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The Effect of High Carbohydrate Meals with Different Glycemic Indices on Recovery of Performance During Prolonged Intermittent High-Intensity Shuttle Running

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This study examined the effect of high carbohydrate meals with different glycemic indices (GI) on recovery of performance during prolonged intermittent high-intensity shuttle running. Seven male semi-professional soccer players (age 23 ± 2 y, body mass [BM] 73.7 ± 9.0 kg and maximal oxygen uptake 58 ± 1.0 mL · kg⁻¹ · min⁻¹) participated in two trials in a randomized cross-over design. On day 1, the subjects performed 90 min of an intermittent high-intensity shuttle running protocol [Loughborough Intermittent Shuttle Test (LIST)]. They then consumed a mixed high carbohydrate recovery diet (8 g/kg BM) consisting of either high (HGI) (GI: 70) or low (LGI) (GI: 35) GI foods. Twenty-two hours later (day 2) the subjects completed 75 min of the LIST (part A) followed by alternate sprinting and jogging to fatigue (part B). No differences were found between trials in time to fatigue (HGI 25.3 ± 4.0 min vs. LGI 22.9 ± 5.6 min, $P = 0.649$). Similarly, no differences were found between trials for sprint performance and distance covered during part B of the LIST. In conclusion, the GI of the diet during the 22 h recovery did not affect sprint and endurance performance the following day.

Key Words: glycemic index, recovery, intermittent exercise, fatigue

It is well established that consuming a high carbohydrate (CHO) diet during the recovery period following prolonged exercise increases the rate of muscle glycogen resynthesis compared to a normal mixed diet (6). Furthermore, endurance capacity during prolonged constant paced running (10) and during prolonged intermittent high-intensity shuttle running is improved the day after prolonged exercise with high CHO recovery diets (9 to 10 g/kg BM) (16). Therefore it is common practice

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in many team sports to consume high CHO diets particularly during periods when training or competitive matches are being performed on consecutive days.

However, while the benefits of high CHO recovery diets are clearly recognized little attention has been given to the possible influences of the different types of carbohydrates on subsequent performance. Carbohydrates can be classified according to their postprandial glycemic response (13) and this criteria has been used to classify a large selection of foods (11). High glycemic CHO (HGI) foods are characterized by a rapid increase in blood glucose and accompanying rise in insulin concentrations. Glycogen storage is influenced both by insulin and an available supply of glucose as substrate. Therefore, CHO foods with moderate-to-high glycemic index (GI) would be expected to enhance post-exercise refueling of the body's limited CHO stores. Indeed, a study by Burke and colleagues reported greater muscle glycogen concentrations 24 h after prolonged cycling when subjects consumed a HGI rather than a LGI CHO diet (5). However, the authors did not appear to have assessed exercise performance following the HGI and LGI recovery diets.

Therefore, Stevenson and colleagues conducted a study to examine the influences of high and low GI diets on endurance running capacity after a recovery of 24 h (23). Their subjects ran longer on the LGI recovery diet than they did on the HGI recovery diet. Furthermore, the rate of fatty acid oxidation was also greater during exercise after the LGI than after the HGI recovery diet. This study used constant pace treadmill running and so contributes to the limited literature on carbohydrate diets and endurance running capacity. Nevertheless, there is a dearth of literature on the possible influences of HGI and LGI recovery diets on subsequent exercise capacity during intermittent high-intensity running. Therefore, the purpose of the present study was to examine the effect of high CHO meals with different GI values on 22 h recovery from prolonged intermittent high-intensity shuttle running.

Methods

Participants

Seven male semi-professional soccer players participated in this study. Their mean (\pm standard error of the mean) age, body mass (BM), and maximal oxygen uptake values were 23 ± 2 y, 73.7 ± 9 kg, and 58 ± 0.8 mL \cdot kg⁻¹ \cdot min⁻¹ respectively. The study had approval from the Loughborough University Ethical Advisory Committee and all subjects gave informed written consent before the study began.

Preliminary Measures

The subjects reported to the laboratory 7 to 10 d prior to their first main trial to complete a Progressive Multistage Shuttle Running Test (20) to estimate their maximal oxygen uptake (VO_{2max}). Thereafter, the subjects completed a 45 min familiarization with the Loughborough Intermittent Shuttle Test (LIST) (17).

