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Cost-Effectiveness of Pre-Exercise Carbohydrate Meals and Their Impact on Endurance Performance

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Reference Data

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ABSTRACT

This study examined the effects of ingesting 4 isocaloric carbohydrate (CHO) meals 2 hrs prior to a 60-min bout of endurance cycling. Each meal represented a different combination of type, form, or mode of delivery of CHO: (a) semi-liquid, oat based CHO/fat/protein combination (Combo); (b) semi-liquid, oat based CHO (Oat); (c) semi-liquid, wheat based CHO (Wheat); (d) dense solid, fructose based CHO/protein/vitamin combination (Bar). Cost of the meals ranged from $0.50 to $2.60 each. Trials were conducted in random order over a 4-week period. Exercise and diet was standardized prior to each trial. Feedings were ingested 2 hrs before each 60-min self-paced cycle ergometry trial. Dependent variables were assessed every 15 min during each trial. Regardless of which meal was ingested, no significant group differences were found for blood glucose concentration, distance traveled, heart rate, oxygen consumption, or respiratory exchange ratio. It is suggested that some endurance athletes may save money yet suffer no performance disadvantage with CHO-based cereal instead of the more costly commercial sports bars.

Key Words: sports bars, breakfast cereal, diet, cycling, blood glucose

Introduction

Adequate substrate availability is a fundamental requirement for participation in prolonged, high-intensity physical activity (>60 min @ 65–75% $\dot{V}O_2$ max). During such activity, performance is largely determined by glycogen reserves in the muscle and liver. However, if glycogen stores are low prior to exercise, as often occurs when athletes complete multiple training sessions on successive days, the ability to maintain blood glucose concentration during prolonged, high-intensity endurance exercise becomes a major determinant of successful performance (1, 12, 23). In such circumstances the preexercise meal plays a pivotal role in blood glucose regulation and endurance performance.

Many variables associated with preexercise carbohydrate ingestion have been thoroughly investigated, for example, the amount (2, 12), timing (6, 10, 22), mode of delivery (4, 15, 18, 21), nutrient combination (13, 27), and type of carbohydrate ingested (11, 19). While it may be possible to optimize one's preexercise diet through careful manipulation of these factors, most athletes rely on more general principles. In such cases the choice of preexercise meal often depends on the recognition, availability, and perceived suitability of particular foods.

Magazine-style sport or exercise publications contain a multitude of ads for carbohydrate based sports bars (3, 17). In many cases the claims of ergogenic benefits appear to be based on research that is not peer-reviewed, and on the anecdotal testimony of elite athletes. The increasing popularity of these products suggests that consumers are willing to spend a lot of money on a comparatively small amount of food (3). In comparison, commonly available oat and wheat-based cooked cereals cost much less yet provide a similar amount of carbohydrate (CHO). Therefore, given the higher cost and relative lack of scientific support for the effectiveness of sports bars beyond that afforded by basic oat and wheat cereals, the ergogenic effect of sports bars needs to be addressed and subsequent recommendations should be based on cost effectiveness rather than market appeal.

The purpose of this study was to compare the effect on distance traveled, blood glucose concentration, respiratory exchange ratio (RER), oxygen consumption ($\dot{V}O_2$), and heart rate (HR) during a 60-min bout of endurance cycling following ingestion of 460 kcal of four preexercise meals: (a) a semi-liquid, oat based CHO/fat/protein cereal (Combo); (b) a semi-liquid, oat based CHO cereal (Oat); (c) a semi-liquid, wheat based CHO cereal (Wheat); or (d) a dense solid, fructose based CHO/protein/vitamin sports bar (Bar).

Methods

Subjects

Eight endurance trained male cyclists volunteered for this study. To be eligible for inclusion, subjects had to fulfill the following criteria: (a) cycle ≥50 km per week for at least the past 4 weeks; (b) have a cycle ergometry

$\dot{V}O_2$ max ≥55 ml · kg^{-1} · min^{-1}; and (c) be free from any injury or pathology that may affect cycling performance or normal gastrointestinal function. Subject characteristics (mean ± *SE*) were: age 26.6 ± 1.0 yrs; Ht 1.79 ± 0.03 m; Wt 72.2 ± 2.9 kg; sum of 7 skinfolds 59.9 ± 6.1 mm; $\dot{V}O_2$ max 4.73 ± 0.27 L; 70% $\dot{V}O_2$ max workload 283 ± 18 W; sprint workload 453 ± 11 W.

