Effect of Low- and High-Glycemic-Index Meals on Metabolism and Performance During High-Intensity, Intermittent Exercise

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Consuming carbohydrate-rich meals before continuous endurance exercise improves performance, yet few studies have evaluated the ideal preexercise meal for high-intensity intermittent exercise, which is characteristic of many team sports. The authors’ purpose was to investigate the effects of low- and high-glycemic-index (GI) meals on metabolism and performance during high-intensity, intermittent exercise. Sixteen male participants completed three 90-min high-intensity intermittent running trials in a single-blinded random order, separated by ~7 d, while fasted (control) and 2 hr after ingesting an isoenergetic low-GI (lentil), or high-GI (potato and egg white) preexercise meal. Serum free fatty acids were higher and insulin lower throughout exercise in the fasted condition ($p < .05$), but there were no differences in blood glucose during exercise between conditions. Distance covered on a repeated-sprint test at the end of exercise was significantly greater in the low-GI and high-GI conditions than in the control ($p < .05$). Rating of perceived exertion was lower in the low-GI condition than in the control ($p = .01$). In a subsample of 5 participants, muscle glycogen availability was greater in the low- and high-GI conditions versus fasted control before the repeated-sprint test ($p < .05$), with no differences between low and high GI. When exogenous carbohydrates are not provided during exercise both low- and high-GI preexercise meals improve high-intensity, intermittent exercise performance, probably by increasing the availability of muscle glycogen. However, the GI does not influence markers of substrate oxidation during high-intensity, intermittent exercise.

Keywords: muscle glycogen, nutrition, carbohydrate, soccer

Athletes participating in endurance sports are generally instructed to consume a carbohydrate-rich meal several hours before competition (Hargreaves, Hawley, & Jeukendrup, 2004; Williams & Serratosa, 2006). Ingesting carbohydrates ensures that exercise commences with optimal levels of liver and muscle glycogen, thereby maximizing the availability of carbohydrates, which are the primary fuel source for exercising skeletal muscle (van Loon, Greenhaff, Constantin-Teodosiu, Saris, & Wagenmakers, 2001). Despite a plethora of research in this area (e.g., Chryssanthopoulos & Williams, 1997; Chryssanthopoulos, Williams, Nowitz, Kotsiopoulou, & Vleck, 2002; Kirwan, Cyr-Campbell, Campbell, Scheiber, & Evans, 2001; Kirwan, O’Gorman, & Evans, 1998; Schabort, Bosch, Welton, & Noakes, 1999; Wright, Sherman, & Dernbach, 1991), the characteristics of the ideal preexercise meal have not been firmly established, and little research has been done with high-intensity, intermittent endurance exercise, which is characteristic of most team sports. Some researchers have suggested that consuming low-glycemic-index (GI) carbohydrate sources before exercise may be beneficial (Kirwan et al., 2001; Burke, Collier, & Hargreaves, 1998; DeMarco, Sucher, Cisar, & Butterfield, 1999; Thomas, Brotherhood, & Brand 1991; Walton & Rhodes, 1997). Low-GI carbohydrates, in contrast to high-GI carbohydrates, are digested and absorbed slowly, resulting in a lower rise in circulating glucose and insulin (Jenkins et al., 1981). Because insulin inhibits lipolysis and skeletal-muscle fatty-acid oxidation (Horowitz, Mora-Rodriguez, Byerley, & Coyle, 1997; Sidossis, Stuart, Shulman, Lopaschuk, & Wolfe, 1996) and these effects can persist for at least 4 hr after carbohydrate ingestion (Montain, Hopper, Coggan, & Coyle, 1991), lower levels of circulating insulin after low-GI preexercise meals may promote greater fat oxidation, thus preserving endogenous carbohydrate stores and delaying the onset of fatigue. Indeed, most studies examining whole-body substrate oxidation have reported increased fat oxidation and decreased carbohydrate oxidation during exercise after low- compared with high-GI meals (Febbraio, Keenan, Angus, Campbell, & Garnham, 2000; Stevenson, Williams, Mash, Phillips, & Nute, 2006; Wee, Williams, Gray, & Horabin, 1999; Wee, Williams, Tsintzas, & Boobis, 2005; Wu & Williams, 2006). Wee et al. (2005) demonstrated that when a high-GI carbohydrate meal was consumed 3 hr before continuous moderate-intensity running, fat oxidation was blunted and the rate of muscle glycogen degradation was greater than when a low-GI carbohydrate meal was consumed. Unfortunately, exercise lasted only 30 min and performance was not assessed in that study, so