Experimental Design

Each subject participated in two experimental trials separated by at least 7 to 10 d. Each main trial was completed over a 2-d period. During the 2 d immediately

prior to the first main trial subjects recorded their food intake so that they could consume the same diet prior to the second main trial. Furthermore, they were asked not to drink alcohol or caffeine-containing beverages nor perform strenuous exercise during the 2 d before the main trials. On the morning of each main trial the subjects arrived at the laboratory in a fasted state where they provided a urine sample and then their nude body mass was obtained using a beam balance (model 3306, Avery, Birmingham, UK). A cannula (Venflon 18G, Becton-Dickinson Ltd., Helsingborg, Sweden) was then inserted into an antecubital forearm vein and connected to a 3-way tap (Becton-Dickinson) with a 10 cm extension tube for blood sampling. Heart rates were recorded using a short-range telemetry system (Polar Electro, Kempele, Finland).

On day 1 the subjects performed 90 min of an intermittent high-intensity shuttle running protocol (R1) (LIST) (17). The LIST protocol involves shuttle running between two lines 20 m apart at speeds that are based on the estimated VO_{2max} of the subjects, i.e. 55% and 95% VO_{2max} . The running speed between the two lines was dictated by a computer-generated audio signal. The 90 min LIST was divided into 6×15 min blocks of activity that were separated by 3 min rest periods. Each 15 min block involved periods of walking (1.5 m/s) jogging (55% VO_{2max}) and running (95% VO_{2max}) as well as maximal sprints. The time taken to complete each 15 min sprint was measured using infra-red photo-electric cells (R.S. Components, Switzerland) interfaced with computer software. Each activity was repeated approximately 11 times in each 15 min block of the LIST (17). Following R1 they were given a diet that provided 8 g CHO/kg BM for the 22 h recovery. Meals and snacks were composed of either high (HGI) or low (LGI) GI carbohydrates in a randomized cross-over design (Table 1). On day 2, subjects returned to the laboratory, again in a fasting state and performed 5×15 min of the LIST (R2 –part A). This was followed by the following pattern of activity: two jogs (55% VO_{2max}), one walk and one maximal sprint that were continued to the point of fatigue (R2–part B). Volitional fatigue was defined as the inability of the subjects to maintain the required pace or maintain consecutive sprints at times that were no less than 95% of their mean times in blocks 2 and 3 of the LIST during R2–part A.

On all occasions subjects were given 5 mL/kg BM of water before exercise and 2 mL/kg BM every 15 min during the 3 min rest periods.

Test Meals

Isocaloric recovery meals consisting of HGI or LGI CHO foods, as calculated by the method of Wolever et al. (26), were provided for each subject after R1 (Table 1). Breakfast was consumed 30 min following the completion of R1 and lunch was provided 3 h later. Both of these meals were prepared and consumed in the laboratory. Subjects were then provided with two snacks and an evening meal that was later consumed at home. Participants were asked to eat one snack between lunch and the evening meal (7 PM) and were required to eat the final snack between 8 and 9 PM. The diets were composed of predominantly HGI or LGI carbohydrates; however, other foods (e.g., milk, cheese, and lettuce) were included in both diets to make the meals more palatable. The amount of CHO in each of the two diets was calculated as available carbohydrates. Both diets consisted of 72% CHO, 11% fat, and 17% protein. The nutritional content of each meal was calculated from

Table 1 Characteristics of Test Meals (for a 70 kg subject)

