Carbohydrates and physical/mental performance during intermittent exercise to fatigue

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ABSTRACT

WELSH, R. S., J. M. DAVIS, J. R. BURKE, and H. G. WILLIAMS. Carbohydrates and physical/mental performance during intermittent exercise to fatigue. Med. Sci. Sports Exerc., Vol. 34, No. 4, pp. 723–731, 2002. Purpose: This study was designed to examine the effects of carbohydrate-electrolyte ingestion on physical and mental function associated with the performance of intermittent high-intensity (IHI) exercise similar to many common competitive sporting events. Methods: Physically active men (N = 5) and women (N = 5), experienced in competitive soccer or basketball, completed three practice sessions and two experimental trials of an IHI shuttle running protocol designed to closely stimulate the demands of an actual competitive sporting event such as basketball. The experimental trials consisted of four 15-min quarters (QTR) of intermittent shuttle running at various percentages of VO2max (walking, jogging, running, sprinting and jumping), separated by a 20-min halftime rest period (HALF) and followed by a shuttle run to fatigue. Various tests of physical and mental function (shuttle run to fatigue, 20-m maximal sprint, 10-repetition maximal vertical jumping, whole body motor skill test (MS-Test), profile of mood states (POMS), and Stroop Color-Word Test) were performed throughout the experimental trial. Carbohydrate-electrolyte (CHO) or placebo (P) drinks were consumed before exercise (5 mL·kg−1; 6% solution) and at halftime (5 mL·kg−1; 6% solution). Smaller volumes (3 mL·kg−1; 6% solution) were given after QTR-1, HALF, QTR-3, and QTR-4. Results: CHO ingestion resulted in a 37% longer run time to fatigue and faster 20-m sprint time during QTR-4 (P < 0.05). MS-Test performance was also improved during the latter stages of exercise along with self-reported perceptions of fatigue (subscale of POMS) (P < 0.05) in CHO versus P. Conclusion: These results suggest a beneficial role of carbohydrate-electrolyte ingestion on physical and mental function during intermittent exercise similar to that of many competitive team sports. Key Words: INTERMITTENT HIGH-INTENSITY EXERCISE, SHUTTLE RUNNING, TEAM SPORTS, MOTOR SKILL, STROOP, POMS, GLUCOSE, FREE FATTY ACIDS, INSULIN

A common observation in many competitive sporting situations is that decreases in both physical and mental performance occur toward the later stages of an event. The causes of this fatigue are complex and multifaceted as they can be of central and/or peripheral origin. Decreases in performance also tend to vary across sports that are influenced more or less by factors such as decreased muscular power and endurance, decreased motor skill performance, and mental lapses. Fatigue can also be influenced by the nutritional needs of an athlete that go along with a particular sport (29).

Athletes often utilize supplements such as carbohydrate-electrolyte sports drinks that are known to delay fatigue during submaximal endurance exercise (2). The potential mechanisms for this effect on fatigue include reducing muscle glycogen depletion, maintaining blood glucose as an important energy source for both muscle and brain, and/or by altering neurotransmitter activity that could influence cognition, mood, motivation, and motor skill performance (4). Unfortunately, this information has been derived from experiments involving primarily prolonged submaximal exercise and may not be applicable to sports that involve intermittent high-intensity (IHI) exercise (e.g., basketball, soccer, tennis, and hockey). It is possible that the mechanisms by which CHO affect endurance exercise are different in IHI exercise in which the exercise intensity, the duration of exercise and rest intervals, and the skill requirements are constantly changing.

The potential role of CHO on performance of sports like soccer and basketball has received limited attention. A few studies have examined the effects of CHO ingestion on performance during intermittent high-intensity bouts of soccer (14,17,20,31), cycling (6), ice hockey (25), and shuttle running (7,8,21,22). Results indicated that CHO ingestion increased the amount of time spent at top velocities during a soccer match (14) and an ice hockey game (25). It also increased the ratio of goals scored to goals conceded during soccer play (20). Various well-controlled laboratory protocols involving intermittent high-intensity exercise have shown CHO ingestion to improve performance as reflected by an increase in the amount of time spent cycling and shuttle running before fatigue (6,7,8,21,22). In those studies where muscle glycogen concentrations were measured, CHO ingestion was also shown to reduce muscle glycogen

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depletion during a soccer match (17) and after intermittent shuttle running (21).

