Carbohydrate Intake and Recovery of Intermittent Running Capacity

Ceri W. Nicholas, Paul A. Green, Richard D. Hawkins, and Clyde Williams

The purpose of the present study was to examine the influence of an increased carbohydrate intake on the recovery of endurance running capacity after exhaustive intermittent running. Six male subjects were randomly assigned to two dietary recovery conditions, each involving two running tests separated by 22 hr. The protocol comprised a prolonged, intermittent, high-intensity shuttle run test (I–HI). One week later subjects repeated the I–HI on consecutive days under different dietary conditions. During the 22-hr recovery, either the carbohydrate intake of the subjects was increased (CHO) or they ate an isocaloric diet by supplementing their normal diet with extra protein and fat (CON). Intermittent running capacity was improved when subjects increased their carbohydrate intake to 10 g · kg\(^{-1}\) · bm during the 22-hr recovery between trials, but an isocaloric diet without additional carbohydrate did not bring about the same improvements.

Key Words: intermittent high-intensity running, carbohydrate metabolism, diet

The ability to sustain prolonged exercise at intensities ranging from 65 to 85\% \(\text{VO}_2\text{max}\) is related to the preexercise concentration of muscle glycogen (3, 11). Fatigue during such exercise is associated with depletion of the muscle's limited glycogen stores. The replenishment of muscle glycogen stores may take 24 hr or longer following intense, intermittent, exhaustive cycling exercise (15, 13, 21) and is dependent upon CHO intake postexercise (4, 7, 5, 12). However, replenishment of muscle glycogen may not guarantee a restoration of functional capacity.

Keizer et al. (13) reported that even though muscle glycogen concentration was restored during 22 hr of recovery, their subjects' maximal physical working capacity was reduced by 7\%. A high-CHO diet during a 22-hr recovery period was also ineffective in preventing the fall in peak power output during brief periods of treadmill sprinting (19). In contrast, Fallowfield and Williams (9) showed that submaximal endurance running was restored within 24 hr when CHO intake during recovery was increased to 8.8 g · kg\(^{-1}\) · bm · day\(^{-1}\).

Multiple-sprint sports such as soccer, hockey, and rugby involve short bouts of high-intensity exercise interspersed with longer periods of low-intensity exercise.

The authors are with the Department of Physical Education, Sports Science and Recreation Management, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK.
or rest. Relatively little information is available on the effect of dietary intervention during this type of activity (2, 19). However, several researchers have examined the influences of carbohydrate ingestion on sprint performance following prolonged submaximal and intermittent high-intensity cycling (10, 18, 17).

Therefore, the purpose of the present study was to investigate whether intermittent high-intensity running capacity could be restored within 22 hr following consumption of a diet containing additional energy, in the form of either carbohydrate or fat and protein.

Methods

Subjects

Six healthy male games players (age [mean ± SEM] 21.8 ± 0.7 years, height 174.4 ± 4.0 cm, body mass 70.5 ± 4.2 kg, maximal oxygen uptake 56.0 ± 0.9 ml·kg⁻¹·min⁻¹) volunteered and gave their informed consent to take part in this study. Each subject had at least 5 years playing experience in soccer, rugby, hockey, or basketball. Weekly training and playing time ranged from 5 to 8 hr.

Procedures

The 6 subjects attended the laboratory on four occasions. Four trials were performed under two dietary conditions: carbohydrate (CHO) and control (CON). For each condition, subjects completed two trials—Trials 1 and 2 (CHO) and Trials 1 and 2 (CON)—separated by 22 hr recovery. One week later, the two trials were repeated, 22 hr apart, under a different dietary condition. The experiment was a counterbalanced, crossover design, and the order of dietary condition, CHO or CON, was randomly assigned. The initial trial (T1) was undertaken without nutritional intervention in order to obtain an assessment of running capacity. Trial 2 was performed following dietary manipulation of either a carbohydrate (CHO) or control (CON) condition (Figure 1).

Maximal oxygen uptake (VO₂max) was estimated by means of a progressive 20-m shuttle run test (22), modified from the original protocol (14). From this estimate of VO₂max, running speeds corresponding to 55% and 95% of predicted VO₂max were calculated (22). Subjects were then familiarized with the intermittent, high-intensity, shuttle run test protocol (I–HI protocol) for 30 min to acquaint them with the required pace and activity pattern of the test.

For the 2 days prior to the first trial (T1 CHO and T1 CON) and during the 22-hr recovery periods, subjects were requested to abstain from training and from consuming alcohol. This eliminated the possible effects of exercise on muscle glycogen stores prior to the experimental trials. Subjects arrived in the laboratory in the morning following an overnight fast of approximately 10 hr. They then voided before nude body mass was measured. Nude body mass was recorded pre- and postexercise.

