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Chocolate Milk as a Post-Exercise Recovery Aid

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Nine male, endurance-trained cyclists performed an interval workout followed by 4 h of recovery, and a subsequent endurance trial to exhaustion at 70% VO_{2max}, on three separate days. Immediately following the first exercise bout and 2 h of recovery, subjects drank isovolumic amounts of chocolate milk, fluid replacement drink (FR), or carbohydrate replacement drink (CR), in a single-blind, randomized design. Carbohydrate content was equivalent for chocolate milk and CR. Time to exhaustion (TTE), average heart rate (HR), rating of perceived exertion (RPE), and total work (W_T) for the endurance exercise were compared between trials. TTE and W_T were significantly greater for chocolate milk and FR trials compared to CR trial. The results of this study suggest that chocolate milk is an effective recovery aid between two exhausting exercise bouts.

Key Words: glycogen resynthesis, endurance performance, nutrition, sports drink

It is well known that endurance exercise performance is influenced by the amount of stored glycogen in skeletal muscles, and that intense endurance exercise decreases muscle glycogen stores (9, 10, 13, 18), leading to a diminution in performance. The resynthesis of glycogen between training sessions occurs most rapidly if carbohydrates (CHO) are consumed within 30 min to 1 h after exercise (9, 13, 17). Indeed, delaying carbohydrate ingestion for 2 h after a workout can reduce the rate of glycogen resynthesis by half (20, 22). To maximize the rate of glycogen resynthesis, it is suggested that 50 to 75 g of CHO be ingested within 30 to 45 min after exercise (1), with ingestion of 1.2 to 1.5 g CHO/kg of body weight/hour for the next few hours (12, 19, 20, 24, 29). Ingesting protein along with carbohydrate (at a CHO-to-protein ratio of 2 to 2.9:1) has been shown to hasten the rate of glycogen synthesis and improve endurance performance, especially when the amount of carbohydrate ingested is less than current recommendations (20, 21, 35, 39). Of particular importance is the study of Ivy et al. (23), who found that the ingestion of a solution containing a 4:1 CHO-to-protein ratio improved endurance performance

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over carbohydrate ingestion alone, although not all studies report similar results (5, 30, 34). Studies not showing a benefit of protein ingestion on glycogen resynthesis used beverages that either were not isocaloric or did not contain the same amount of carbohydrate. For example, the beverages used by Carrithers et al. (5) (carbohydrate, carbohydrate-protein, and carbohydrate-amino acid) and Tarnopolsky et al. (32) (carbohydrate and carbohydrate-protein-fat) were isocaloric, but contained different amounts of carbohydrate. It is possible, therefore, that Carrithers et al. (5) and Tarnopolsky et al. (32) did not observe differences in muscle glycogen content between the treatments because the carbohydrate-protein beverages contained less carbohydrate than the carbohydrate-only beverages. Conversely, the beverages used by Van Hall et al. (34) (carbohydrate and carbohydrate-protein) contained equal amounts of carbohydrate but were not isocaloric.

Based on the above recommendations, two primary types of post-exercise recovery drinks have emerged on the commercial market—"carbohydrate replacement drinks" (CR), which contain added carbohydrate to replenish glycogen-depleted muscles following exhausting exercise, and "fluid replacement drinks" (FR), which contain less carbohydrate, and are used to replenish fluid and electrolytes lost during exercise. CR have been shown to have a greater effect than plain water on the rate of post-exercise glycogen resynthesis (28).

Since flavored milk, such as chocolate milk, has a similar carbohydrate and protein content to that of many CR, it may be an effective means of refueling glycogen-depleted muscles, enabling individuals to exercise at a high intensity during a second workout of the day. One study (37) has indeed found no difference in muscle glycogen resynthesis following glycogen-depleting cycling exercise plus eccentric resistance exercise between subjects who drank FR (Gatorade), flavored skim milk, or a placebo. However, the results are difficult to interpret since the subjects of this study did not receive all three beverages and the carbohydrate content of the three beverages differed. Chocolate milk is a drink that is easily available and commonly found in many household refrigerators. To meet the current recommendations for post-exercise carbohydrate intake (19, 24), a 70-kg male and a 60-kg female would need to consume 17 to 27 and 14.5 to 23 fluid ounces, respectively, of low-fat chocolate milk, depending on the brand. These volumes of chocolate milk contain 70 to 84 g of carbohydrate and 19 to 30 g of protein for the reference male, and 60 to 72 g of carbohydrate and 16 to 26 g of protein for the reference female. The carbohydrate in chocolate milk is composed of sucrose (glucose plus fructose), lactose (glucose plus galactose), and high fructose corn syrup.