Although evidence about the beneficial role of CHO ingestion on physical performance during IHI exercise activities is increasing, far less is known about its role on mental function. In the few studies that have investigated this parameter, CHO ingestion appeared to improve mental function. For example, CHO supplementation improved mood states during prolonged training periods in elite female cyclists and field hockey players (13,15) with results of CHO supplementation on motor skill performance in tennis players and soccer players being mixed (27,31).

Although these studies support potential physical and mental benefits of CHO during IHI exercise, more evidence is needed from controlled laboratory studies designed to reflect the actual physical and mental demands of sporting activities such as basketball, soccer, tennis, and field hockey. Sports such as these include frequent short breaks, prolonged rest periods (e.g., time outs, period breaks, and halftime times), and frequent intervals in which maximal effort, concentration, and skilled motor performance are required. Both physical and mental function are required for optimal performance under these conditions.

This study was designed to investigate the effects of CHO ingestion on physical and mental function during IHI shuttle running that more closely simulated game-like situations involved in many competitive sporting events (e.g., basketball and soccer). It was hypothesized that carbohydrate-electrolyte drink consumption would enhance performance of various physical and mental functions important for high level performance in these sports.

**MATERIALS AND METHODS**

**Subjects**

The subjects for this study included 10 college aged men \((N = 5)\) and women \((N = 5)\) who were currently involved in regular IHI exercise and had at least 3 yr of competitive experience on a basketball or soccer team at the collegiate or intramural levels. Subject characteristics are presented in Table 1. Subjects participated in a series of three preliminary practice sessions and two experimental trials of an IHI shuttle running protocol similar to one used by Nicholas et al. (22). The experimental protocol involved approximately 60 min of IHI shuttle running and vertical jumping \((4 \times 15\)-min quarters with a 20-min halftime break and various tests of physical and mental function); this was followed by an IHI shuttle run to fatigue. The experimental protocol was performed on two separate occasions while receiving either CHO supplementation or flavored water placebo \((P)\) in a randomly assigned cross-over order. All subjects were informed of the experimental procedures and risks associated with participation before the study. The experimental protocol was approved by the University’s Institutional Review Board for human subject research.

**Preliminary Sessions**

Before the two experimental trials, subjects reported to the laboratory for three visits. During these preliminary visits, physiological information was obtained, and subjects were acclimated to the various tests of physical and mental function to eliminate potential learning effects during the experimental sessions. Physiological data consisted of subjects’ maximal vertical jump height and maximal oxygen uptake \((\dot{V}O_{2max})\), as predicted from a standardized progressive shuttle running test that has previously been shown to be valid when compared with traditional treadmill tests (24). The tests of physical and mental function included: 1) 20-m sprint; 2) 30-s, 10-repetition maximal vertical-jumping test; 3) shuttle run to fatigue; 4) whole body motor skill test \((\text{MS-Test})\); 5) a cognitive functioning test \((\text{Stroop Color-Word Test})\); and 6) a mood evaluation test \((\text{POMS})\).

**Physical and mental function tests.** Twenty-meter sprint time was measured throughout the experimental protocol, and recorded as the average sprint time per quarter. During the 10-repetition maximal vertical-jumping test, all subjects performed a single step approach, maximal vertical jump, every 3 s for a 30-s period. Jump heights were measured on an overhanging cardboard banner by chalk marks made from the subject’s finger. Jump height was taken as an average of the 10 maximal jumps minus the standing reach height. Shuttle run to fatigue was measured as the time to fatigue. The “shuttle run to fatigue” protocol, which is described later, followed the four quarters of exercise.