A standardized warm-up consisting of jogging, stretching, and striding was then performed by each subject for 20 min before starting the I–HI protocol.

The experimental protocol was conducted on a sprung wooden floor in a gymnasium. Subjects were required to perform continuous 20-m shuttles, identified by cones and floor markings, at various speeds related to estimated individual
maximal oxygen uptake (VO$_2$ max) values in 20-min and 30-min exercise blocks. The combination of running, sprinting, and walking speeds was designed to mimic the activity pattern typically recorded for soccer match play (23, 26). One exercise cycle consisted of the following activities and exercise intensities:

- $3 \times 20$ m at walking pace
- $1 \times 20$ m at maximal running speed
- $3 \times 20$ m at a running speed corresponding to 55% of individual VO$_2$ max
- $3 \times 20$ m at a running speed corresponding to 95% of individual VO$_2$ max

This exercise cycle was repeated for 20 min before a rest period of 2.5 min was introduced, during which time blood samples were collected. This pattern of intermittent exercise was continued for a further 20 min, followed by a 5-min rest period and then another 30 min intermittent exercise. Thus, the total fixed duration of exercise was 70 min (Figure 2).

Following the fixed period of I–HI exercise (Part A), subjects performed a shuttle run to fatigue (Part B). This consisted of running speeds alternating between 55% and 95% VO$_2$ max, repeated continuously until subjects could no longer maintain the required speed for two consecutive shuttles at the higher exercise intensity. This time to reach fatigue was recorded as a measure of their endurance capacity.

The running and walking speeds during each 20 m of the I–HI were dictated by an audio signal from a microcomputer (BBC Master Series) using software developed for this purpose. Sprint times were measured in one direction over the first 15 m by two infrared photoelectric cells (RS Components Ltd) interfaced with the microcomputer.

Heart rate was monitored by a short-range telemetry system (Sport Tester PE$_{2000}$) every 15 s during exercise, and the mean was recorded for each exercise block. Subjective ratings of perceived exertion (RPE) (6) were obtained after every
Figure 2 — Schematic illustration of the protocol and experimental design.
five completed exercise cycles during Part A. The mean values during each exercise block (0–20, 20–40, and 40–70 min of exercise) and at exhaustion were recorded. The temperature of the gymnasium was maintained at ≤20 °C by adjusting the thermostats on the radiators and by opening and closing doors and windows. Dry and wet bulb temperatures were recorded at 0, 20, 40, and 70 min of exercise and at exhaustion using a whirling hydrometer (Brannan Thermometers Ltd.), from which relative humidity was calculated. Water ingestion during each trial was allowed ad libitum. The total amount ingested for the duration of each trial was recorded and was accounted for when we calculated the subjects’ changes in body mass from their preexercise values. The subjects drank the same amounts at the corresponding times during the second trial.

Duplicate 20-μl capillary blood samples were obtained at rest from the thumb of a prewarmed hand and then during exercise after 20, 40, and 70 min and at exhaustion. At each sampling point, duplicate 20-μl samples were deproteinized in 200 μl of cooled 0.4 M perchloric acid and were mixed, centrifuged, and stored at −20 °C until analyzed for concentration of blood lactate and glucose (16).

Subjects weighed and recorded all food and drink consumed in their normal diets for 2 days prior to T1 under both dietary conditions. From these food diaries, the average daily energy intake (10.7 ± 0.7 MJ) and amount of carbohydrate ingested (5.4 g · kg⁻¹ bm) was recorded for each individual (Table 1). From this information, the amount of carbohydrate needed to increase each subject’s individual daily intake to 10 g · kg⁻¹ bm was calculated. For the 22-hr recovery period, subjects were prescribed a diet that either increased their carbohydrate intake (CHO condition) or increased their energy intake in the form of fat and protein (CON condition). The recovery diet was prescribed by a dietitian using a food exchange system, offering foods that were consistent with the subjects’ normal diets. Subjects weighed and recorded their food intakes over the 22-hr recovery period, and from these diaries, the energy intake and amount of carbohydrate consumed were calculated (Table 1).

Within 20 min of the termination of T1 under both dietary conditions, all subjects were provided with 1 g · kg⁻¹ bm of a 6.9% carbohydrate–electrolyte drink (Lucozade Sport, SmithKline Beecham) and breakfast. The energy content of the breakfast was similar for both conditions (603 kcal and 607 kcal for the CHO and CON conditions, respectively), but the carbohydrate content of the meal was higher in the CHO condition (122 g CHO) compared with CON (18 g CHO).

