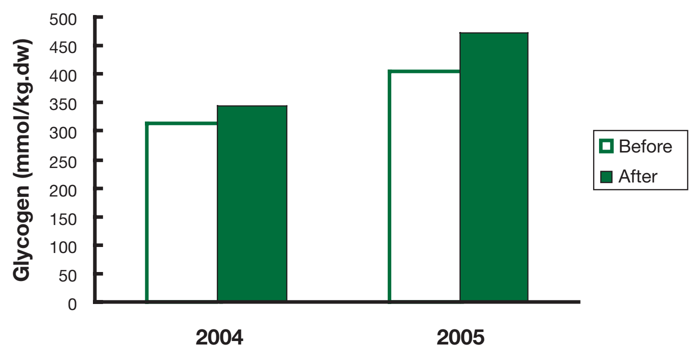

FIGURE 1: ***Muscle glycogen concentrations 3 h after a high-carbohydrate breakfast.*** Glycogen values were significantly greater following the breakfast. (Chryssanthopoulos et al., 2004; Wee et al., 2005)

All of the carbohydrate consumed in a pre-exercise meal will not appear as muscle glycogen because a large proportion will be deposited in the liver and some may still be in the gastrointestinal tract, i.e., still undergoing digestion and absorption, during the 3-h period after eating (Hultman & Nilsson, 1971). There are sound reasons to recommend that athletes consume an easy-to-digest high-carbohydrate meal before prolonged heavy exercise. However, the obvious question is “Does a high-carbohydrate breakfast lead to an improvement in performance during subsequent exercise?” Therefore, the aim of this article is to briefly review those reports in the literature that have addressed this question.

LIMITATIONS OF PUBLISHED RESEARCH

Most of the evidence that underpins the recommendation for athletes to eat high-carbohydrate meals before exercise has been obtained from studies that have assessed endurance capacity (time to exhaustion) during cycling and, less frequently, during running. Typically, endurance capacity tests require participants to cycle at a constant power output to the point of fatigue, i.e., when they can no longer maintain the prescribed pedal frequency, or to run at a prescribed pace for as long as possible. In sporting events, rarely are there competitions that require participants to cycle or run as long as possible. Most endurance competitions require participants to complete a set distance as quickly as possible, i.e., a time trial, or, as in team sports such as soccer and basketball, to exercise intermittently as hard as possible in a given time period. Unfortunately, there are too few studies that assess endurance performance using a time-trial protocol or an appropriate intermittent exercise protocol. Even those that are available rarely report the test-retest reliability of their methodologies. Other limitations are the small number of subjects commonly used in the studies and the dearth of studies on females. Also, when prescribing meals that use commonly available foods, it is difficult to mask the composition of the meal; this limitation is difficult to overcome. Furthermore, a subject's dietary habits can have a significant influence on the outcome of a feeding study, and yet it is extremely difficult to accurately assess the recent nutritional history of participants in these studies. Finally, in some feeding studies, the authors report that the experimental feedings were ingested 3-5 h after an unspecified meal, so it is difficult to judge the influence of the total nutrition, rather than just the prescribed experimental feeding, on subsequent performance. Nevertheless, even with these limitations, many of the published studies have led to a greater understanding of how pre-exercise carbohydrate feedings may influence subsequent performance.

RESEARCH REVIEW

CARBOHYDRATE INGESTED 1.5-4 HOURS BEFORE EXERCISE BUT WITHOUT CARBOHYDRATE SUPPLEMENTATION DURING EXERCISE: EFFECTS ON ENDURANCE CAPACITY (TIME TO EXHAUSTION)

Several studies have shown that pre-exercise carbohydrate feeding improves endurance capacity during cycling to exhaustion (Gleeson et al., 1986; Sherman et al., 1989; Wright et al., 1991). For example, Schabort and colleagues (1999) assessed time to exhaustion while cycling at 70% VO_2max in one trial that included a 3-h pre-exercise breakfast containing 100 g of carbohydrate and in another trial in which subjects ate no breakfast. Only water was provided during exercise. Time to exhaustion was 109 min after the overnight fast and 136 min when the fast was followed by breakfast 3 h before exercise.