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it is unclear whether the increased reliance on muscle glycogen after high-GI preexercise meals had an effect on running performance.

Research examining the effects of low- and high-GI preexercise meals on exercise performance has produced mixed results, most likely because specific foods, methods, and ingestion times have differed (for review see Little, Chilibek, Bennett, & Zello, 2009). Some studies indicate improved endurance performance in the low-GI condition (DeMarco et al., 1999; Kirwan et al., 2001; Thomas et al., 1991; Wu & Williams, 2006), whereas most have reported no significant differences between low- and high-GI preexercise meals (Febbraio et al., 2000; Febbraio & Stewart, 1996; Sparks, Selig, & Febbraio, 1998; Stannard, Constantini, & Miller, 2000; Thomas, Brotherhood, & Miller, 1994). Note that most previous research has focused on continuous, moderate-intensity exercise. Many team sports (e.g., soccer, basketball, hockey) involve prolonged, high-intensity, intermittent exercise. Only one study to date has looked at the effect of the GI on intermittent exercise performance (Erith et al., 2006). In this study participants consumed low- and high-GI recovery diets over ~24 hr between two bouts of exhaustive intermittent exercise. However, the second intermittent exercise trial was performed in the fasted state and thus did not examine the influence of preexercise carbohydrate ingestion. Low-GI meals may be beneficial for prolonged high-intensity intermittent exercise, because the blunted insulin response and subsequent increased fat oxidation, especially during the periods of rest and recovery, could preserve endogenous carbohydrate sources for later high-intensity efforts. Accordingly, the primary purpose of the current study was to examine the effects of low- and high-GI preexercise meals on metabolism and performance during high-intensity intermittent exercise. We hypothesized that both low- and high-GI meals would improve performance compared with a fasted control condition but that the low-GI meal would be superior to the high-GI meal as a result of increased fat oxidation and muscle glycogen sparing.

Methods

Participants

Sixteen male athletes participated in the study (age 22.8 ± 3.2 years, maximal oxygen uptake [VO2peak] 55.4 ± 4.3 ml·kg¹·min⁻¹, peak treadmill speed [Vmax] 17.9 ± 1.7 km/hr). Eight were varsity men’s soccer players, 5 were club-level soccer players, and 3 were middle-distance runners with recreational soccer experience. The study protocol was approved by the University of Saskatchewan Biomedical Research Ethics board, and participants provided written informed consent before any data were collected.

Experimental Design

Of the 16 participants, 13 completed the entire study but did not undergo muscle-biopsy trials. The collection of muscle biopsies required exercise to be performed at the Saskatoon City Hospital, so only a subsample of 5 participants underwent biopsy trials. Two of these 5 participants were recruited from the original 13, and 3 were newly recruited. These participants performed the same protocol and provided muscle biopsy samples, but other metabolic and performance data were not obtained during the biopsy trials. Participants made five visits to the laboratory over the course of ~6 weeks. Preliminary testing included a VO2peak test and a familiarization session for the high-intensity intermittent running protocol. After these visits, each participant underwent three experimental trials separated by ~7 days in a counterbalanced, randomized crossover design. A different preexercise meal condition was administered in each trial. The experimental conditions were low GI, high GI, and fasted control. The study was single-blind; personnel conducting the exercise tests and evaluating results were blinded to experimental conditions, but the participants knew what meals they consumed. Participants were not aware of the study hypothesis.