Meal	Description	Macronutrient content
HGI breakfast	62 g corn flakes ^a + 257 mL skim milk	730 kcal
	80 g white bread + 10 g flora + 20 g jam	139 g CHO, 9.9 g fat
	155 mL Lucozade Original ^a	20 g protein
LGI breakfast	86 g muesli + 257 mL skim milk	732 kcal
	67 g apple, 103 g canned peaches	139 g CHO, 9g fat
	128 g yogurt, 257 mL apple juice	23 g protein
HGI lunch	158 g white bread, 154 g turkey breast	1076 kcal
	50 g cheese, 40 g lettuce, 180 g banana	148 g CHO, 24g fat
	200 mL Lucozade Original ^a	63 g protein
LGI lunch	154 g whole wheat pasta, 150 g turkey breast,	1075 kcal
	50 g cheese, 40 g lettuce	149 g CHO, 25 g fat
	185 g pasta sauce, 150 g pear 150 mL apple juice	60 g protein
GI dinner	255 g baked potato	1100 kcal
	410 g canned spaghetti	176 g CHO, 31 g fat
	50 g cheese, 40 g lettuce, 67 g Mars bar 170 mL Lucozade Original ^a	28 g protein
LGI dinner	360 g chili beans, 200 g wheat tortilla	1100 kcal
	50 g cheese, 40 g lettuce	176 g CHO, 29 g fat
	260 mL orange juice	39 g protein
HGI snacks	154 g white bread, 40 g jam, 20 g flora	600 kcal
		96 g CHO, 17 g fat
		15 g protein
LGI snacks	170 g yogurt, 100 g apple, 100 g flapjack	625 kcal
		97 g CHO, 25 g fat
		15 g protein
HGI total		3520 kcal. 560 g CHO
		84 g fat, 126 g protein
		(72% CHO, 11% fat, 17% protein)
		GI = 70^b
LGI total		3600 kcal. 560 g CHO
		88 g fat, 135 g protein
		(72% CHO, 11% fat 17% protein)
		GI = 35^b

Note. ^aCorn Flakes: Kellogg's (UK) Ltd. Manchester UK; Lucozade Original drink: GlaxoSmithKline (UK). ^bGI calculated by previously described method (Wolever et al., 1986) with GI values taken from Foster-Powell and co-workers (2002).

the information provided by the manufacturer. The GI of the total mixed diets was calculated from the weighted means of the GI values for the component foods (26). The calculated GI for the HGI and LGI diets was 70 and 35, respectively.

Sample Collection and Analysis

Participants were asked to remain standing for all blood samples. At each sampling point, 11 mL of blood was collected and 5 mL of whole blood was immediately dispensed into an EDTA tube. Hemoglobin (Hb) concentration was determined on duplicate 20 μ l samples of whole blood using the cyanmethemoglobin method (Boehringer Mannheim, Mannheim, Germany). Hematocrit (Hct) values were determined in triplicate on samples of whole blood following microcentrifugation using a sliding micro-hematocrit reader (Gelman-Hawksley Ltd., Lancing, Sussex, UK). Changes in plasma volume were estimated using the method of Dill and Costill (8). Blood lactate concentration was determined fluorometrically using an enzymatic method (model 8-9, Locarte Co., London, UK) (15). Plasma samples were obtained by centrifugation of the remaining blood for a period of 10 min at 1700 \times G and 4 $^{\circ}$ C. The aliquoted plasma was then stored at -80° C for later analysis of free fatty acids (FFA) (ASC-ACOD method, Wako NEFA C, Wako Chemicals, Richmond, VA), glucose (GOD-PAP method, Randox, Co. Antrim, UK), and glycerol (Randox, Co. Antrim, UK) using an automatic photometric analyzer (Cobas-Mira plus, Roche, Basel, Switzerland). The remaining whole blood sample was dispensed into a tube containing a clotting activator and left to clot for 45 min. Serum samples were then obtained after centrifugation at 1700 \times G for 10 min at 4 $^{\circ}$ C. The aliquoted serum was stored at -80° C and later analyzed for insulin (Coat-A-count Diagnostica Products Corp., Caernavon, UK) by radioimmunoassay (RIA) using an automated gamma counter (Cobra 5000, Packard, Pangbourne, UK).

Statistical Procedures

An analysis of variance (ANOVA) with repeated measures on both factors (experimental treatment and time) was used to examine differences in the physiological and metabolic responses in R1 and R2—part A. However, due to variations in run times to exhaustion, a Student's paired *t*-test was used to analyze differences at the point of fatigue. The same analysis was carried out on all non-time dependant variables. Statistical significance was accepted at an alpha level of $P < 0.05$. All results are presented as means \pm standard error of the mean.

Results

Run Times

All subjects completed R1 and R2 but no differences were found in run times to exhaustion between trials during part B of R2 (HGI 25.3 ± 4.0 min vs. LGI 22.9 ± 5.6 min, $P = 0.649$). Neither were there differences between trials in the calculated fatigue index for sprint performance during part B of R2. Furthermore, no differences were found in the number of sprints attempted or the total distance covered during part B of R2 (HGI 43 ± 7 vs. LGI 39 ± 10 and HGI 3474 ± 531 m vs. LGI 3097 ± 793 m, respectively).