With the exception of the study of Schabort et al. (1999), the other reports mentioned above involved feeding their subjects carbohydrate solutions rather than meals containing commonly consumed foods. Therefore, Chryssanthopoulos et al. (2002) completed a series of studies in which they fed their subjects a high-carbohydrate mixed meal (2.5 g of carbohydrate/kg body mass) containing mainly carbohydrate foods 3 h before a constant-pace treadmill run (70% VO_2max) to fatigue. The running time of 111.9 min was significantly longer after the high-carbohydrate breakfast compared to the 102.9 min recorded after the runners ingested a liquid placebo (Chryssanthopoulos et al., 2002). These results might be regarded as a predictable outcome of a study that compared a breakfast with an overnight fast on constant-pace running to fatigue. The subsequent question is whether or not a high-carbohydrate pre-exercise meal confers any greater performance benefit than, for example, a high-fat meal. In other words, is it just the extra energy that provides a benefit, or is the benefit specific to carbohydrate energy?

In an attempt to answer this question, Okano and colleagues (1996) provided their well trained subjects with either a high-carbohydrate or high-fat isocaloric breakfast 4 h before exercise. Their subjects cycled for 120 min at 65% VO_2max and then the intensity was increased to 80% VO_2max; the subjects maintained this higher power output until exhaustion. Although there was no statistical difference in the times to fatigue, there was a tendency for longer exercise times (8 min at 80% VO_2max) following the high-carbohydrate breakfast than following the high-fat breakfast (2 min) (Okano et al., 1996). However, similar findings of no statistical differences in performance were reported by Rowlands and Hopkins (2002), who compared diets high in carbohydrate or fat or protein and fed the cyclists a carbohydrate beverage during exercise prior to 50 km time trials (see later discussion of this report). Therefore, it seems clear that eating a high-carbohydrate meal several hours before prolonged exercise is better than eating nothing, but it may not be better than eating a meal containing adequate energy with lower amounts of carbohydrate.

As reviewed by Rankin (1997), in many of these studies, the foods used were mainly high glycemic-index (GI) carbohydrates. Examples of carbohydrates with a high GI are simple sugars, potatoes, white bread, and white rice. Consumption of these carbohydrates leads to a fast rise in blood glucose concentration that is followed by a rapid decline. In contrast, eating carbohydrates with medium to low GI values, such as whole-grain breads, lentils, beans, brown rice, and pasta, usually results in a slower rise and decline of blood glucose concentrations than is the case with high-GI carbohydrate foods. It has been suggested that consuming a pre-exercise meal consisting of low-GI carbohydrates may shift energy metabolism towards greater fat oxidation as a result of a lower insulin response to these carbohydrates. Theoretically, this increased reliance on fat for energy might lead to a reduction in the utilization of the limited muscle glycogen stores and so improve exercise capacity beyond that achieved following the consumption of high-GI foods (Thomas et al., 1991). However, many of the subsequent studies that tested this hypothesis produced contradictory results. The lack of consensus may be a consequence of the different approaches that investigators used to examine this proposal. For example, most studies used single foods (e.g., Febbraio & Stewart, 1996) rather than mixed meals, and the timing of the pre-exercise meals has also varied between studies (Kirwan et al., 1998; Wee et al., 1999). To add to the confusion, some studies have assessed endurance capacity during cycling and running (Thomas et al., 1991; Wu & Williams, 2006), whereas others used cycling time-trial performance (Febbraio et al., 2000; Sparks et al., 1998).