Details of Experimental Meal Conditions

The energy and macronutrient profile for the experimental foods is presented in Table 1. The low-GI meal (decarcitated unsplit CDC Robin red lentils, SaskCan Pulse Trading, Regina, SK, Canada) provided 1.5 g of available carbohydrate per kg of body mass. The high-GI meal (McCain instant mashed potatoes, McCain Foods, Florenceville, NB, Canada; Wonder Enriched White Bread, Weston Bakeries Ltd., Toronto, ON, Canada; and Naturegg Simply Egg Whites, Burnbrae Farms, Upton, QC, Canada) was matched for macronutrient content with the low-GI meal. Amounts of preexercise meal consumed were measured on a research-grade scale to the nearest tenth of a gram. Consumed amounts in the first experimental condition were used to match the energy provided in the following experimental conditions. The foods were chosen for several reasons. First, Thomas et al. (1991)
originally demonstrated that lentils enhanced endurance-exercise performance, and we therefore wanted to assess the effects of lentils on intermittent exercise performance. Second, lentils are low GI yet have a high protein content, and we reasoned that a low-GI, high-carbohydrate, high-protein food may represent the best preexercise meal. It was easier to prepare and match preexercise foods using lentils than with a mixed meal. Finally, this study is part of a larger program of research that is examining the effects of lentils on exercise performance with the end goal of developing prepackaged foods containing lentils as the main ingredient (e.g., energy bars). Therefore, we chose lentils as our low-GI food and matched macronutrient content with a simple high-GI food combination of instant mashed potatoes (for carbohydrate) and egg whites (for protein).

Details of Exercise Tests

**VO₂peak** and **Vmax** were determined using an incremental running test to exhaustion on a treadmill according to the methods of Harling, Tong, and Mickleborough (2003). Briefly, the test began at 10 km/hr, and the speed was increased by 1 km/hr every minute until volitional exhaustion. **VO₂** was measured breath by breath using open-circuit indirect calorimetry (Sensor Medics, Vmax Series 29, Anaheim, CA). Heart rate was measured continuously using a Polar 610i heart-rate monitor (Polar Series 29, Anaheim, CA). VO₂peak was calculated as the highest 20-s mean for VO₂, and maximal heart rate was determined using the highest 5-s mean. Vmax was defined as the highest treadmill speed that was maintained for 1 min (Harling et al., 2003).

The high-intensity intermittent running protocol consisted of two 45-min sections separated by a 15-min break. A programmable treadmill (Vacu Med, Model 13622, Ventura, CA) and its software package were used to simulate the activity pattern of a soccer game by alternating between periods of rest, walking, jogging, running, and sprinting based on the protocol of Drust, Reilly, and Cable (2000). The proportion of time spent at each speed was based on time–motion analysis of professional soccer players that demonstrated that they spend approximately 7% of the game standing still, 56% of the game walking (~6 km/hr), 30% of the game jogging (~10 km/hr), 4% of the game running (~17 km/hr), and 3% of the game sprinting (~21–23 km/hr; Ali & Farrally, 1991). The protocol was administered in standardized 15-min blocks, each consisting of six walking intervals, six jogging intervals, three running intervals, and eight sprints. The mean time spent during each interval, including speed transitions, was 72 s walking, 42 s jogging, 17 s running, and 13 s sprinting. A 95-s standing period was incorporated into the protocol at the end of each 15-min block to allow for blood sampling during the experimental trials. During the familiarization trial, the speeds of the running and sprinting intervals were adjusted on a participant-to-participant basis and were kept constant for all subsequent trials.