The purpose of this study was to test the efficacy of chocolate milk as a recovery aid following glycogen-depleting exercise, as determined by performance during a second bout of exercise. We hypothesized that 1) due to chocolate milk's greater carbohydrate and protein content compared to FR, time to exhaustion during a second bout of endurance exercise would be greater following ingestion of chocolate milk during the recovery period than following ingestion of FR, and 2) because of chocolate milk's similar carbohydrate and protein content to that of CR, there would be no difference in time to exhaustion during a second bout of endurance exercise following ingestion of chocolate milk or an isocaloric CR containing an equal amount of carbohydrate.

Methods

Subjects

Nine male, healthy, non-smoking, highly-trained cyclists from the Indiana University cycling community volunteered to participate in this study. Subjects' physical characteristics are listed in Table 1. Each subject received a verbal explanation of the nature of the study, including the slight risks associated with performing exhausting exercise, and was required to sign an informed consent form prior to participation. All procedures were approved by Indiana University's Institutional Review Board.

Each subject participated in four testing sessions, with each session separated by 1 wk. The first testing session consisted of an incremental exercise test on a cycle ergometer to determine maximum oxygen consumption (VO_{2max}) and maximum power output at VO_{2max} (P_{max}). The remaining three testing sessions were conducted as a randomized, crossover design with each subject serving as his own control, and consisted of two bouts of cycling exercise to exhaustion separated by 4 h of recovery. Subjects were required to keep a written record of their dietary intake for the 3 d prior to each of the three testing sessions. Additionally, all subjects were asked to report to the laboratory following an overnight fast of approximately 10 to 12 h and refrain from heavy exercise for 24 h prior to testing. For the three testing sessions, the first exercise bout consisted of alternating periods of work and recovery in an interval format, with the intention of depleting the subjects' muscle glycogen stores (25). Following the glycogen depletion exercise, subjects remained in the laboratory for 4 h of relaxed recovery, during which they received either low-fat chocolate milk (The Kroger Co., Cincinnati, OH), a fluid replacement drink (Gatorade, The Gatorade Co., Chicago, IL), or a carbohydrate replacement drink

Table 1 Subjects' Physical Characteristics

Subject	Age (y)	Mass (kg)	Height (cm)	VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)
1	22	72.4	175.3	66.9
2	22	74.6	183.7	82.1
3	21	82.5	183.6	56.0
4	24	76.5	188.5	63.7
5	19	70.2	172.3	58.8
6	22	69.0	187.0	76.6
7	26	74.4	174.0	56.3
8	21	68.0	172.9	64.8
9	22	69.6	181.7	60.1
Mean	22.1	73.0	179.9	65.0
SD	2.0	4.6	6.3	9.0

Table 2 Comparison of Post-Exercise Recovery Drinks*

Drink	CM	FR	CR
Volume (mL)	509.1 ± 36.0	509.1 ± 36.0	509.1 ± 36.0
Carbohydrate (g)[1]	70.0 ± 4.9	29.7 ± 2.1	70.0 ± 4.9
Protein (g)	19.1 ± 1.3	0.0 ± 0.0	18.5 ± 1.3
Fat (g)	5.3 ± 0.4	0.0 ± 0.0	1.5 ± 0.1
Energy (Kcals)	381.8 ± 27.0	106.1 ± 7.5	381.8 ± 27.0
Electrolytes (mg)	403.0 ± 28.5 Na^{++}	233.3 ± 16.5 Na^{++}	311.2 ± 22.0 Na^{++}
	903.7 ± 63.9 K^{+}	63.6 ± 4.5 K^{+}	169.7 ± 12.0 K^{+}

Note. Values are means ± standard deviation. *Ingested immediately after exercise and after 2 h recovery. CM, chocolate milk; FR, fluid replacement drink; CR, carbohydrate replacement drink.