Even when investigators used the same exercise protocols, different results have been obtained for time to exhaustion. For example, two studies used isocaloric mixed meals, rather than single foods containing either high-GI or low-GI carbohydrates, and fed their subjects 3 h before they ran to exhaustion on a treadmill (Wee et al., 1999; Wu & Williams, 2006). Both showed that fat metabolism was greater following the low-GI meal compared with the high-GI meal, but the performance outcomes were inconsistent. In one study (Wee et al., 1999), there was no difference between the running times to exhaustion in the trials with high-GI (113 min) and low-GI (111 min) ,whereas in the other, there was a 7.4-min improvement in endurance running capacity following the low-GI meal (108.8 min vs. 101.4 min) (Wu & Williams, 2006). In the latter study, the pre-exercise meals were comprised of foods that are commonly consumed by athletes and were matched for macronutrient content, whereas in the former study, the carbohydrate in the low-GI meal was mainly lentils. Therefore, more studies are needed to assess the possible benefits of consuming pre-exercise meals composed of commonly available foods containing either high-GI or low-GI carbohydrates.

It should be noted that these are difficult studies to undertake because of the need to match the meals for macronutrient and energy content as well as for available carbohydrate. For example, low-GI foods are high in fiber, so the biologically available carbohydrate is not the same as the total carbohydrate content of the food. Therefore, to match low-GI and high-GI meals, a greater amount of the low-GI food must be consumed to achieve the same quantity of available carbohydrate as in the high-GI meal. The consumption of a larger amount of food in the low-GI meals results a greater sensation of gut fullness. Conversely, if the carbohydrate content of the meals is matched for total carbohydrate, then the low-GI meal will contain less available carbohydrate than the high-GI meal. Therefore, advising athletes to consume low-GI pre-exercise meals might cause them to eat insufficient carbohydrate because the fiber content of these foods promotes early feelings of fullness, which is not the case for high-GI foods. What is not known is how the sensation of simply feeling pleasantly full before exercise may influence performance.

CARBOHYDRATE INGESTED 1.5-4 HOURS BEFORE EXERCISE PLUS CARBOHYDRATE SUPPLEMENTATION DURING EXERCISE: EFFECTS ON ENDURANCE CAPACITY (TIME TO EXHAUSTION)

Wright and colleagues (1991) examined whether or not further improvements in endurance capacity for cycling could be achieved if carbohydrate was ingested not only in a pre-exercise feeding but also throughout prolonged exercise. They found that when their subjects ingested a carbohydrate solution that provided 5 g of carbohydrate/kg body weight 3 h before exercise and also ingested an 8% carbohydrate solution while cycling to exhaustion at a constant workload, their endurance capacity was greater (290 min) than when carbohydrate was ingested only before exercise (237 min), only during exercise (266 min), or neither before nor during exercise (201 min).

The benefits of consuming a high-carbohydrate pre-exercise meal 3 h before prolonged constant-pace running during which the runners ingested a 6.9% carbohydrate-electrolyte solution was reported by Chryssanthopoulos et al. (2002). Their subjects completed three trials in randomized order. In one trial they consumed a high-carbohydrate meal (2.5 g/kg body mass) and then ingested a 6.9% carbohydrate-electrolyte solution during exercise. In another trial they ate the same high-carbohydrate meal and ingested only water during exercise. In the third trial they ingested a placebo solution instead of a meal and drank only water during exercise. The exercise test required the subjects to run to exhaustion on a treadmill at an intensity equivalent to 70% VO_2max. The combination of a high-carbohydrate meal and ingesting a carbohydrate-electrolyte solution during exercise resulted in a significantly longer run time of 125 min, compared to the times for the meal-plus-water trial (111.9 min) and the water-only trial (103 min) (Figure 2).

To summarize, based on the limited research available, it appears that a combination of a pre-exercise carbohydrate meal plus carbohydrate supplementation during exercise is the optimal nutritional strategy for enhancing time to exhaustion in exercise lasting 90 min or longer.