To assess exercise performance, a repeated-sprint test was performed during the sixth 15-min section of the protocol. Therefore, the 90-min high-intensity intermittent exercise protocol consisted of five identical 15-min sections (with a 15-min break after the third section to simulate halftime of a soccer match) plus a repeated-sprint test during the final 15 min. The repeated-sprint test consisted of five 1-min sprints with 2.5 min of recovery between sprints. Each sprint started at individual Vmax, and the participant was allowed to adjust the speed of the treadmill by verbally instructing a researcher to increase or decrease the speed. The participants were kept blind to the speed and distance during the sprints but were allowed to see the elapsed time. A researcher informed the participant after 15, 30, 45, and 50 s and counted down the last 5 s of each sprint. The treadmill was stopped at the end of each sprint, and the participant stood still for 15 s and then walked at 5 km/hr for 2.5 min before the speed was increased again for the next sprint. Pilot testing indicated that participants were generally able to complete 1-min sprints at a speed slightly above their Vmax, making individual Vmax an ideal speed for standardizing the start of the sprints. Performance was determined by the distance covered over the five sprints. This performance test was designed to mimic the approximate proportion of time soccer players spend at higher intensities. Soccer players spend approximately one third of a match at higher intensity exercise, either jogging, running, or sprinting (Ali & Farrally, 1991). We therefore chose five 1-min bouts (5 min total) during the final 15 min to represent the proportion of time that players may spend at a higher intensity.

Experimental Protocol

On testing days, participants reported to the laboratory in the morning after an overnight (210-hr) fast. On arrival at the laboratory, a baseline fingertip capillary blood sample was taken to determine blood glucose (Accu-check Compact Plus, Roche Diagnostics, Mannheim, Germany) and blood lactate (Accutrend Lactate, Roche Diagnostics, Mannheim, Germany). Participants then had 20 min to consume one of the test meals. Capillary blood samples were obtained 15, 30, 60, and 120 min after completion of the meal. Exactly 120 min after participants had completed the meal, a venous blood sample was obtained by venipuncture and then the high-intensity intermittent protocol began. Expired-gas samples for determination of VO₂, carbon dioxide output (VCO₂), and the respiratory-exchange ratio (the ratio between VCO₂ and VO₂) were collected for 7-min periods from the third to the tenth minute of the first, third, and fifth 15-min sections (i.e., during Minutes 3–10, 33–40, and 63–70). The rates of carbohydrate and fat oxidation were estimated using published equations that are adapted for high-intensity exercise (Jeukendrup & Wallis, 2005). The propensity for indwelling venous catheters to become dislodged during high-intensity running required blood to be collected by venipuncture during exercise. Therefore, blood samples...
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Capillary blood samples were taken at the same time points as the venous blood samples, and an additional sample was taken at the end of the fifth 15-min block. Muscle biopsy samples were obtained at the end of the fifth 15-min block (i.e., immediately before the repeated-sprint test). Water was provided ad libitum during the standing periods at the end of every 15-min section in the first trial and was matched on subsequent trials. Ratings of perceived exertion (RPE) were obtained at the end of each 15-min section (6–20 scale; Borg, 1975).

Postprandial digestive symptoms of hunger, fullness, nausea, bloating, and abdominal cramping were assessed using a 5-point symptom-rating scale (0 = no symptoms to 4 = severe symptoms) at six time points (–120, –105, –60, 0, 45, and 90 min, where –120 min represents when meals are consumed before the start of exercise, which is Time 0).

Venous Blood Sample Collection and Analysis

Whole blood was collected into 10-ml tubes (BD Vacutainer SST) and processed according to manufacturers’ instructions. Serum insulin (Insulin EIA, Alpco Diagnostics, Salem, NH, USA), epinephrine and norepinephrine (BA 10–1500, Rocky Mountain Diagnostics, Colorado Springs, CO, USA), and free fatty acids (FFAs; NEFA HR[2], Wako Diagnostics, Richmond, VA, USA) were measured using a Biotek Synergy HT microplate reader with Gen5 software (Biotek Instruments, Winooski, VT, USA). The intra-assay coefficients of variation for the insulin, epinephrine, norepinephrine, and FFA assays were all ≤10%.