Equipment

All exercise was performed on an electronically braked cycle ergometer (Cybex Metabolic Systems 100, Ronkonkoma, NY). Measurement of oxygen consumption was obtained by circulating expired breath samples through a mixing chamber and analyzing for O_2 (S-3A, Ametek, Pittsburgh) and CO_2 (CD-32, Ametek). Inspired volume was measured using a flowmeter (Rayfield Equipment, Waitsfield, VT). Exercise HR was monitored via telemetry (Polar Vantage XL, Polar Electro, Port Washington, NY). Body weight was measured to the nearest 0.1 kg using balance scales (Continental Scale Corp., Bridgeview, IL). Body fat was estimated by summing the average of three measurements of skinfold thickness at the calf, thigh, abdomen, subscapular, triceps, chest, and midaxilla sites (Lange skinfold calipers, Cambridge Scientific Industries, Cambridge, MD). Finger-stick blood samples were analyzed for blood glucose concentration on a Reflotron (Boehringer Mannheim GmbH, Germany).

All subjects reported extensive previous exposure to the ergometer and techniques used in this study. Nevertheless, all completed at least one 60-min session of familiarization with the mouthpiece and headgear used for gas analysis and completion of the exercise protocol employed during data collection.

One week prior to the performance trials, subjects underwent an incremental cycle ergometry test of maximum oxygen consumption ($\dot{V}O_2$ max). Two days later they completed a 60-min bout of cycle ergometry to identify the workload corresponding to 70% $\dot{V}O_2$ max.

Exercise and Diet Manipulation

Subjects were encouraged to continue normal dietary and exercise practices outside of the testing period. However, pretrial diet and exercise regimens were standardized to reduce performance variations based on endogenous fuel availability. A written record was made of each subject's dietary intake and exercise history during the 3 days prior to the first trial. This information served as a reference to ensure that a similar diet and exercise regimen was followed leading up to subsequent trails. Subjects abstained from all extraneous exercise the day before each trial.

Between 6 and 8 p.m. the evening preceding each performance trial, subjects performed a 60-min bout of cycle ergometry at an intensity of 70% $\dot{V}O_2$ max. One hour after the ride they consumed an 800-kcal evening meal with a nutritional breakdown of 46% CHO, 27% protein, and 27% fat. They also ingested approximately 1 liter of water or other noncaloric, noncaffeinated beverage. The next morning, subjects returned to the laboratory in a fasted state (~10 hrs postprandial). To detect potential noncompliance or variation from the prescribed feeding and exercise schedule, a resting finger-stick blood sample was analyzed for blood glucose concentration (unacceptable: ≤4.0 mmol · L^{-1} and ≥6.0 mmol · L^{-1}).

To further standardize endogenous glycogen availability, subjects underwent a 30-min cycle ergometry bout at 70% $\dot{V}O_2$ max immediately followed by six 1-min sprints at a power output of 110% of the workload produced at $\dot{V}O_2$ max. A 3-min rest interval was provided between sprints.

Thirty minutes after the final sprint, subjects consumed one of the four 460-kcal isocaloric feedings within a 10-min time frame. The meals were provided in random order; their nutritional breakdown is shown in Table 1. The caloric content of each feeding was equivalent to two standard servings of Bar. The Combo, Wheat, and Oat cereals were mixed with 200 ml of water to obtain a semi-liquid consistency and were cooked in a microwave oven for 3 min. No milk or sweeteners were used.

Two hours after the preexercise meal, subjects began the 60-min performance ride. They received no feedback on performance during each ride but were aware of the elapsed time. They were told their goal was to cover as much distance as possible in 1 hour. The isokinetic mode of the ergometers was selected to provide accommodating pedal resistance (60–500 watts) at a cadence of 90 rpm. Distance, heart rate, oxygen consumption, and RER were obtained at 15-min intervals during each trial. Finger-stick blood samples for blood glucose analysis were taken immediately before, midway through, and immediately after each performance trial (0, 30, and 60 min). The amount of water consumed during the first trial was recorded and the same amount was provided during subsequent trials.