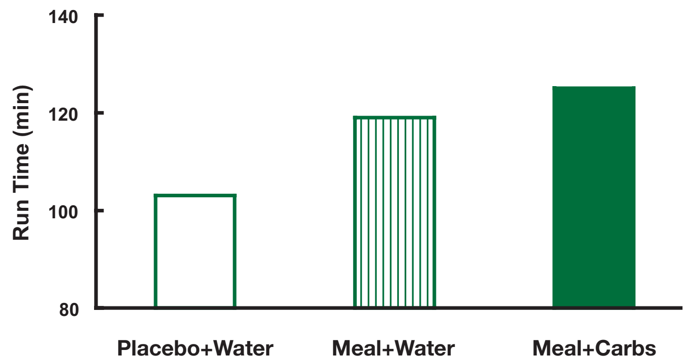

FIGURE 2: ***Endurance running capacity under the following conditions (i) placebo solution before exercise plus the ingestion of water during exercise (ii) high-carbohydrate meal plus water during exercise and (iii) high-carbohydrate meal plus the ingestion of a carbohydrate-electrolyte solution (Carbs) during exercise.*** All means were significantly different from one another (Chryssanthopoulos et al., 2002).

CARBOHYDRATE INGESTED 3-4 HOURS BEFORE EXERCISE BUT WITHOUT CARBOHYDRATE SUPPLEMENTATION DURING EXERCISE: EFFECTS ON "REAL-WORLD" TIME-TRIAL TYPES OF PERFORMANCE

There have been only a few studies on the effects of pre-exercise carbohydrate meals on time-trial types of performance, and the results of these studies do not follow a consistent pattern. In one of the early studies, Neufer and colleagues (1987) examined the influence of different amounts of pre-exercise carbohydrate on power output during a cycling test. Their subjects exercised the day before the performance test to lower their muscle glycogen concentrations. After an overnight fast and 5 min before exercise, they consumed A) a liquid placebo, B) a glucose polymer solution that provided 45 g carbohydrate, or C) a solid confectionary bar (45 g carbohydrate) in combination with 400 ml water. In a fourth trial, the subjects consumed a light carbohydrate breakfast (200 g carbohydrate) 4 h before exercise and then a confectionary bar 5 min before the test. The exercise test was 45 min of cycling at 77% VO_2max and then a 15-min all-out effort on an isokinetic cycle ergometer.

All three pre-exercise feeding trials resulted in a greater total amount of work produced during the 15-min performance test than during the placebo trial. Further improvements in the work completed were achieved when the subjects consumed the carbohydrate breakfast 4 h before and the confectionary bar 5 min before the exercise test. Although this latter combination produced a 15% increase in muscle glycogen concentration, it was not significantly different from the pre-exercise glycogen concentrations achieved in the other three trials. Therefore, the greater amount of work produced after the combination of breakfast and a confectionary bar could not be attributed to a greater pre-exercise glycogen store, but it was associated with a greater amount of carbohydrate oxidation during the 45 min of exercise that preceded the 15-min performance test.

In four separate trials, Sherman et al. (1989) fed subjects 4 h before cycling exercise either a placebo or carbohydrate in one of three different doses (45 g, 156 g, or 312 g). The subjects first performed intermittent cycle ergometry for 95 min, alternating 15-min periods at 70% and 52% VO_2max, and then completed a time trial as rapidly as possible. Exercise and diets were controlled for 48 h before the trials, and only water was provided during exercise. In the placebo trial, the subjects completed the time trial in 56.2 min, whereas the times for the 45 g, 156 g, and 312 g trials were 54.1, 54.0, and 47.9 min, respectively. Only the average time for the 312 g feeding trial was significantly faster than the time for the placebo trial.

In an experiment designed to compare the influences of high-carbohydrate and high-fat meals on 10-km time-trial performance, Whitley et al. (1998) fed eight very well trained cyclists 4 h before exercise. In one trial, they ate a high-carbohydrate meal containing approximately 250 g carbohydrate (3.6 g/kg), 26 g protein and 3 g fat. In a second trial, they ate a high-fat meal containing 50 g carbohydrate (0.7 g/kg), 14 g protein, and 80 g fat. On a third occasion, the cyclists fasted overnight and ate nothing before exercise. The exercise test required them to cycle for 90 min at a workload equivalent to 70% VO_2max and then to complete 10 km as fast as possible. There were no differences in the times to complete the three time trials, i.e., 14.6 min, 14.2 min, and 14.6 min for the fasting, high-fat, and high-carbohydrate trials, respectively.