The MS-Test, which we developed for this study, consisted of a pseudo hopscotch course made up of twelve 1-foot-wide squares positioned side by side in a 6-foot-long by 2-foot-wide arrangement. Half of the squares on the course were colored in with similar squares (colored or uncolored) being positioned diagonal to each other. Subjects were instructed to hop down and back on the course two consecutive times as fast and accurately as possible. The initial time down subjects hopped on the right foot and landed only on the colored squares; on the return, they hopped only on the left foot landing only on the uncolored squares. During the second trip down and back, subjects hopped on both feet simultaneously making sure to place the right foot on colored squares and the left on uncolored squares. The MS-Test score was taken as the time to complete the course \((\text{Time})\) plus an additional 0.5-s for every

**TABLE 1. Subject characteristics (mean ± SD).**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Maximal Jump Height (cm)</th>
<th>VO2max (ml kg⁻¹ min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men ((N = 5))</td>
<td>24.6 ± 4.1</td>
<td>176.3 ± 5.8</td>
<td>71.0 ± 8.0</td>
<td>64.3 ± 9.6</td>
<td>51.9 ± 1.8</td>
</tr>
<tr>
<td>Women ((N = 5))</td>
<td>24.0 ± 4.0</td>
<td>166.1 ± 8.2</td>
<td>61.9 ± 5.4</td>
<td>44.2 ± 3.5</td>
<td>48.2 ± 3.8</td>
</tr>
<tr>
<td>Total ((N = 10))</td>
<td>24.3 ± 3.8</td>
<td>171.2 ± 6.6</td>
<td>66.4 ± 8.0</td>
<td>54.3 ± 12.6</td>
<td>50.1 ± 3.4</td>
</tr>
</tbody>
</table>
error (Errors) made. An error occurred when the anterior 6 inches of the shoe failed to land completely within the appropriate square. The same evaluator determined errors and time during all trials of the experimental sessions while being blinded to the treatment. Two consecutive MS-Tests were performed separated by 10-s rest each. The score used in the analysis was the average of the two trials. Before performing the MS-Test, subjects were instructed to complete the course as fast and accurate as possible but were reminded that errors would be weighted fairly heavily in their final score.

MS-Test practice sessions were performed on each of the three preliminary visits (four sessions total) and consisted of 12 trials of the test (2 sets of 6 trials). Feedback on technique and accuracy was provided during the first six trials with the second set of six trials being scored for time and errors. MS-Test practice sessions that consisted of eight scored trials were also performed before each experimental session. The reliability of the MS-Test was determined from MS-Test scores (average score of trials 7 and 8) obtained during these latter practice sessions. Finally, the Stroop and POMS tests were administered in a standard isolated environment, according to test guidelines provided, on the first and last preliminary visits and during the experimental trials (12,19).

Estimated \( \text{VO}_{2\max} \) and maximal vertical jump height data were used to establish the relative shuttle running intensities and jumping heights to be performed during the experimental protocol. Subjects with similar predicted \( \text{VO}_{2\max} \) values were grouped together (two per group) for the practice shuttle running trial; this was performed on the last of the preliminary visits. To ensure adequate warm-up, the practice shuttle running trial was preceded by a standardized 15-min warm-up that consisted of 5–7 min of easy jogging, stretching, two 90-s segments of the shuttle running protocol, and eight practice trials of the MS-Test. After the warm-up, one full 15-min quarter of the shuttle running protocol along with tests of physical and mental function were performed to familiarize subjects with the testing procedures and to confirm appropriate shuttle running intensities and jumping heights. Pre- and post-test data were also collected during this practice session for the physical and mental tests to further ensure acclimation. A consistent level of strong verbal encouragement was provided to the subjects throughout this practice session and during the experimental sessions. Individuals providing encouragement were blinded to treatment conditions.