[1]Based on body mass (1.0 g/kg).

(Endurox R4, PacificHealth Laboratories, Woodbridge, NJ) (Table 2). Following the recovery period, the subjects performed a second exercise bout, cycling at 70% VO_{2max} until exhaustion. The investigators were blind to which drink the subjects received. All drinks were poured into unmarked, opaque bottles by an individual not associated with the experiment. While the distinctive tastes of the drinks precluded an attempt to blind the subjects to the treatments, there was no apparent bias on their part. However the subjects were not directly asked prior to or at the end of the experiment whether they had a preference for any of the drinks.

Experimental Procedures

Maximal Oxygen Uptake Test. After a self-determined warm-up, the progressive maximal exercise test began with the cycle ergometer (model 834E, Monark, Varberg, Sweden) resistance set at 100 W, and increased by 50W every 2 min using a step protocol until the subject reached volitional exhaustion (adapted from references 25, 34, and 36). The pedal rate, which varied between subjects, was determined during the subjects' warm-up, as they cycled at their normal training cadences (85 to 100 RPM). Once the cadence was determined, each subject was instructed to maintain that pedal rate throughout the test. The chosen pedal cadence for each subject was also used for all other tests. Respiratory gases were sampled using a dual thermistor flow probe (Torrent 1200, Hector Engineering Co., Ellettsville, IN) and oxygen and carbon dioxide analyzers (models S-3A and CD-3A, Applied Electrochemistry, Ametek, Pittsburgh, PA) as subjects breathed through a 2-way breathing valve (model 2700, Hans Rudolph, Kansas City, MO). Minute ventilation (VE), oxygen uptake (VO_2), expired carbon dioxide (VCO_2), and the respiratory exchange ratio (RER) were recorded by a data acquisition system (Workbench for Windows 3.0, Strawberry Tree, Sunnyvale, CA) sampling at 50 Hz and averaged over each minute of exercise. RPM were measured continuously by a pedal counter connected from the bike to an analog/digital converter and displayed each minute on a computer screen. Subjects' heart rates during the tests were also recorded every minute using a heart rate monitor (Polar Electro, Port Washington, NY). VO_{2max} was considered as the maximal value attained during the test, provided at least two of three criteria were met, which included an RER of greater than 1.10, achievement of 90% of age-predicted maximal heart rate, and an increase in VO_2 of less than 0.15 L/min over the previous workload (33). P_{max} was defined as the maximal power output that was achieved during the final completed stage of the test.

Glycogen Depletion Trial. The protocol for this test has been described elsewhere (25, 34, 35), and was modified for the present study to accommodate the high training cadences of the trained cyclists. Briefly, the workout consisted of 2-min intervals at 90% P_{max}, with a 2-min recovery at 50% P_{max}, until the subjects could no longer maintain their chosen pedal cadence, which was the same as for the initial VO_{2max} test (85 to 100 RPM). At that time, the intensity of the work interval was decreased from 90% P_{max} to 80% P_{max}, with the subjects continuing to cycle until they again could no longer maintain the required RPM. The intensity of the work interval was then decreased from 80% P_{max} to 70% P_{max}, and subsequently to 60% P_{max}, with the subjects continuing to cycle with alternating 2-min periods at each work interval and 50% P_{max} until they could no longer maintain the required RPM over a minute. At that time, subjects were told to stop the exercise.

Recovery Period. Subjects were given the recovery drinks immediately following the glycogen depletion exercise and again 2 h into the post-exercise recovery period. The volume of chocolate milk given to the subjects was calculated to yield 1.0 g CHO/kg of body weight. Subjects were given an equivalent volume of FR and CR, so that all three drinks were isovolumic in an effort to control for hydration status. In addition, the carbohydrate content of CR was equivalent to that of the chocolate milk (1.0 g/kg). No other food was allowed during the recovery period, however, subjects were allowed to drink water ad libitum.

During the recovery period, subjects were allowed to engage in simple activities of daily living, including watching television, listening to music, studying, reading a book, or walking around the laboratory. No strenuous activity was performed.