In a similar report on pre-exercise feeding, Paul et al. (2003) found no beneficial effect of a high-carbohydrate meal consumed by eight men 3.5 h before a 20-km cycling time trial. The meals were consumed 6 h after a breakfast that consisted of 191 g of carbohydrate, 22 g of fat and 12 g of protein. The early high-carbohydrate breakfast was provided to ensure that liver and muscle glycogen stores were adequately stocked before the time-trials. Their subjects consumed one of three test meals 3.5 h before cycling for 30 min at a workload calculated to be 25 W above their lactate thresholds followed by a 15-min rest period and a subsequent 20-km time trial. One meal was high in carbohydrate (3 g/kg body weight), a second was an isocaloric high-fat meal, and the placebo meal contained no energy. The subjects completed the high-carbohydrate trial in 32.7 min, the high-fat trial in 33.1 min, and the placebo trial in 33.0 min; these times were not statistically different.

It should be noted that the exercise times in the studies of both Neufer et al. (1987) and Paul et al. (2003) were probably too brief to cause a marked depletion of glycogen stores in either muscle or liver. No studies reported adverse effects of consuming carbohydrate meals, but more research is needed before specific recommendations can be made regarding carbohydrate meals before time trial types of exercise performance when athletes ingest only water during exercise.

CARBOHYDRATE INGESTED 1.5-4 HOURS BEFORE EXERCISE PLUS CARBOHYDRATE SUPPLEMENTATION DURING EXERCISE: EFFECTS ON "REAL-WORLD" TIME-TRIAL TYPES OF PERFORMANCE

In an investigation in which pre-exercise meals were administered 90 min before exercise, cyclists ingested a high-carbohydrate meal (258 g carbohydrate), a high-protein meal (122 g carbohydrate) or a high-fat meal (15 g carbohydrate) before cycling for ~ 3 h, ending with a 50-km time trial (Rowlands & Hopkins, 2002). A 6% carbohydrate solution was provided during the exercise. There were no differences in performance among the three trials, suggesting that the carbohydrate supplementation during exercise provided adequate carbohydrate.

Burke and colleagues (1998) examined the combination of different carbohydrate breakfasts consumed 2 h before exercise and the ingestion of a carbohydrate-electrolyte solution during exercise on time-trial performance in six well trained cyclists. The cyclists completed three trials that included the consumption of two high-carbohydrate meals (2 g/kg body mass), one of which was composed of high-GI carbohydrates and the other of low-GI carbohydrates. In the third trial, the pre-exercise meal consisted of low-energy jelly. Immediately before and throughout the exercise the cyclists ingested a 10% glucose solution. The exercise protocol consisted of cycling for 2 h at 70% VO_2max followed by completing a workload of 300 kJ as quickly as possible. There were no differences in the times to complete the two carbohydrate-meal trials, and the control trial (~15-16 min), supporting the view that the carbohydrate supplementation during exercise provided sufficient carbohydrate for the exercise tasks.

Similar indeterminate results, this time for 4-h pre-exercise meals, were reported by Chryssanthopoulos and colleagues (1994b) in a study in which 10 male endurance runners completed two 30-km treadmill time trials in randomized order. In one, they ate a high-carbohydrate meal (2 g/kg body mass), and in the other, they drank a placebo solution 4 h before the time trial. During the 30-km run following the carbohydrate meal, the runners drank water (2 ml/kg body mass) every 5 km, whereas during the placebo trial, they drank 8 ml/kg of a 6.9% carbohydrate-electrolyte solution immediately before the run and then 2 ml/kg at 5 km intervals. The runners were able to choose their own running pace in their attempt to finish the 30 km as fast as possible. Although distance covered was displayed on a computer screen in front of the treadmill, the runners were not shown the time elapsed. The performance times for the two trials were essentially identical (121.7 min and 121.8 min), even though the total carbohydrate consumed in the meal trial (135 g) was greater than in the control trial (84 g). It appears that ingesting the carbohydrate-electrolyte solution immediately before and during exercise was sufficient to meet the carbohydrate demands of the 30-km time trial.