Muscle Biopsy Sampling and Analyses

Skeletal-muscle samples were obtained under local anesthetic (1% lidocaine) from the vastus lateralis using the percutaneous needle-biopsy technique adapted for suction (Evans, Phinney, & Young, 1982) and stored at –80 °C. Freeze-dried, powdered muscle samples (~2 mg) were hydrolyzed by heating for 2 hr at 100 °C in 500-μl 2.0-mol/L HCl. The sample was neutralized with an equal volume of 2.0-mol/L NaOH, and muscle glycogen was determined as previously described (Passonneau & Lowry, 1993).

Dietary and Physical Activity Controls

To minimize any potential diet-induced variability in resting muscle substrates or exercise metabolism, participants were asked to complete a 24-hr diet record before the first experimental trial. A trained nutrition researcher reviewed records with each participant to ensure accuracy. Diet records were photocopied and returned to participants, and they were instructed to consume the same types and quantities of food during the 24 hr before each experimental trial. Compliance was verified when participants arrived at the laboratory on each testing day.

To limit any potential effects of prior physical activity on exercise metabolism or performance, participants were asked to refrain from strenuous physical activity on the day before each trial, and this was confirmed through physical activity records.

Statistics

Repeated-sprint performance (total distance covered over five sprints) and muscle glycogen concentration were analyzed using a one-factor (meal condition) repeated-measures ANOVA. Capillary blood glucose and lactate concentration, VO2, heart rate, RPE, serum measures, and expired-gas parameters were all analyzed by two-factor (Meal Condition × Time) repeated-measures ANOVAs. The significance level was set at $p \leq .05$. Bonferroni post hoc tests were used when significance was found. All results are reported as $M \pm SD$, except on graphs, where results are presented as $M \pm SEM$ for clarity. Analyses were carried out with Statistica version 7.0 (StatSoft Inc., Tulsa, OK).

Results

Exercise Performance

There was a significant effect of meal condition for total distance covered over five sprints ($p < .01$, Figure 1). The distance covered was significantly greater in low GI ($p = .01$) and high GI ($p = .04$) than in control.

Expired-Gas Analyses

Mean VO2 was ~63% VO2peak during the soccer-match simulation, with no differences between conditions ($p = .475$, data not shown). Respiratory-exchange ratio was

![Image](image.png)

Figure 1 — Distance covered on all five sprints of the repeated-sprint test, $M \pm SEM$, $N = 13$. GI = glycemic index. *Significantly greater than control ($p < .05$).
not different between conditions \((p = .29, \text{Figure 2[A]})\). There was a lower rate of fat oxidation in the high-GI condition than in the control for Collection Period 2 \((p = .005\) and a lower rate of fat oxidation in the low-GI condition than in the control for Collection Period 3 \((p = .01, \text{Figure 2[B]})\). For respiratory-exchange ratio, rate of fat oxidation, and rate of carbohydrate oxidation, there were main effects of time \((all \ p < .001, \text{Figure 2[A–C]})\), indicating that fat oxidation increased and carbohydrate oxidation decreased throughout exercise, as would be expected.

**Capillary-Blood Analyses**

Blood glucose rose immediately after the high-GI meal such that it was greater than low-GI and control at 15, 30, and 60 min after meal consumption \((\text{Meal Condition} \times \text{Time interaction}, p < .001, \text{Figure 3})\). There were no differences between conditions for blood glucose at any other time points.

There were no differences between meal conditions for blood lactate concentration at rest or during exercise. There was a time main effect \((p < .001\) such that blood lactate was significantly higher after the repeated-sprint test than all other time points, as would be expected (data not shown).

**Serum Measures**

Serum insulin concentration was significantly lower in the fasted control condition than with either low or high GI \((\text{main effect of meal condition}, p < .001, \text{Figure 4[A]})\). The concentration of serum FFA was significantly higher in the fasted control condition than in all other meal conditions \((\text{main effect of meal condition}, p < .001, \text{Figure 4[B]})\). There was a significant Meal Condition \(\times\) Time interaction for serum catecholamines \((p < .05, \text{Figure 4[C]})\). Serum catecholamine concentration was significantly greater at the end of exercise in high GI than in fasted control.