**Experimental Sessions**

**Experimental protocol.** Subjects were instructed to maintain normal activity patterns and to carefully monitor their food intake for 2 days before the first experimental session and then to replicate that food intake before the subsequent session. Subjects were reminded of these guidelines before each experimental session but no formal evaluation of their physical activity and dietary habits was done. Subjects reported to the laboratory at 7:00 a.m. after a 12-h fast for the two experimental sessions; the sessions were separated by 1 wk and were performed in similar environmental conditions. Upon arriving to the lab, nude body weight was measured and an indwelling catheter was inserted into an antecubital vein. A standing preexercise blood sample was collected 30 min later, and the standard 15-min warm-up was begun followed by the exercise protocol. The catheter was maintained throughout the exercise session and blood collection time points. All blood collection procedures were performed as described in previous studies from this laboratory (6).

**Exercise protocol.** The exercise protocol included four 15-min sequences (quarters) of IHI shuttle running with a 20-min rest period (halftime) between the 2nd and 3rd quarters (Fig. 1). This was followed immediately by the shuttle run to fatigue. At the end of each 15-min quarter, a 3-min standing rest period was taken during which a blood sample was collected and experimental drinks were consumed. A 2- to 3-min warm-up period consisting of easy jogging was performed after the halftime break. Each of the four 15-min shuttle running sequences consisted of ten 90-s bouts of the following: 3 × 20-m moderate paced walking (~30% \( \text{VO}_{2\max} \)), 2 vertical jumps of 80% maximal jump height, 1 × 20-m maximal sprint, 3 × 20-m running at 120% \( \text{VO}_{2\max} \) pace, 2 vertical jumps of 80% maximal jump height, and 3 × 20-m jogging at 55% \( \text{VO}_{2\max} \) pace (Fig. 2).

The shuttle run to fatigue consisted of repeated 20-min intervals at 120% \( \text{VO}_{2\max} \) and 55% \( \text{VO}_{2\max} \) pace until volitional fatigue occurred (Fig. 2). Running speeds were selected to correspond to predicted intensities (% \( \text{VO}_{2\max} \)) determined from the initial progressive shuttle running test. Appropriate speeds throughout the exercise sessions were maintained by the subjects keeping pace with a computer generated series of audible “beeps” which indicated when the subjects were to be at the end of the 20-m court. Fatigue was defined as an
inability of the subject to maintain running speeds (>2 consecutively missed end courts) on time with the audible “beeps” while receiving strong verbal encouragement. Fatigue was always determined by the same evaluator who was blinded to the experimental treatments.

**Timing of the physical and mental function tests.**
Timing of the physical and mental function tests are summarized in Figure 1; tests are listed in order of completion. These tests and blood collections were performed at various intervals during the experimental sessions at the following time points: preexercise (PRE), 1st quarter (QTR-1), 2nd quarter (QTR-2), end of the halftime (HALF), 3rd quarter (QTR-3), 4th quarter (QTR-4), and after the shuttle run to fatigue (FTG). Heart rates were monitored and recorded every 5 s throughout the experimental sessions with the use of heart rate telemetry (Polar Vantage XL, Port Washington, NY).

**Experimental feedings.** To help assure a proper hydration status going into the experimental sessions, subjects ingested 5 mL·kg⁻¹ body weight of water 90 min before the experimental sessions. During the two experimental sessions, subjects received drinks containing either carbohydrate-electrolytes (CHO) or flavored water placebo (P). Immediately after the PRE blood sample and before the 15-min warm-up, subjects received 5 mL·kg⁻¹ body weight of a 6% CHO solution (60 g·L⁻¹) (Gatorlode®) or P. Just before QTR-2, QTR-3, QTR-4, and FTG, a 3 mL·kg⁻¹ body weight volume of the 6% solution (60 g·L⁻¹) or P was consumed. Immediately before the 20-min halftime break (HALF), a 5 mL·kg⁻¹ body weight volume of 18% CHO solution (180 g·L⁻¹) (Gatorlode) or P was consumed. Total carbohydrate consumed during the CHO trial was 127.5 ± 4.9 g (1st half, 32 g; halftime, 60 g; and 2 nd half, 36 g). Qualitative inquiry upon the completion of the study revealed that all subjects were unable to identify which drink treatments were received during the experimental trials. The order of the experimental sessions was administered in a double blind, counterbalanced fashion with each subject receiving each treatment.