To summarize, there is a consistent finding in the three studies reported in this section, namely, carbohydrate meals ingested 90 min to 4 h before time trials are of no apparent benefit as long as the subjects ingest carbohydrate-containing drinks during exercise.

CARBOHYDRATE INGESTED 30-60 MINUTES BEFORE EXERCISE BUT WITHOUT CARBOHYDRATE SUPPLEMENTATION DURING EXERCISE: EFFECTS ON ENDURANCE CAPACITY (TIME TO EXHAUSTION)

Earlier studies on the influence of ingesting carbohydrate 30-60 min before exercise suggested that this practice would have a detrimental influence on performance and should be avoided (Costill et al., 1977; Foster et al., 1979). This recommendation emanated from a study that was originally designed to investigate pre-exercise consumption of carbohydrate on fat metabolism during a 30-min submaximal treadmill run. The study found that there was a greater rate of glycogen degradation during exercise after ingesting a concentrated (25%) carbohydrate solution than after ingesting water, but exercise performance was not tested in this experiment (Costill et al., 1977). In a subsequent study, it appeared that fatigue occurred 19% sooner during cycling to exhaustion at 80% VO_2max after the cyclists ingested a 25% glucose solution (Foster et al., 1979). But this negative effect of carbohydrate ingestion was not shown in a third study from the same laboratory (Hargreaves et al., 1987). In that study, six cyclists exercised to fatigue at 75% VO_2max on three separate occasions following the ingestion of three different solutions 45 min before exercise. The cyclists ingested (i) 75 g of glucose in 350 ml water, (ii) 75 g of fructose in 350 ml of water, or (iii) the same volume of a flavored placebo solution. There were no differences in time to fatigue during the three trials (92-93 min) nor differences in the amount of muscle glycogen used (Hargreaves et al., 1987).

There are other reports that carbohydrate feedings in the hour before exercise have caused either no difference in endurance performance (Chryssanthopoulos et al., 1994a; Palmer et al., 1998) or a beneficial effect (Burke et al., 1998; Chryssanthopoulos et al., 1994a; El-Sayed et al., 1997; Gleeson et al., 1986; Sherman et al., 1991).

In one study, a group of well trained runners ingested either 75 g of glucose in 300 ml of water or, on a separate occasion, just 300 ml of flavored water 30 min before treadmill running to exhaustion at 70% VO_2max. Even though there was a transient rise and fall in plasma glucose concentration following the ingestion of the glucose solution, there were no statistically significant differences between the times to fatigue for the glucose (134 min) and placebo (122 min) trials (Chryssanthopoulos et al., 1994a). In some cases the transient fall in plasma glucose early in exercise can reach hypoglycemic values, but subjects rarely experience adverse symptoms nor are their performances compromised (Chryssanthopoulos et al., 1994a; Jentjens et al., 2003), However, similar decreases in blood glucose concentrations towards the end of prolonged exercise probably hasten the onset of fatigue (Claassen et al., 2005; Coyle et al., 1983).

An example of a report showing an improvement in performance following carbohydrate feedings in the hour before exercise is one published by Gleeson et al. (1986). Their study included three trials in which six men ingested either placebo or solutions of glucose or glycerol (1 g of carbohydrate/kg body mass in 400 ml water) 45 min before cycling to fatigue at 73% VO_2max. The time to fatigue was significantly longer following the ingestion of the glucose solution (108.6 min) than following the trials with glycerol (86.0 min) or placebo (95.9 min). The difference in time to fatigue between the glycerol and placebo trials was not statistically significant.

CARBOHYDRATE INGESTED 30-60 MINUTES BEFORE EXERCISE: EFFECTS ON "REAL-WORLD" TIME-TRIAL TYPES OF PERFORMANCE

Sherman et al. (1991) controlled the diets and exercise of their subjects for 2 days before initiating a study of the effects of 1-h pre-exercise meals of 75 g or 150 g of liquid carbohydrate or placebo on performance of a cycling time trial that followed a 90-min ride at 70% VO_2max. The carbohydrate feedings followed an overnight fast, and only water was provided during exercise. During the placebo trial, the subjects completed the time trial in ~47 min, whereas during the two carbohydrate trials, performance was significantly improved to ~41-41.5 min.