Table 1 Energy Content and Composition of the Normal and Recovery Diets

<table>
<thead>
<tr>
<th></th>
<th>Energy (MJ)</th>
<th>Energy (kcal)</th>
<th>CHO (g)</th>
<th>CHO (g · kg⁻¹ bm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SEM</td>
<td>M</td>
<td>SEM</td>
</tr>
<tr>
<td>Normal</td>
<td>10.7</td>
<td>0.7</td>
<td>2,601</td>
<td>157</td>
</tr>
<tr>
<td>Recovery (CHO)</td>
<td>15.6**</td>
<td>1.0</td>
<td>3,818**</td>
<td>230</td>
</tr>
<tr>
<td>Recovery (CON)</td>
<td>15.6**</td>
<td>1.0</td>
<td>3,818**</td>
<td>230</td>
</tr>
</tbody>
</table>

**p < .01; normal vs. recovery diet.
**Statistical Analyses**

Performance times and the physiological responses of subjects following dietary manipulation during trials were analyzed by means of a two-way analysis of variance (ANOVA) for repeated measures on two factors and Student's paired t test, where applicable. Where differences emerged, a post hoc Tukey test was used to identify where the differences occurred. Statistical significance was accepted at the \( p < .05 \) level. Values are reported as mean ± SEM.

**Results**

The run times during Part B in Trials 1 and 2 for both dietary conditions are presented in Figure 3. No differences were found between conditions for Trial 1 run time. Furthermore, no order effect was found for running times to exhaustion for the first and second trials. However, following the CHO recovery diet, subjects ran in Part B of the test for 3.3 ± 1.1 min longer during T2 than in T1 (\( P < .05 \)) and 7.4 min longer than their relative performance during T2 following the CON recovery diet (\( p < .01 \)). When the differences in performance times between T1 and T2 were compared across experimental conditions, subjects ran for 5.8 ± 1.7 min longer in the CHO trial (\( p < .05 \)). Therefore, not only was intermittent running capacity restored in the 22-hr recovery period, it was also improved. No such improvement was observed in the CON group.

During Part A, the distance covered was similar for all trials, ranging from 9,919 to 9,928 m. For the CHO trial, subjects covered a total distance of 13.2 km and

![Figure 3 - Running time (min) for Part B during the four intermittent exercise trials (*\( p < .05 \): CHO T2 vs. T1; CHO T2 vs. CON T2).*]
13.8 km for Trials 1 and 2, respectively (p < .05). In the CON trial, the total distance was 12.9 km for T1 and 12.4 km for T2 (NS). Thus, subjects ran a further 1.1 ± 0.3 km (p < .05) when the differences in performance times between T1 and T2 were compared between treatments.

Similar sprint times were recorded between trials and also within each trial over the 70 min (Table 2). However, there was a tendency for the fastest sprints to be recorded in the first 20 min of exercise.

Blood glucose concentrations remained within the normal range during all trials, namely between 4.4 mmol·L⁻¹ at rest and 4.8 mmol·L⁻¹ after 40 min. No differences were observed between trials or groups, although blood glucose concentration tended to be lower during T2 than T1, under both dietary conditions.

No differences in blood lactate concentrations were observed between experimental trials. The blood lactate concentration increased throughout exercise, rising from resting values of approximately 1 mmol·L⁻¹, to a peak of between 6 and 7 mmol·L⁻¹ at the end of exercise. The concentrations at the end of exercise were higher than resting values in all trials (p < .01) and after 20 and 40 min of exercise in T2 in both CHO (p < .01 and p < .05, respectively) and CON groups (p < .05).

Similar reductions in body mass of 2.2% (corrected for volume of fluid intake) were observed during all trials. Fluid ingestion during T1 and T2 (CHO) was 524 ± 85 ml and 536 ± 74 ml (NS), respectively. During the CON condition, fluid intakes of 520 ± 69 ml (T1) and 657 ± 97 ml (T2) were recorded (NS). Body mass was restored to T1 preexercise values during the 22-hr recovery.

No differences in heart rates were observed between trials or conditions. During the first 20 min of exercise, mean heart rate increased from resting values to between 150 and 155 b·min⁻¹ (p < .01) and were then maintained within a range of 3 b·min⁻¹ for the subsequent 20 and further 30 min of exercise during Part A of the I–HI for all trials. Heart rates increased during Part B (p < .01) during all trials, reaching a maximum of 179 b·min⁻¹ immediately prior to the end of exercise.

The total energy consumed and the carbohydrate intake during the 22-hr recovery period for both dietary conditions are shown in Table 1. In the CHO trial, a greater amount of carbohydrate was consumed during recovery compared with the normal dietary intake of carbohydrate in the CON trial (p < .01). The corresponding increases in energy consumed during the recovery periods were greater than the subjects’ normal food intake (p < .01).