Table 1
Nutritional Breakdown and Main Ingredients of Feedings

Product	Energy (kcal)	CHO%	Protein %	Fat %
Wheat	460	75	11	–
Oat	460	68	14	1.7
Combo	460	77	7	5
Bar	460	69	14	3

Main Ingredients

Wheat: Wheat farina, salt, wheat germ, guar gum
Oat: Whole grain rolled oats, calcium carbonate, guar gum
Combo: Oatmeal, sugar, whole wheat, brown sugar, dried bananas, barley flakes, wheat farina, almonds, guar gum
Bar: High fructose corn syrup, fruit juice concentrate, oat bran, maltodextrins, milk protein, banana, cashew butter, rice

Statistical Analysis

A two-way ANOVA with repeated measures (treatment × time) was performed to investigate possible differences between dependent variables (distance, blood glucose, RER, $\dot{V}O_2$, HR). Where necessary, post hoc testing was performed using Tukey's pairwise comparisons to examine differences between means. Significance was accepted at $p < 0.05$. Effect sizes were calculated using the techniques described by Thomas et al. (25).

Results

All 8 subjects successfully completed each required element of the experimental protocol. There were no indications of variance from the required pretrial regimen.

There were no significant differences in blood glucose concentrations the morning prior to each meal and performance trial. Values were: 5.03 ± 0.18 (Combo); 4.90 ± 0.17 (Oat); 5.07 ± 0.16 (Wheat); and 5.04 ± 0.08 mmol · L^{-1} (Bar). Similarly, regardless of meal, there were no significant differences in blood glucose concentration at 0, 30, and 60 min of each performance trial ($p = 0.133$) (Figure 1). However, calculation of effect sizes revealed values of 2.78, 3.13, 2.63, and 2.09 for Combo, Oat, Wheat, and Bar feedings, respectively. Values greater than 0.8 are considered to represent a meaningful treatment effect (25).

There were no significant differences in $\dot{V}O_2$ at any stage of the performance trials. Similarly, there were no differences in $\dot{V}O_2$ between the four experimental conditions (Figure 2). Mean $\dot{V}O_2$ values during each performance trial were 3.00 ± 0.12, 3.04 ± 0.14, 2.86 ± 0.13, and 3.10 ± 0.14 L · min^{-1} for Combo, Oat, Wheat, and Bar, respectively.

Mean heart rates at 15, 30, 45, and 60 min of each performance trial did not change significantly. Mean (±*SE*) heart rates during each 60-min trial were 151.5 ± 5.7 (Combo), 157.0 ± 6.6 (Oat), 149.1 ± 6.9 (Wheat), and 157.6 ± 4.1 bpm (Bar). No significant differences were found between experimental groups.

Subjects completed an average of 33.73 ± 0.59 km during each 60-min performance trial. Total distance and distance at 15, 30, and 45 min was not significantly altered by any of the feedings. Indeed, the homogeneity of the mean group values is revealed in Figure 3. In all pooled trials there was a strong linear relationship between distance and time.

There were no significant differences in RER between feedings (Figure 4). Similarly, RER values did not change significantly over the course of each trial. Grouped values at 15, 30, 45, and 60 minutes ranged from 0.845 to 0.901 and were similarly distributed among feeding conditions.

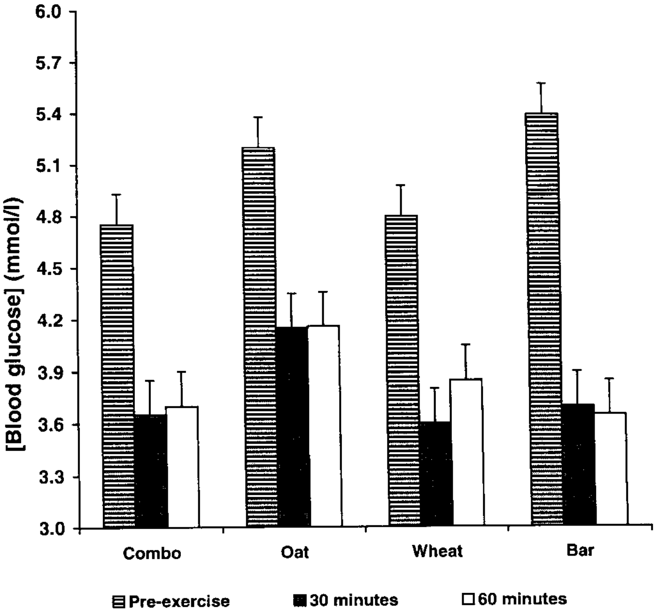

Figure 1. Blood glucose concentrations (means ± *SE*) at 0, 30, and 60 min of each 60-min performance trial. No significant differences were found.