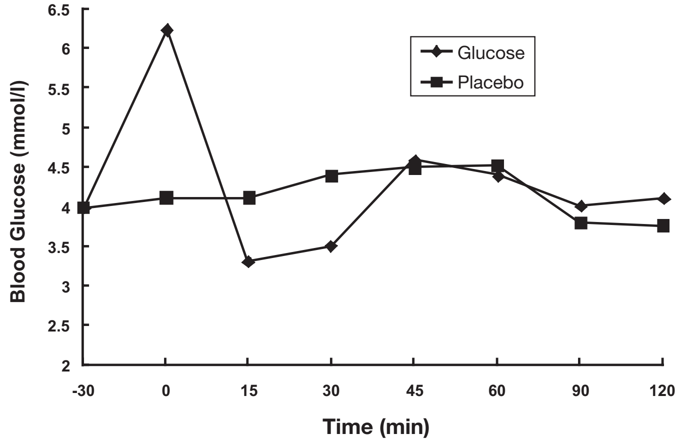

FIGURE 3: ***Blood glucose responses to drinking a solution of 25% glucose or a sweetened placebo solution 30 min before treadmill running to fatigue at 70% VO_2max*** (Chryssanthopoulos et al., 1994a)

Using a slightly different 1-h time trial protocol, El-Sayed and colleagues (1997) examined the influence of ingesting either an 8% carbohydrate solution (4.5 ml/kg body mass) or a sweetened, colored placebo 25 min before exercise on cycling performance. In this cross-over study, eight very well trained male cyclists used their own bikes fitted to an air-braked ergometer to complete the greatest distance possible in 1 h. During the trial, the cyclists could see the time elapsed but were not informed of the distance covered nor power output until the completion of both trials. The cyclists completed the two trials 6 h after their last meal, but no details of the 6-h pre-exercise meals were provided other than that they were identical before each of the two trials. The carbohydrate ingested 25 min before the time trial was equivalent to about 25 g. The cyclists covered a significantly greater distance (41.5 km) following the ingestion of the carbohydrate solution than after ingestion of the placebo (41.0 km) (El-Sayed et al., 1997).

However, not all studies have reported positive benefits from ingesting a carbohydrate solution during the hour before exercise on time-trial performance. For example, 14 endurance trained cyclists (11 men, 3 women) completed a 20-km time trial on their own bikes fixed to an air-braked ergometer after ingesting 8 ml/kg body mass of a 6.8% carbohydrate-electrolyte solution or a placebo 10 min before exercise (Palmer et al., 1998). The ingestion of the carbohydrate-electrolyte solution before exercise provided the cyclists with ~ 40 g of carbohydrate, but average times to complete the 20-km time trials (27.66 min) were identical.

DIRECTIONS FOR FUTURE RESEARCH

As can be seen from the wide range of studies described above, even when time-trial protocols have been used to assess performance, only a few experiments have simulated real-life conditions. Therefore, there is a clear need for additional studies on the influence of pre-exercise high-carbohydrate meals on time-trial performance, not only in cycling, but especially in running, including experiments in which subjects consume sports drinks during the time trials. These time-trial studies should try to simulate real-life conditions, including the use of longer-duration time trials and the employment of females as subjects. Additional studies are also needed to determine the efficacy of pre-exercise meals on performance in team sports such as soccer and in sports like tennis and swimming.

SUMMARY

- Eating an easy-to-digest high-carbohydrate breakfast 2-4 h before morning exercise is recommended because it will help restock liver glycogen stores after an overnight fast. However, the available evidence suggests that although this practice will likely enhance endurance capacity (time to exhaustion), it may not improve time-trial performance.
- Although early studies suggest an impairment of performance following the ingestion of a carbohydrate beverage within the hour before exercise, this has not been supported by subsequent studies; rather, there are several reports of beneficial effects of such feedings.