Plasma FFA and Glycerol

Plasma FFA and glycerol concentrations rose progressively during R1 ($P \leq 0.05$). Immediately post-exercise, FFA concentrations reached 0.54 ± 0.16 and 0.49 ± 0.07 mmol/L for HGI and LGI trials, respectively. During R2 there was a similar rise in plasma FFA (Figure 1) and glycerol concentrations; however, there were no differences between HGI and LGI trials (Figure 2).

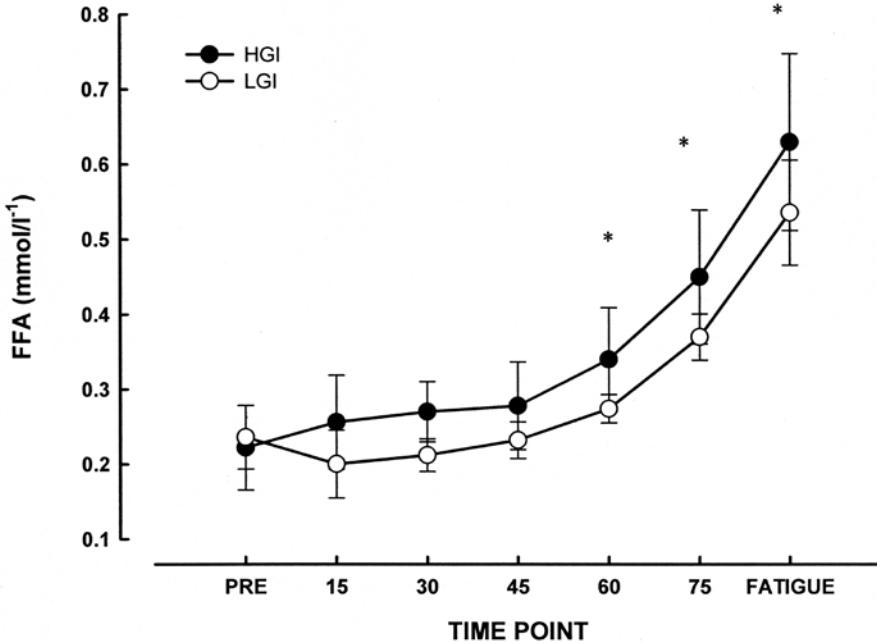


Figure 1 — Plasma FFA concentrations (mmol/L) during R2 in the HGI and LGI trials (mean \pm standard error of the mean). $P \leq 0.05$ * different from pre-exercise for both groups.

Plasma Glucose and Serum Insulin Responses

Plasma glucose concentrations rose during first 30 min of exercise in both R1 and R2 for both conditions and no differences were observed between trials. Plasma glucose concentrations were maintained within a range of 4 to 6 mmol/L throughout all runs. At the point of fatigue during part B of R2, plasma glucose concentrations were similar for both trials (5.01 ± 0.56 and 4.97 ± 0.57 mmol/L in the HGI and LGI trials, respectively) (Figure 3). Serum insulin concentrations decreased at the start of exercise from pre-exercise concentrations and continued to fall slowly throughout exercise in both trials (Figure 4) ($P \leq 0.05$).

Blood Lactate

During R1 and R2 there were no differences in blood lactate concentrations between trials (average concentrations during R1 were 2.6 ± 0.8 mmol/L in the HGI trial