**Blood collection.** Ten-mL blood samples were collected at 30 min post catheterization (PRE), after the MS-Test of QTR-2, at the end of halftime (HALF), and after the MS-Tests of QTR-3, QTR-4, and FTG. Samples were collected in anticoagulant treated tubes and analyzed for plasma volume shifts, lactate, glucose, free fatty acids, and insulin as described in previous studies from this laboratory (6).

**Statistical Analysis**
A paired Student’s t-test was used to determine differences (CHO vs P) in shuttle run to fatigue times. Two-way ANOVAs (drink treatment × time) with repeated measures were used to analyze the remaining 10 variables (glucose, lactate, insulin, free fatty acids, heart rate, average 20-m sprint times, MS-Test scores, average vertical jump height, Stroop scores, and POMS scores). Significance was set at $P < 0.05$. Preplanned time points corresponding to the second half of exercise for physical and mental tests, and all time points for the blood variables were used for analysis. The between days reliability of the MS-Test was estimated using intraclass correlations. All data are presented as means ± SEM unless otherwise indicated.

**RESULTS**

**Physiological Responses to the Exercise Protocol**
Plasma lactate concentrations during the exercise portions of the shuttle running protocol were maintained in the 4.0 mmol·L⁻¹ to 6.0 mmol·L⁻¹ range (Fig. 3A). Heart rate during exercise ranged from approximately 170–180 beats·min⁻¹ (Fig. 3B). Plasma volume changes during exercise and at fatigue were minimal at ± 6% (Fig. 3C). No significant drink treatment effects were detected between exercise sessions at any of the time points. This lack of drink treatment effects for heart rate, lactate, and plasma volume change would indicate that similar physiological demands were placed upon the subjects during both of the experimental trials. The lactate and heart rate values are similar to values reported in previous studies measuring the physiological demands of athletes during a soccer match (10,29).

**Physical/Mental Function Tasks**
Average time to fatigue during the “shuttle run to fatigue” was significantly longer ($P < 0.0001$) with CHO (3.58 ±
0.47 min) than with P (2.61 ± 0.42 min). This represents a 37% improvement in run time to fatigue; all subjects performed better with the CHO treatment. Average 20-m sprint time was also enhanced (approximately 14%) during QTR-4 when subjects were provided CHO feedings. The CHO group maintained significantly (P = 0.02) faster sprint times than the P group during QTR-4 (Fig. 4). Although the standard error bars appear too high to be statistically significant, it is important to note that intrasubject (within-subject) comparisons were used for statistical comparisons. The large standard error bars in Figure 4 reflect the between-subject variability in sprint times for male and female subjects. Seven of 10 subjects performed better in QTR-4 while on the CHO treatment. Two subjects performed slightly worse on CHO than P, and one subject performed the same on both CHO and P trials. No differences were detected between groups at any time points before QTR-4. Analysis of the 30-s maximal vertical jumping test data revealed no significant differences between drink treatments at any time point.

Reliability of the whole body MS-Test score was high; the intraclass correlation coefficient between practice sessions 4 and 5 was 0.91. The total score for the MS-Test was significantly lower (P = 0.02) after QTR-4 when subjects consumed CHO as compared with P (Fig. 5A). The time component of the total score in QTR-4 was also significantly faster for subjects on CHO (P = 0.0002) (Fig. 5B). Analysis of the error component of the total score revealed no significant differences between drink treatments at any time point.

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the PRE nonexercising time point (Fig. 6A). However, no significant drink treatment effects were detected for the total POMS score at any time point.

Analysis of the individual subcomponents of the POMS test revealed a similar overall time effect for both vigor ($P = 0.01$) and fatigue ($P = 0.0001$) with a greater negative mood state (vigor decreased, fatigue increased) occurring at the HALF and FTG time points (Fig. 6, B and C). No overall time effects were detected for any of the remaining subcomponents of the POMS test. The only drink treatment effect was at FTG where the fatigue subcomponent of the POMS test was significantly lower in subjects consuming CHO ($P = 0.048$). This represents a lower self-report sensation of fatigue in subjects consuming CHO beverages at the end of the shuttle run to fatigue test. No significant treatment effects were present for any other subcomponents of the POMS test at any other time points.