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**Figure 2** — (A) Respiratory-exchange ratio (RER), (B) rate of fat oxidation, and (C) rate of carbohydrate oxidation during expired-gas Collection Periods 1 (3–10 min), 2 (33–40 min), and 3 (63–70 min) of high-intensity intermittent exercise, \(M \pm SEM, N = 13\). *High glycemic index (GI) significantly different from control \((p < .05\). †Low GI significantly different from control \((p < .05\).

**Figure 3** — Blood glucose concentration at baseline \((-140 \text{ min})\), during the postprandial period \((-105 \text{ to } 0 \text{ min})\), and throughout exercise \((0–105 \text{ min})\), \(M \pm SEM, N = 13\). *High glycemic index (GI) significantly greater than low GI and control \((p < .001\).
Muscle Glycogen

Muscle glycogen availability was significantly greater before the repeated-sprint test in both the low-GI and high-GI condition than in fasted control ($p = .04$, Figure 5), with no other differences between conditions.

RPE

RPE during exercise was significantly lower in the low-GI condition (13.0 ± 1.6) than in fasted control (13.9 ± 1.2; meal condition main effect, $p = .01$). As expected, there was a significant time main effect ($p < .001$), with RPE increasing throughout the course of exercise (data not shown).

Digestive Symptoms

Perceived fullness was greater ($p < .05$) and perceived hunger was lower ($p < .05$) throughout the entire postprandial period in both meal conditions than in fasting, but there were no significant differences between meal conditions (data not shown). No differences in other digestive symptoms were noted between the meal conditions during the exercise period ($p > .05$, data not shown). Preexercise meal consumption did not differ between the experimental conditions ($p > .05$).

Discussion

The main finding from the current study was that low- and high-GI preexercise meals improved sprint performance over a fasted control condition in the last 15 min of a 90-min high-intensity intermittent running protocol.

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**Figure 4** — (A) Serum insulin, (B) free fatty acid, and (C) epinephrine plus norepinephrine concentration throughout high-intensity intermittent exercise, $M \pm SEM, N = 13$. *Control significantly different from low glycemic index (GI) and high GI (main effect of meal condition, $p < .05$). #High GI significantly greater than control at this time point (Meal Condition $\times$ Time interaction, $p < .05$).

**Figure 5** — Muscle glycogen concentration after 75 min of high-intensity intermittent exercise, $M \pm SEM, n = 5$. $dw =$ dry weight; GI = glycemic index. *Significantly greater than control ($p < .05$).
Muscle glycogen content was greater in the low-GI and high-GI conditions than in the fasted control immediately before the repeated-sprint test, indicating that increased muscle glycogen availability in the low-GI and high-GI conditions probably contributed to the improved sprinting performance. Our study is unique because it is the first to assess the effect of low- and high-GI meals given shortly before prolonged, high-intensity intermittent exercise, which is characteristic of many team sports. It is also the first study to show that glycogen availability along with performance is enhanced after preexercise low- and high-GI meals. Although serum insulin was lower and FFAs higher in the fasted control condition, overall there were no significant differences in circulating hormones, glucose, and fatty acids or substrate oxidation during high-intensity intermittent exercise between the low-GI and high-GI preexercise meal conditions. RPEs were lower in the low-GI condition than with fasting, providing some evidence that exercise may have felt easier when a low-GI preexercise meal had been consumed. Erith et al. (2006) also found that the GI of carbohydrate did not affect high-intensity intermittent exercise performance; however, they gave high- and low-GI diets after exhaustive exercise and then evaluated intermittent exercise performance after an overnight fast.