Endurance Performance Trial. After 4 h of relaxed recovery from the initial exercise bout, each subject cycled at 70% VO_{2max} until exhaustion (adapted from references 14 and 38). Subjects were instructed to maintain their previously chosen pedal cadence (85 to 100 RPM) throughout the trial, and resistance was added to the bike during the first 5 min (which was used as a warm-up) until 70% VO_{2max} was reached. Once reaching this intensity, the elapsed time of the trial began, with the power output remaining constant for the duration of the exercise. Pedal cadence was monitored continuously and recorded each minute. Heart rate was recorded every 15 min and the subject's rating of perceived exertion (RPE) using the Borg scale (4) was recorded at the end of the trial. Subjects were allowed to listen to music, which was the same for each trial and for each subject. They were given no feedback regarding elapsed time, but were verbally encouraged throughout each trial to cycle for as long as they could. Subjects were not permitted to stand on the pedals while cycling. As in the initial glycogen depletion exercise, subjects were allowed to drink as much water as they wanted throughout the trial. Once the subjects could no longer maintain their cadence within 10 RPM of their chosen RPM for 1 min, they were given one chance to re-attain the cadence. The second time they failed to maintain the cadence within 10 RPM, the trial was terminated. Each subject's time to exhaustion was recorded.

Lactate Measurement. Blood samples were taken from each subject's fingertip using a lancet prior to and upon completion of each exercise trial and at 2 h into the recovery period. Each blood sample (~ 75 μL) was collected into a 100-μL heparinized capillary tube containing fluoride and nitrite, and was frozen at –3 °C until later assayed for lactate concentration using a blood metabolite analyzer (Micro-Stat, P-GM7, Analox Instruments, Lunenburg, MA). A drop of blood was also collected on a microcuvette and immediately analyzed for hemoglobin concentration using a B-hemoglobin photometer (HemoCue, Ängelholm, Sweden). Blood samples for lactate were analyzed in triplicate, with the mean concentration used for data analysis after being corrected for hemoconcentration using the subjects' resting hemoglobin values.

Body Mass and Hydration Status. Each subject's body mass and hydration status were determined prior to and upon completion of both the glycogen depletion exercise and the endurance performance trial. Body mass was measured using a digital scale (model D-7470, Sauter, Ebingen, Germany) and hydration status was estimated using bioelectrical impedance analysis (RJL Systems, Clinton Twp., MI) with a tetrapolar electrode placement. Total body water was used as a measure of hydration status, and was calculated from the subjects' height, mass, and body resistance using the equation of Kushner et al. (26).

At the end of the recovery period, and again after the endurance performance trial, subjects were given a questionnaire asking them to rate the degree (on a scale of 1 to 10, with 1 signifying no symptoms and 10 signifying severe symptoms) to which they experienced gastrointestinal distress and fatigue, including hunger, thirst, nausea, and headache/lightheadedness (27).

Data Analysis

Subjects' diets for the 3 d prior to each trial were analyzed for carbohydrate, fat, and protein composition using a computer software program (Nutritionist Five version 2.2, First DataBank, San Bruno, CA). All data were analyzed with a one-way repeated measures ANOVA using commercially available software (SPSS version 11.5, SPSS, Inc., Chicago, IL). Statistical significance was set at $P < 0.05$ and, in the case of a significant main effect, Fisher's LSD post hoc test was used to detect the source of the differences.

Results

Both time to exhaustion and total work performed during the endurance performance ride were significantly greater ($P < 0.05$) in the chocolate milk and FR trials compared to the CR trial (Figure 1). However, there were no significant differences among the three trials in any of the other variables examined in this study, including

HR (Figure 2) and RPE during the endurance performance trials, and post-exercise blood lactate for the glycogen depletion and endurance performance trials (Table 3). Pooled values for post-exercise blood lactate concentration significantly increased ($P < 0.05$) from pre-exercise values, both for the glycogen depletion and the endurance performance trials. Both body mass and total body water did not differ between treatments or within trials (Table 3). There were no significant differences in the amount of water consumed by the subjects between the chocolate milk, FR, and CR trials during the recovery period (506.7 ± 212.0, 729.4 ± 400.3, and 866.4 ± 631.0 mL, respectively) or during the subsequent endurance performance trial (323.4 ± 256.4, 363.6 ± 172.0, and 249.4 ± 229.3 mL, respectively). In addition, there were no significant differences in the macronutrient composition of the subjects' diets prior to each trial (Table 4), or in the subjects' responses to any of the questions on both questionnaires between trials.