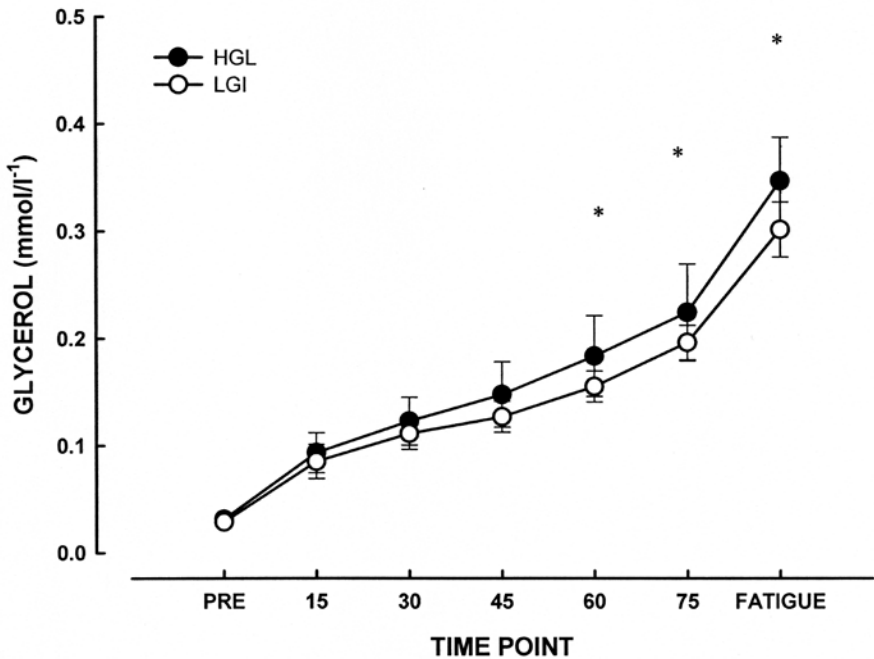


Figure 2 — Plasma glycerol concentrations (mmol/L) during R2 in the HGI and LGI trials (mean \pm standard error of the mean). $P \leq 0.05$ * different from pre-exercise for both groups.

and 2.6 ± 0.6 mmol/L in the LGI trial and average concentrations during R2 were 2.6 ± 0.2 mmol/L in the HGI trial and 2.1 ± 0.3 mmol/L in the LGI trial). However, blood lactate concentrations were higher during R2 part B compared with R2 part A in both trials (average concentrations during R2 part A were 2.6 ± 0.7 compared to R2 part B 3.6 ± 0.44 mmol/L, $P \leq 0.05$).

Heart Rate and Rating of Perceived Exertion (RPE)

Heart rate values were similar for both trials on day 1 and day 2 and were higher during part B of R2 in both trials compared to earlier in exercise ($P \leq 0.05$). Although there were no differences in RPE values between trials they were higher during part B than part A of the LIST ($P \leq 0.05$).

Hydration Status

There was no difference in pre-exercise body mass before each trial. At the end of R1 in both trials subjects lost approximately 1% of their pre-exercise body mass and a similar percentage change in body mass occurred during R2. There were no significant differences in pre-exercise urine osmolality values between trials (640 ± 243 and 684 ± 231 mL \cdot Osmol \cdot kg⁻¹ in the HGI and LGI trials, respectively).

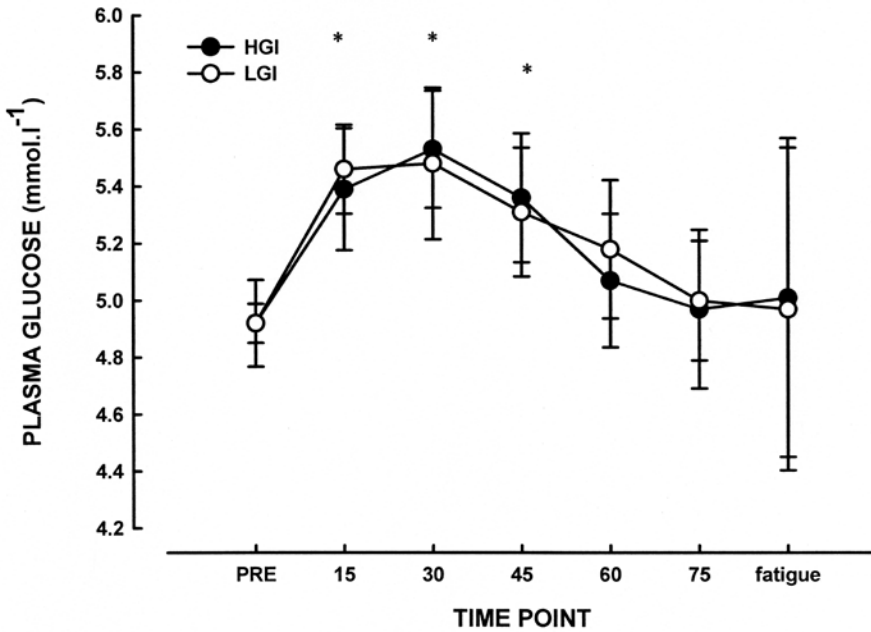


Figure 3 — Plasma glucose concentrations (mmol/L) during R2 in the HGI and LGI trials (mean \pm standard error of the mean). $P \leq 0.05$. * different from pre-exercise for both groups.