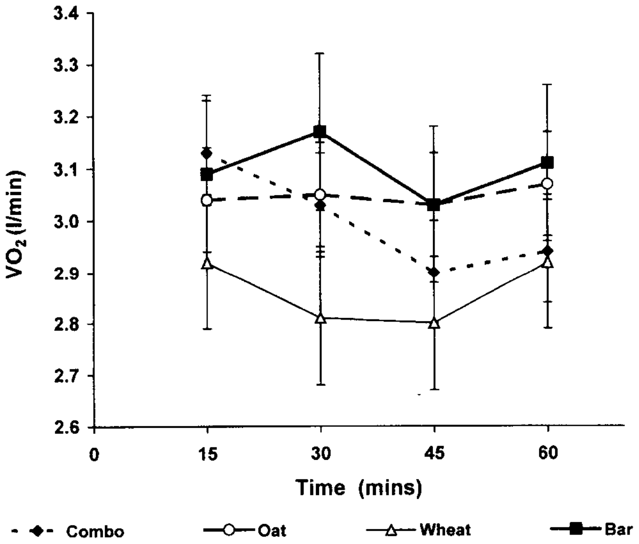

Figure 2. $\dot{V}O_2$ values (means ± *SE*) taken at 15-min intervals during a 60-min cycling performance ride. No significant differences were found.

Discussion

The experimental protocol was designed to lower and standardize each subject's glycogen levels prior to the meals and performance trials. Although glycogen stores were not directly measured, previous research has demonstrated that a similar exercise and dietary regimen caused a reduction in muscle and liver glycogen reserves, placing more emphasis on the ability of the preexercise feeding to maintain blood glucose (14). Gollnick et al. (9) reported that a lowering of muscle glycogen is associated with an increased extraction of glucose from the blood. Therefore, given that subjects reported strict adherence to the preparatory exercise and dietary protocol, in addition to similarities in fasting blood glu-

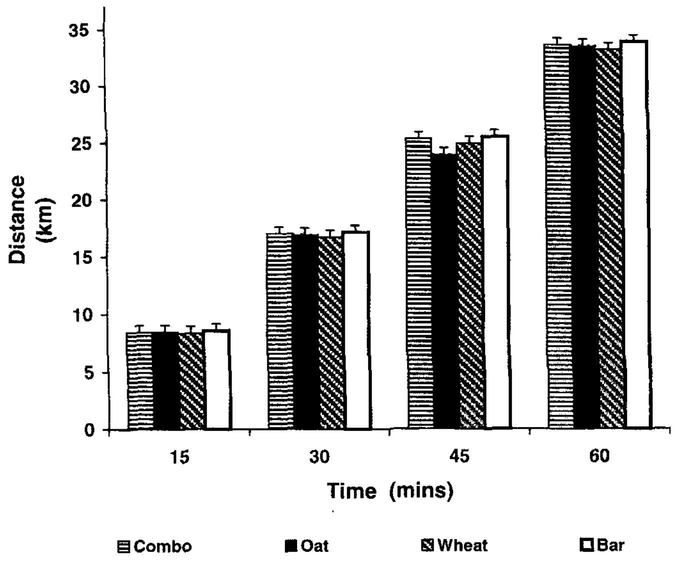

Figure 3. Distance covered (means ± *SE*) at 15-min intervals during a 60-min cycling performance ride. No significant differences between meals were found.

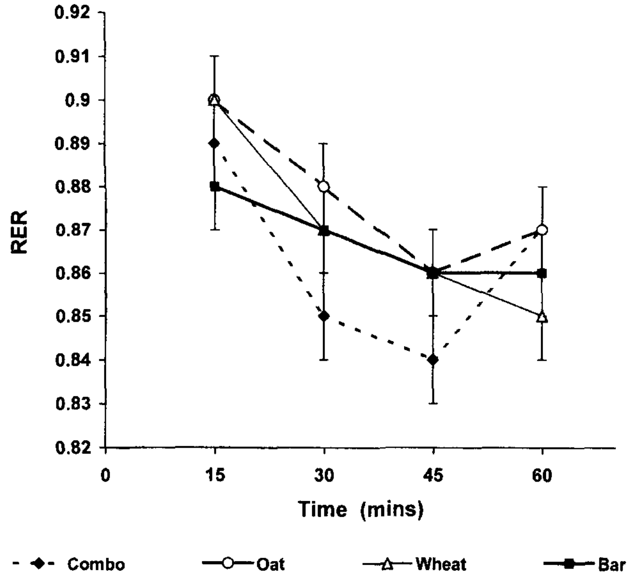

Figure 4. RER values (means ± *SE*) at 15-min intervals during a 60-min performance ride. No significant differences were found.

cose concentrations, it appears that endogenous substrate concentrations were uniformly reduced prior to each trial.