The workloads for the initial glycogen depleting exercise are listed in Table 5. The subjects averaged 65.8 ± 23.4 min of cycling during this initial exercise, with no significant differences between trials (60.8 ± 25.1, 64.1 ± 20.1, and 72.6 ± 25.7 min for the chocolate milk, FR, and CR trials, respectively).

Discussion

Despite an equivalent carbohydrate content between chocolate milk and CR, and less carbohydrate in FR, subjects cycled 49% and 54% longer following chocolate

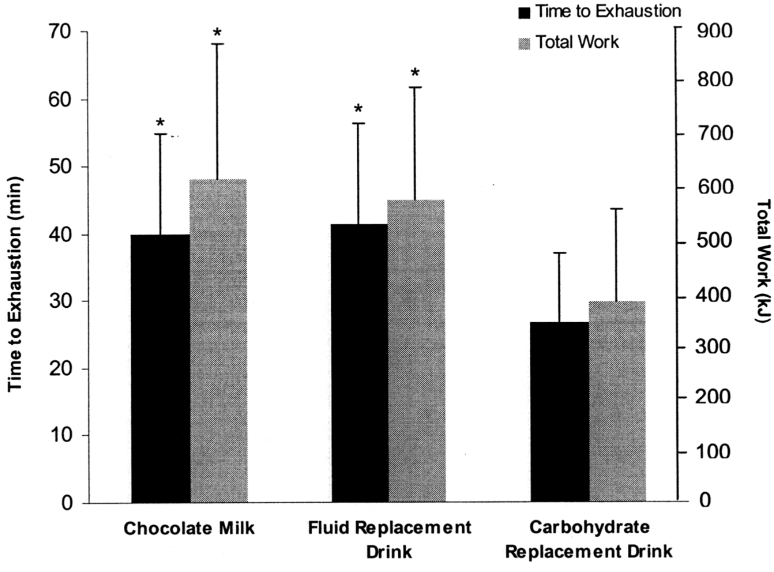

Figure 1 —Time to exhaustion and total work performed during the endurance performance trial following ingestion of three different recovery drinks. *Significantly different from carbohydrate replacement drink ($P < 0.05$).

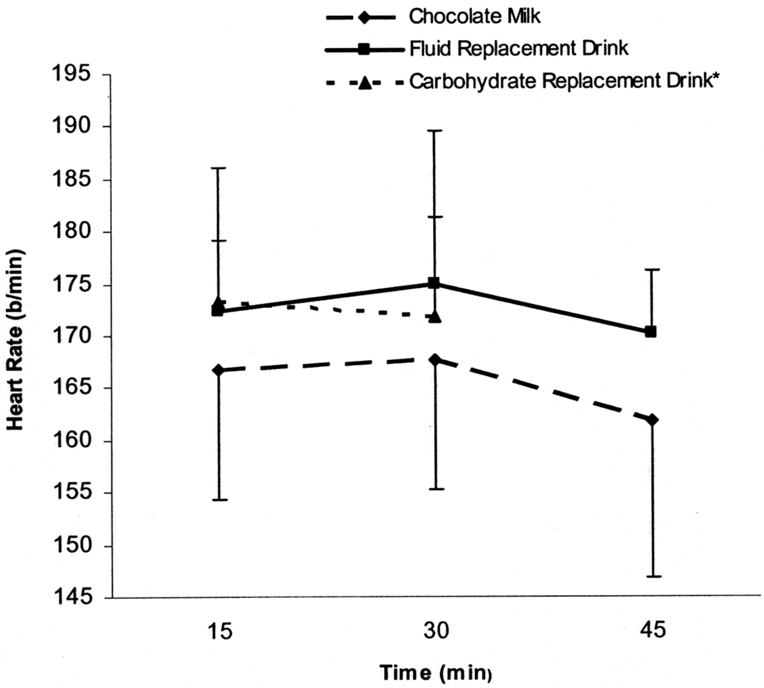

Figure 2—Heart rate (beats/min) during the endurance performance trial following ingestion of three different recovery drinks. Heart rate did not differ between treatments at any time point during exercise. *None of the subjects during the carbohydrate replacement drink trial reached 45 min.