**Blood Variables**

Plasma glucose concentrations were significantly elevated at all time points after the first half of shuttle running (HALF, QTR-3, QTR-4, and FTG) when subjects received CHO feedings (Fig. 7A). The only difference before HALF was a lower blood glucose concentration at QTR-1 for the CHO treatment. Plasma insulin concentrations during the CHO trial were also significantly elevated at all time points after the first half of shuttle running (Fig. 7B). In contrast, plasma free fatty acid concentrations were significantly lower at all time points after the first quarter of shuttle running for subjects receiving CHO feedings (Fig. 7C).

**DISCUSSION**

The purpose of this study was to examine the effects of ingesting a carbohydrate “sports” drink on physical and mental function during an experimental protocol that closely simulated activities of an actual sporting event. Until recently, there has been little scientific evidence to support this nutritional strategy in sports involving “stop and go” activities during which high-intensity exercise is performed for only a small fraction of the 1- to 2-h game.

Data from this study indicated that ingestion of a carbohydrate-electrolyte sports drink during exercise that simulated a competitive game (a) enhanced the performance of 20-m sprints, (b) improved the speed and agility of whole body motor skills, (c) enhanced self-reported perceptions of fatigue (POMS) during the second half of the protocol, and (d) delayed fatigue in the IHI running test that followed QTR-4. CHO did not improve the 30-s vertical-jumping
Previous laboratory based studies have shown that CHO feedings can delay fatigue by 50% during repeated 1-min bouts of cycling at 120–130% of VO\(_2\)\(_{\text{max}}\) with 3-min rest in between (6) and by 37–52% during shuttle running (7,8,22). This is similar to the 37% delay in fatigue found in this study. However, this study is unique in that additional tasks are included in the shuttle running protocol in an attempt to mimic other physical and mental challenges typically encountered in competitive team sports. Results of CHO feedings are mixed for our more physically demanding tasks of 20-m sprinting and vertical jumping. Sprint times were significantly faster during the fourth quarter with CHO, but no significant improvements were found in the 30-s 10-repetition vertical-jumping test that was designed as a sport-specific anaerobic power test. However, performance in the vertical-jumping test did not deteriorate during either trial of the exercise protocol. With little or no evidence existing in support of CHO feedings actually increasing performance above that which occurs early in exercise before fatigue, it was not too surprising that a benefit of the CHO feedings was not found.

Additional factors important for optimal athletic outcomes include skilled motor performance, heightened cognitive function, and positive mood states. We are aware of only two studies in which the effect of CHO feedings on sport-specific motor skill performance has been examined. Both studies were field studies that involved tennis and soccer players (27,31). Results of these field studies provide evidence of a benefit of CHO feedings on tennis serve and ground stroke performance (27) but not on soccer-specific skills during a match (31).

In the present laboratory study, we provide further support for a beneficial effect of CHO feedings on motor skill performance (MS-Test). In this case, individuals who received CHO treatment during the exercise session maintained speed while also maintaining accuracy and control of performance. In contrast, when individuals received P, in order to maintain accuracy and control, speed of performance was slowed down. This decrease in motor skill performance that occurred during the strenuous protocol in the placebo condition was attenuated during the final quarter of shuttle running when CHO was consumed. The improvement in motor skill performance during QTR-4 is suggestive of enhanced central nervous system (CNS) control of motor units as supported by the speed accuracy trade off principle (Fitts’ law). In other words, with decreases in central control, individuals tend to slow down the speed at which they perform a task to maintain the same level of accuracy (11). This is especially likely in this task in which subjects were consistently reminded that errors would be weighed heavily in their final score.