Muscle glycogen depletion is a key factor contributing to fatigue during high-intensity exercise (Foskett, Williams, Boobis, & Tsintzas, 2008; Maughan & Poole, 1981; Nicholas, Tsintzas, Boobis, & Williams, 1999). This has particular relevance to soccer, in which players with lower levels of muscle glycogen perform less high-speed running and cover less distance, especially during the critical last 15 min of the match (Saltin, 1973). Increased muscle glycogen availability probably contributed to the improved sprint performance in the low- and high-GI conditions over fasting in the current study, but there appeared to be no differences in sprint performance between the two conditions. Previous research involving continuous, moderate-intensity exercise demonstrates that increased fat oxidation during exercise after low-GI meals may decrease the reliance on muscle glycogen (Wee et al., 2005). This did not appear to be a dominant mechanism for sparing of muscle glycogen in the current study because there were no significant differences in substrate oxidation between the low-GI and high-GI trials, and, if anything, fat oxidation was slightly decreased in both meal conditions compared with fasting (Figure 2[B]). Therefore, it appears that providing a carbohydrate-rich preexercise meal, irrespective of its GI, provides exogenous carbohydrates that can be used during subsequent exercise. This extra carbohydrate may help preserve muscle glycogen for the later stages of exercise and thereby contribute to the improved ability to fuel high-intensity sprint running.

We did not determine the effect of the meal ingestion before exercise on liver glycogen levels, but preservation of liver glycogen may also have improved performance. Stevenson et al. (2009) had participants perform 90 min of cycling at 70% VO₂peak, followed by 12 hr of a high- or low-GI diet, an overnight fast, and the same exercise the following day. Magnetic resonance imaging indicated no differences between the conditions for muscle or liver glycogen depletion during the next day’s exercise session; however, those meal conditions were not compared with a fasting condition as in our study.

It is possible that there are differences in the mechanisms of the relative muscle glycogen preservation between low- and high-GI meals. The rapid digestion of high-GI meals may acutely increase liver and muscle glycogen (Wee et al., 2005), whereas ongoing digestion and absorption of carbohydrate after slower digestion of the low GI-meal may have provided glucose for exercising skeletal muscle or allowed for muscle glycogen resynthesis during the rest and recovery periods of intermittent exercise (Nicholas et al., 1999). Testing these hypotheses would require multiple muscle biopsies and the use of traceable low- and high-GI foods to determine the relative contribution of endogenous and exogenous carbohydrate sources.

Previous studies that have reported improved endurance performance after low-GI preexercise meals have noted that low-GI meals tend to result in higher blood glucose concentrations in the late stages of exercise and have attributed the performance enhancement largely to prevention of hypoglycemia (DeMarco et al., 1999; Kirwan et al., 2001; Thomas et al., 1991). We did not see any differences in blood glucose concentration between meal conditions during exercise. This is likely a function of the high intensity and more pronounced catecholamine response. Note that the high-GI meal resulted in a greater catecholamine response at the end of exercise. This may suggest that a greater stimulus was required to promote hepatic glycogenolysis and preserve blood glucose concentration when high-GI preexercise meals are consumed (Galbo, Holst, & Christensen, 1979).