**Table 2** Mean Sprint Times (s) for Each Exercise Period

<table>
<thead>
<tr>
<th>Trial</th>
<th>0–20</th>
<th>20–40</th>
<th>40–70</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SEM</td>
<td>M</td>
<td>SEM</td>
</tr>
<tr>
<td>CHO T1</td>
<td>2.50</td>
<td>0.05</td>
<td>2.51</td>
<td>0.07</td>
</tr>
<tr>
<td>CHO T2</td>
<td>2.52</td>
<td>0.06</td>
<td>2.59</td>
<td>0.08</td>
</tr>
<tr>
<td>CON T1</td>
<td>2.48</td>
<td>0.05</td>
<td>2.48</td>
<td>0.05</td>
</tr>
<tr>
<td>CON T2</td>
<td>2.55</td>
<td>0.07</td>
<td>2.56</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Discussion

The activity pattern used during the I–HI protocol is similar to that which occurs in multiple-sprint sports such as soccer, rugby, and hockey. Total running distance during the I–HI was between 12.4 km and 13.8 km, which is similar to the distance covered during professional soccer matches (23, 26, 1). Analysis of the relative time that elite soccer players spend performing a range of activities shows that walking and low-intensity running account for the greatest portion (40% and 35%, respectively), while standing still and high-intensity running account for 17% and 8% of total time, respectively (1). Sprints have been reported to average 15 m, repeated every 90 s (23). These patterns of activity were performed in similar proportions in the present study. Consequently, the observations made in this study have practical implications for games players.

The main finding of the present study was that a normal diet supplemented with carbohydrate to the order of 10 g·kg⁻¹·bm⁻¹·day⁻¹ improved endurance capacity during intermittent high-intensity running after a recovery of 22 hr. An equivalent return in exercise performance did not occur when subjects consumed an isocaloric diet containing their normal amount of CHO plus additional fat and protein during the same period of recovery.

The performance times were similar during Trial 1 for both experimental conditions; however, during CHO Trial 2, subjects were able to run 1.1 km farther than in CON Trial 2. This increase in running capacity is similar to the 0.7-km improvement in intermittent high-speed running by soccer players following the ingestion of a CHO-enriched diet for 2 days (2). The carbohydrate intake in this study over the 22-hr recovery period was 705 ± 42 g (10 g·kg⁻¹·bm⁻¹·day⁻¹) and 381 ± 23 g (5.4 g·kg⁻¹·bm⁻¹·day⁻¹) for the CHO and CON trials, respectively. Thus, the intake of 10 g·kg⁻¹·bm⁻¹·day⁻¹ of carbohydrate restored and enhanced intermittent running capacity, which endorses previous recommendations for a high-carbohydrate diet during short-term recovery (7, 13). These results also confirm and extend the findings of Fallowfield and Williams (9), who investigated the influence of an increased carbohydrate intake on endurance running capacity 22.5 hr following recovery from 90 min of prolonged treadmill running at 70%VO₂max. A high-carbohydrate diet (8.8 g·kg⁻¹·bm⁻¹·day⁻¹) restored endurance capacity, whereas exercise capacity was not restored following an isocaloric diet with additional energy provided in the form of fat and protein.

However, the improvement in performance in this study is in contrast to the findings of Kelizer et al. (13), who reported that although muscle glycogen levels were replenished to preexercise values following an increased carbohydrate intake, maximal physical working capacity was reduced by 7%, 22 hr after the cessation of exhaustive interval exercise. In addition, Sherman et al. (24, 25) reported that 7 days following marathon running, isokinetic strength was still lower compared with premarathon values, despite the restoration of normal muscle glycogen levels. Thus, the recovery of maximal physical performance following exhaustive exercise clearly depends on events in addition to muscle glycogen restoration.

Exercise capacity was clearly improved following the ingestion of additional carbohydrate during the 22-hr recovery period. In a previous study from our laboratory, in which the same exercise protocol was used, muscle glycogen was reduced by 61% (20). Although muscle glycogen concentrations were not measured in the present study, the available evidence suggests that the increased CHO intake over
the 22 hr between exercise trials resulted in higher muscle glycogen concentrations compared with the CON condition. It is possible that liver glycogen may have been increased to a greater extent compared with the CON condition. However, blood glucose concentrations were maintained within the normal range for the duration of each trial and were similar between trials and between dietary groups. Thus, hypoglycemia was not responsible for the onset of fatigue during prolonged intermittent exercise in the present study. Thus, the circumstantial evidence suggests that the delay in the onset of fatigue during Trial 2 after the increased CHO intake may have been due to the increased availability of muscle glycogen at the start of exercise.

In summary, increasing the carbohydrate intake of a normal diet to 10 g·kg\(^{-1}\)·day\(^{-1}\) improves intermittent high-intensity running capacity after 22 hr of recovery. This study confirms the need for increased CHO intake so that athletes participating in prolonged, intermittent high-intensity exercise can compete and train optimally on a daily basis.

References


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