Environmental Conditions

There were no differences in ambient temperatures or relative humidity during each trial (HGI—day 1, 14.9 ± 2.2 °C, relative humidity $64.6 \pm 7.2\%$; HGI—day 2, 15.6 ± 1.0 °C, relative humidity $59.3 \pm 6.9\%$ compared to LGI—day 1, 14.8 ± 2.7 °C, relative humidity $62 \pm 8.4\%$, LGI—day 2, 14.6 ± 2.4 °C, relative humidity $59.9 \pm 7.8\%$).

Discussion

The main finding of the present study was that a HGI carbohydrate diet consumed during the 22 h recovery period following prolonged intermittent high-intensity shuttle running had no greater effect on sprint performance or endurance capacity the following day than a LGI carbohydrate recovery diet.

Prolonged intermittent high-intensity exercise relies heavily on muscle glycogen as a substrate for the sustained high rate of ATP resynthesis (2, 3, 12, 18, 19). During R2 part A of the LIST consisted of five 15 min periods of exercise that includes 11 sprints. Therefore the subjects in the present study completed 55 maximal sprints during the first 75 min and then an additional 43 and 39 sprints during part B of the LIST in the HGI and LGI trials, respectively. In an earlier study using the same intermittent exercise protocol we showed that when a high CHO recovery diet was consumed after performing the LIST to fatigue, endurance

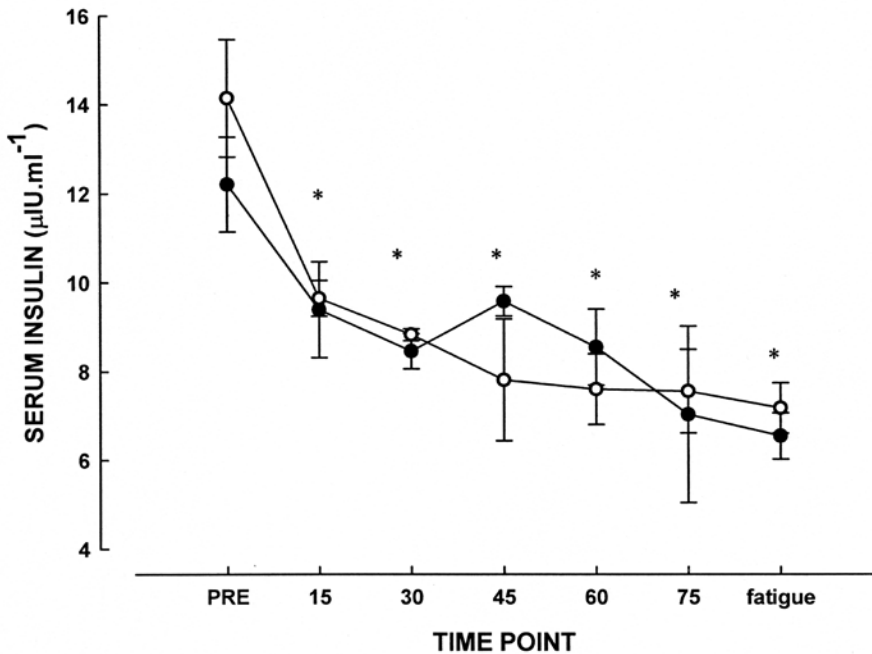


Figure 4 — Serum insulin concentrations ($\mu\text{IU}/\text{mL}$) during R2 in the HGI and LGI trials (mean \pm standard error of the mean). $P \leq 0.05$. * different from pre-exercise for both groups.

capacity was restored 22 h later whereas that was not the case after an isocaloric mixed diet (16). After the high CHO recovery diet the subjects ran for 3.3 min longer than they did on the mixed diet. In contrast, when the subjects consumed the isocaloric mixed diet that included their normal intake of CHO during the 22 h recovery, they ran for 2 min less than on the previous day (16). Therefore it is clear from this earlier study that a high CHO recovery diet improves recovery from prolonged intermittent high-intensity exercise.