In the current study, there were only minor differences in fat oxidation during exercise and no significant differences between low- and high-GI meals. Therefore, somewhat contrary to continuous, moderate-intensity exercise (Febbraio et al., 2000; Stevenson et al., 2006; Wee et al., 1999; Wee et al., 2005; Wu & Williams, 2006), high-GI carbohydrate ingestion may not have a substantial influence on substrate oxidation during prolonged, high-intensity intermittent exercise. Estimating carbohydrate and fat oxidation from expired-gas analyses requires steady-state conditions and therefore may not be appropriate during higher intensity exercise above the ventilatory threshold. However, we collected expired gas over a 7-min period that included both low- and high-intensity exercise. It has been demonstrated that longer collection periods during high-intensity intermittent exercise can produce valid results (Bangsbo, Norregaard, & Thorsoe, 1992). The validity of our results is supported by the expected reduction in carbohydrate oxidation and increase in fat oxidation across time during exercise (Figure 2[B] and [C]). Therefore, it appears that the GI of a preexercise meal has little influence on substrate oxidation during high-intensity intermittent exercise.
Suppression of adipose-tissue lipolysis and the resultant decrease in circulating FFA levels have been hypothesized to contribute to the decrease in fat oxidation after high-GI preexercise meals (Thomas et al., 1991; Wee et al., 2005). FFA concentration was elevated and insulin concentration reduced at all time points in the fasted condition compared with both meal conditions, yet there were no differences between low and high GI. The failure of the high-GI meal to alter insulin or FFA during exercise compared with the low-GI meal likely precluded any influence on substrate oxidation in the current study. In addition, recent research has highlighted the impact of the GI on intramyocellular lipid (IMCL) storage and utilization (Trenell, Stevenson, Stockmann, & Brand-Miller, 2008). High-GI diets appear to blunt FFA oxidation yet increase IMCL utilization during continuous, moderate-intensity exercise (Trenell et al., 2008). Therefore, the substrate for fat oxidation (i.e., FFA vs. IMCL) may be different between low and high GI despite a lack of differences in the overall rate of fat oxidation. Therefore it is possible that enhanced IMCL oxidation after high-GI meals could offset any detriment in FFA utilization. Future research is required to determine the influence of the GI on IMCL metabolism during high-intensity intermittent exercise.

A potentially interesting finding in the current investigation was the lower RPE in the low-GI condition than the fasted control. This implies that exercise felt easier when a low-GI meal had been consumed before high-intensity, intermittent exercise. Because there were no distinct differences between low- and high-GI meals, it is unclear why RPE was only affected in the low-GI trial. This may be related to the greater catecholamine response during the high-GI condition, which could be acting as a signal to increase hepatic glucose production in the face of lower endogenous carbohydrate stores (Galbo et al., 1979; Weltan, Bosch, Dennis, & Noakes, 1998). These findings may highlight a potential benefit of low-GI preexercise meals.

It must be noted that we did not provide exogenous carbohydrates during exercise in the current study. Burke, Claassen, et al. (1998) reported that differences in substrate oxidation during continuous, moderate-intensity cycling between fasting and low-GI and high-GI preexercise meals were negated when exogenous carbohydrates were provided during exercise. It has been argued that preexercise meal consumption is particularly important for team-sport athletes because the opportunity for regular carbohydrate consumption is limited during the match (Williams & Serratosa, 2006). Therefore, we chose not to provide exogenous carbohydrates during intermittent-exercise trials in this study. However, findings may have been different if we provided a carbohydrate solution for participants to consume during exercise (Burke, Claassen, et al., 1998).

It also must be noted that although participants were not aware of the hypotheses of the study, they were not blinded to meal conditions. It is likely that athletes would be aware that consuming carbohydrates before high-intensity exercise would improve performance over fasting, and therefore the improved performance in both meal conditions may have been attributable to psychological factors. However, the greater muscle glycogen availability before the repeated-sprint test in the low- and high-GI conditions suggests that muscle factors were also at play.

Our study used an intermittent running protocol that was designed to simulate the running pattern during a soccer match (Drust et al., 2000). We recognize that it is difficult to accurately simulate the exact pattern common to soccer and that other recently developed testing protocols, which include soccer-specific skills (i.e., dribbling, heading, agility, and shooting), may be more appropriate (Currell, Conway, & Jeukendrup, 2009).

Conclusion

The current study demonstrates that both low-GI and high-GI preexercise meals benefit prolonged, high-intensity intermittent running performance, probably by increasing muscle glycogen availability for the late stages of exercise. This occurred in participants who were not blinded to the treatment and who did not ingest carbohydrate during the exercise. In contrast to previous research examining continuous, moderate-intensity exercise, the GI of a preexercise meal does not appear to have a large influence on metabolism or substrate oxidation during high-intensity intermittent exercise. Therefore, from a practical perspective, soccer players and other team-sport athletes may be well advised to consume a pregame carbohydrate-rich meal to their liking that is either low or high GI.

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References