The fact that blood glucose concentrations had not changed significantly from fasting values when measured immediately prior to each performance trial suggests that each experimental meal had a similar effect on blood glucose following the 30-min ride and sprints. Alternatively, the similarities in fasting and preperformance trial blood glucose concentration may have been due to the 30-min ride, sprints, and the subsequent meal not influencing blood glucose levels. However, previous research has demonstrated that exercise of comparable intensity and duration reduced blood glucose in unfed subjects. Similarly, the ingestion of a carbohydrate meal following exercise has been shown to restore blood glucose concentration to preexercise levels (8, 22).

Though not significant ($p = 0.13$), blood glucose was consistently lower at 30 and 60 min of each performance trial (effect sizes, 2.09 to 3.13). The failure to produce a significant result may have been due to the small subject number coupled with comparatively large intrasubject variations (25). As noted, there was no evidence to suggest noncompliance with the experimental protocol. Therefore it may be assumed that the variance was a consequence of normal variation in glucose metabolism.

The results of this study are consistent with most of the previous research examining preexercise carbohydrate ingestion. Specifically, there were no differences attributable to any of the meals. Indeed, several studies (4, 15, 18, 20, 21) have demonstrated that the type and mode of delivery of a carbohydrate meal offers no specific performance advantage. Furthermore, given that many of these studies employed a slightly different experimental protocol, it appears that the composition of the carbohydrate meal is of little significance across a broad range of subject groups and exercise intensities.

The nutritional breakdown of each meal reveals that fructose syrup and a fruit juice extract are the two major ingredients in Bar. While the performance benefits of preexercise glucose ingestion are widely accepted (5, 24), there is controversy as to the potential ergogenic effects of fructose. Some authors (7, 10, 22), but not all (16), have reported no significant effect on performance following a preexercise fructose meal. While it is possible that the similarities between each meal were due to none of the meals providing an ergogenic effect, previous research suggests that the amount and timing of carbohydrate ingested during each meal in this study should have been enough to provide an ergogenic effect during a 60-min bout of endurance cycling (20, 24, 26). Therefore it appears that the 2-hr interval between the ingestion of the high fructose Bar and the onset of exercise may have been long enough to digest and absorb the meal, phosphorylate fructose in the liver, and deliver it as glucose into the blood.

No performance trial data were obtained on unfed subjects in this study. While this leaves open the question that a fasted subject may have performed as well if not better than his fed counterparts, unpublished research from our laboratory suggests that the physical demands placed on fasting subjects during an exercise protocol of similar intensity and duration may cause excessive fatigue associated with glycogen depletion and hypoglycemia. Second, previous research suggests that subjects who consume a carbohydrate meal prior to exercise perform better than those who are unfed or receive a noncaloric placebo (5, 20, 24, 26).

Practical Applications

In the past decade, the number of commercially available sport/energy bars has increased dramatically. Not surprisingly, there has also been a concomitant increase in their use (3, 17). Despite their popularity, it appears that most of the evidence supporting the effectiveness of sports bars is based on "testimonials" from prominent athletes and company research that was not peer-reviewed. In contrast, the results of this study suggest that ingestion of 460 kcal of a leading sports bar (Bar) confers no performance advantage over three common isocaloric, CHO-based cereals (Combo, Oat, and Wheat). Given these similar results, athletes engaging in continuous submaximal exercise lasting approximately 60 min (e.g., endurance running, cycling) would do well to choose a preexercise meal based on convenience and cost-effectiveness rather than commercial appeal.

Budin (3) reports that most commercially available sports bars cost $1.29 to over $3.00 each. If we use the example of an athlete training/competing 6 times a week and consuming 2 midpriced sports bars (~460 kcal) as part of each preexercise meal, the cost over a single week would be approximately $25. In comparison, if the same number of calories of Combo, Oat, and Wheat were ingested, the accumulated cost would be approximately $8.

The discrepancy in price between sports bars and cereals is further highlighted by the practice of many college athletic departments supplying their athletes with foods not found on the typical dining service menu. Many athletic departments channel considerable funds into the purchase of sports bars and other nutritional supplements. But given the results of the present study, it appears that the rationale for this practice is questionable. Individuals and athletic departments alike may be able to save money by selecting equally effective yet relatively inexpensive oat and/or wheat-based cooked cereals in lieu of more expensive sports bars.

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