Maintenance of a positive mood state and optimal cognitive functioning, as reflected by one’s ability to make split-second decisions and keeping their “head in the game,” is also an important CNS function necessary for optimal performance in competitive sporting events. The Profile of Mood State questionnaire has been used extensively in exercise studies (19). Three studies have examined the effects of CHO feedings on mood states in elite cyclists during heavy training periods (13), in elite field hockey players after a practice session (15), and in trained individuals after a 90-min cycling protocol to fatigue (23). In these studies, CHO was effective in reducing the composite mood state score and selected subscale scores (e.g., tension, depression, anger, and fatigue) when compared with water placebo groups. Data from the present study indicated no effect of CHO on the composite mood score at any time period during the protocol. The significantly lower fatigue subcomponent score at the FTG time point under the CHO condition suggests that subjects felt less fatigued even though they were unable to maintain shuttle running speeds. Measuring mood states after the fourth quarter, before the shuttle run to fatigue, would be a promising place to look for potentially greater differences in future studies.

The specific role of CHO ingestion during exercise on cognitive function has not been reported in the literature. Differences in cognitive functioning, as measured by the Stroop Color-Word Test (12), have been reported in runners who consumed either CHO or CHO plus branched chain amino acids (BCAA), with the latter being hypothesized to optimize cognitive functioning (1). Although this study showed some improvement on selected subcomponents of the Stroop Color-Word Test (Word and Color-Word), there was no improvement in the primary Interference Score. In our more controlled laboratory study, we also failed to detect any benefit of CHO feedings on the Interference score. This suggests that the CHO treatment did not enhance subjects’ ability to deal with cognitively challenging situations during this protocol. However, it is possible that the timing of these tests and/or the small sample size used in the study were insufficient to detect differences if they existed. It is also possible that the Stroop Color-Word Test, which was developed to assess relatively large impairments in cognitive functioning in clinical settings, is not discriminating enough to detect relatively small changes that might occur in sports competition.

This study was not designed to determine underlying mechanisms of potential benefits of CHO feedings on the physical and mental performance measures used. However, the data that show elevated plasma glucose and insulin concentrations with CHO feedings point to two possible mechanisms. It has been proposed that the improved physical and mental function that occurs with CHO feedings result from a prevention of selective Type II fiber fatigue and maintenance of CNS functioning (6,7,16,21). Previous studies involving intermittent high-intensity exercise have shown that Type II muscle fibers can become glycogen depleted to a greater extent than Type I fibers (21,28) and that Type II fiber performance, as measured by maximal force output, is decreased even when Type I fibers are still viable (18). When CHO has been provided during intermittent high-intensity exercise, mixed fiber analysis shows greater muscle glycogen concentrations after trials when CHO was consumed (21). Although muscle glycogen was...
not measured in the present study, elevated plasma glucose and insulin concentrations during later stages of the exercise protocol support this hypothesis by way of increased glucose uptake and glycogen synthesis. Negative expressions of CNS function including feelings of lethargy, increased perception of fatigue, negative mood states, and decreased arousal have all been associated with low blood glucose and elevated brain serotonin (3,4,26,30).

Maintenance of higher blood glucose and lower free fatty acid concentrations has been suggested as possible mediators of enhanced CNS function during heavy exercise with CHO feedings (4). Glucose is clearly an important energy source for the brain, especially in those areas most active during strenuous exercise. In addition, modest changes in glucose within normal ranges can affect cognitive function (9). It has also been suggested that lower plasma FFA levels of lethargy, increased perception of fatigue, negative mood states, and decreased arousal have all been associated with low blood glucose and elevated brain serotonin (3,4,26,30).

In summary, ingestion of carbohydrates during IHI exercise designed to mimic competitive sporting events appears to improve the performance of some of our tasks that require heightened physical and mental function but not all. Among those tasks that were not improved with CHO, we feel it is important to note that no decreases in performance were detected. This would imply that ingestion of CHO during IHI exercise, similar to many competitive sporting events, only enhances physical and mental performance tasks. If the performance tasks examined in this study reflect demands placed on an athlete during actual competitive sporting events, the performance benefits seen in the later minutes of exercise with carbohydrate supplementation would seem even more influential on the outcome of an event as many games are won or lost in the closing moments of competition.

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REFERENCES