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SUPPLEMENT

DOES A HIGH-CARBOHYDRATE BREAKFAST IMPROVE PERFORMANCE?

After an overnight fast, the supply of liver glycogen, the source of blood glucose, is reduced to low values; if liver glycogen stores are not replenished, blood glucose may be reduced to critically low values during prolonged exercise. However, eating a high-carbohydrate meal 3-4 h before exercise will increase the stores of both liver and muscle glycogen. Because glycogen is a critical fuel for most types of athletic competition, this is a chief reason for the well known recommendation that athletes should eat an easy-to-digest high-carbohydrate meal before exercise.

When and What to Eat Before Exercise Lasting Longer Than About 60 Minutes

The optimal preparation for heavy training and competition is to eat a high-carbohydrate meal that consists of easy-to-digest carbohydrates that enter the bloodstream rapidly, i.e., those classified as high glycemic-index (GI) carbohydrates, about 3-4 h before exercise. (Eating within the final 2 hours before exercise can be effective but is more likely to cause digestive disturbances.) Table S1 provides an example of high-GI carbohydrate foods that are frequently consumed as part of a pre-exercise meal.

Type of Food	Quantity	CHO (g)	Fat (g)	Protein (g)	Fiber (g)
White Bread	105 g	48.8	2.2	8.6	1.9
Jam	70 g	48.6	--	0.2	0.8
Corn flakes	56 g	47.0	0.6	4.5	0.9
Skimmed Milk	280 ml	14.0	0.3	9.5	--
Orange Juice	147 ml	16.6	--	0.2	--
Water	315 ml				
Total		175.0	3.1	23.0	3.6

TABLE S1. The composition of a high-carbohydrate meal (2.5 g of carbohydrate/kg body mass; ~800 kcal) ingested 3 h before exercise that resulted in a 10.5% increase in muscle glycogen concentration (Chryssanthopoulos et al., 2004)

What If There Is Too Little Time to Eat a Meal before Endurance Exercise?

Competition in some sports begins so early in the day that it is not practical to eat a pre-exercise meal before the event begins. Moreover, many athletes, often women, find it difficult to eat any solid foods before participating in sports, especially those that involve prolonged continuous or intermittent running. For these athletes, it is important to drink a well-formulated sports beverage 1-2 h before and at frequent intervals throughout exercise to achieve an optimal rate of carbohydrate metabolism.

Should I Eat a High-Carb Pre-Exercise Meal If I Also Use a Sports Drink During Exercise?

The answer depends on the nature of the exercise. There is good evidence to recommend the combined intake of carbohydrate both before and during exercise when performing prolonged exercise to exhaustion. However, there are only a few sports (e.g., adventure racing, which can last several days) that are so open-ended that time to exhaustion is a limiting factor. In most sports the aim is to cover a prescribed distance in as fast a time as possible or, as in team sports like soccer or basketball, to produce as much effort as possible in a prescribed amount of time. In these types of events, the research suggests that successful participation does not require a high-carbohydrate pre-exercise meal if a well-formulated sports drink is used appropriately during the event. However, there is no evidence that a carbohydrate meal will be harmful, and it could help.

RECOMMENDATIONS

To prepare for a period of prolonged heavy exercise, either in training or competition, follow these recommendations:

- About 3-4 h before exercise, eat an easy-to-digest high-carbohydrate meal that provides about 2-2.5 g of carbohydrate/kg body weight. For a 70-kg (154-lb) athlete, 2-2.5 g/kg body weight is 140–175 g of carbohydrate (640–700 kcal).
- About 1-2 h before exercise, ingest 300-600 ml (10-20 oz) of water or a sports drink, to ensure that you are well hydrated before exercise.
- You should drink a sports beverage frequently throughout prolonged exercise, following the simple rule that you should drink enough during exercise so that you do not gain or lose body weight during the exercise period. By following this recommendation, you will avoid performance-sapping dehydration and maximize the benefits of a high-carbohydrate pre-exercise meal.

SUGGESTED ADDITIONAL RESOURCES

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