Burke and colleagues reported that a HGI recovery diet resulted in a 48% greater muscle glycogen concentration 24 h after prolonged cycling than was achieved when their subjects consumed a LGI diet (5). However, they did not assess the exercise performance of their subjects following the 24 h recovery. Nevertheless, it would be reasonable to speculate that their subjects would have produced better performances after the HGI than after the LGI recovery diet because they would have started exercise with higher muscle glycogen stores (5). Therefore, it was surprising to find that there was no difference in performance after the HGI and LGI recovery diets in the present study.

In a previous study, we found a greater endurance capacity 22 h after prolonged treadmill running when runners consumed a LGI CHO recovery diet than when the diet was composed of HGI CHO (23). After completing a 90 min treadmill run at 70% $\text{VO}_{2\text{max}}$ the runners were randomly assigned to either the HGI or LGI recovery diet. After an overnight fast they returned to the laboratory and ran to exhaustion

at the same intensity as on the previous day. The mean run time to exhaustion after the LGI recovery diet was 12 min longer than after the HGI diet (108.9 vs. 96.9 min) (23). Even though runners probably began the second run with higher muscle glycogen stores after the HGI recovery diet (5, 23, 25) it is likely that they would have used more glycogen during the run than when they had consumed the LGI recovery diet (14). It is possible, though only speculation, that after an hour or so of running the muscle glycogen stores may have been similar following the two dietary conditions even though the rates of glycogenolysis were initially different. However, the greater rate of fat oxidation during the second run in the LGI trial may have been able to cover the energy production deficit as muscle glycogen concentrations decreased (27) more completely than in the HGI trial. A compensatory up-regulation of fat oxidation in skeletal muscle may have reduced the need for an increased contribution from blood glucose to cover energy production in the LGI trial but not in the HGI trial. The differences in the demand for an increased turnover of blood glucose towards the end of exercise may have contributed to the differences in the times to fatigue (7).

The lack of differences in sprint performance and endurance capacity in the present study after the LGI and HGI recovery diets is difficult to explain when it appears that the subjects on the HGI recovery diet probably began exercise with higher muscle glycogen concentrations. One explanation might be that following the HGI recovery diet the subjects began intermittent exercise using more CHO than fat because of its greater availability (21), whereas after the LGI recovery diet they used more fat and less CHO. The run-walk-sprint nature of part A of the LIST is conducive to fat metabolism during the low-intensity phase of each 15 min block of activity. Although the rates of glycogenolysis during part A of the LIST may have been different after the HGI and LGI recovery diets, the glycogen stores may have been reduced to similar values at the end of the 75 min of exercise. If this was the case then the subjects would have started part B with similar muscle glycogen concentrations and, as the results show, their run times to fatigue were also similar.

Another consideration is that this intermittent high-intensity shuttle running protocol produces significant post-exercise muscle soreness (24) because of the eccentric muscle contractions during the frequent changes in speed and direction. Extensive eccentric muscle contractions have been shown to decrease the rate of glycogen resynthesis (9) and lead to an increased rate of glycogen utilization during subsequent exercise (1). If this were the case in the present study then it would be reasonable to expect poorer sprint performance and endurance capacity after the LGI recovery diet because the lower recovery rate of muscle glycogen resynthesis would have been exacerbated by the eccentric nature of the prior exercise, i.e., R1. However, the absence of a difference in sprint performance and endurance capacity between the two trials suggests that fatigue during part B may not have been entirely due to differences in pre-exercise glycogen concentrations.

Fatigue during part B may have been due in part to low muscle glycogen stores and the inability to resynthesize phosphocreatine (PCr) rapidly enough to maintain ATP turnover rate at the required level (4, 12). In addition, the accumulation of metabolites such as hydrogen ions, ADP, AMP, inorganic phosphate, and magnesium may have created a cellular environment that contributed to the inability of the working muscles to sustain energy production (22).

In summary, the main finding of this study was that the type of CHO (high or low GI) provided as part of a recovery diet did not influence performance during subsequent prolonged high-intensity intermittent shuttle running. Carbohydrate rather than fat would have been the main fuel during this high-intensity running protocol and therefore the potential benefit of a recovery diet that promotes fat oxidation during continuous running would have had little impact during this type of exercise.

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