milk and FR ingestion, respectively, compared to CR ingestion. In addition, the total amount of work performed by the subjects at 70% VO_{2max} was 57% and 48% greater, respectively, compared to CR ingestion. Other studies have also found no difference in exercise performance or glycogen restoration rate when subjects ingested different amounts of carbohydrate (14, 37). Bergen and coworkers (3) found that time to exhaustion during incremental cycling exercise to fatigue was slightly but significantly less with CR (Endurox) ingestion than with either FR (PowerAde) or a placebo. Wojcik and coworkers (37) found no difference in muscle glycogen resynthesis 24 and 72 h following eccentric quadriceps exercise between subjects ingesting FR (Gatorade), flavored skim milk, or a placebo. However, despite the large difference (per serving) in the carbohydrate content of the drinks, subjects were given a slightly greater amount of carbohydrate with the FR (1.25 g CHO/kg) compared to the flavored milk (0.875 g CHO/kg), which may have partly explained their results. Therefore, differences in the carbohydrate content of the drinks between the present study and Wojcik et al. (37), in addition to differences in the experimental design, exercise protocol, and duration of the recovery period, makes a comparison of the results difficult.

Table 3 Influence of Three Recovery Drinks on Selected Physiological Variables

	Chocolate milk[1]	Fluid replacement drink[2]	Carbohydrate replacement drink[3]
Time to exhaustion (min)[4]	40.0 ± 14.7*	41.3 ± 15.0*	26.8 ± 10.3
Total work (kJ)[4]	626.5 ± 262.7*	590.5 ± 218.7*	398.6 ± 185.0
Average HR (beats/min)[4]	169 ± 13	172 ± 5	172 ± 13
RPE[4]	16.2 ± 2.3	16.8 ± 1.4	17.2 ± 1.5
Blood lactate (mmol/L)			
(Pooled values for 3 treatments in parentheses)			
Pre-glycogen depletion exercise (1.3 ± 0.3)	1.4 ± 0.4	1.2 ± 0.4	1.4 ± 0.2
Post-glycogen depletion exercise (3.0 ± 1.6)	3.1 ± 1.2	3.2 ± 2.2	2.7 ± 1.3
Pre-endurance performance trial (1.8 ± 0.9)	2.0 ± 1.4	1.8 ± 0.6	1.6 ± 0.3
Post-endurance performance trial (2.7 ± 1.3)	2.9 ± 1.7	2.8 ± 1.4	2.5 ± 0.8
Body mass (kg)			
Pre-glycogen depletion exercise	73.4 ± 4.0	73.5 ± 4.4	73.0 ± 4.2
Post-glycogen depletion exercise	72.6 ± 3.9	72.9 ± 4.4	72.5 ± 4.2
Pre-endurance performance trial	73.0 ± 4.3	72.9 ± 3.9	73.1 ± 4.0
Post-endurance performance trial	72.5 ± 4.3	72.3 ± 3.9	72.5 ± 4.2
Total body water (kg)			
Pre-glycogen depletion exercise	43.8 ± 2.9	43.7 ± 3.2	44.2 ± 2.8
Post-glycogen depletion exercise	43.0 ± 3.5	43.2 ± 3.7	43.1 ± 2.7
Pre-endurance performance trial	43.1 ± 2.8	43.2 ± 3.2	43.3 ± 2.4
Post-endurance performance trial	43.9 ± 2.8	43.7 ± 2.5	44.9 ± 2.4

Note. Values are means ± standard deviation. [1]Kroger chocolate milk: 180 kcals, 33 g carbohydrate, 9 g protein, 2.5 g fat; [2]Fluid replacement drink: 50 kcals, 14 g carbohydrate, 0 g protein, 0 g fat; [3]Carbohydrate replacement drink: 180 kcals, 35.3 g carbohydrate, 8.7 g protein, 0.7 g fat per serving. [4]For the endurance performance trial. *Significantly different from carbohydrate replacement drink ($P < 0.05$).

Table 4 Average Composition of Subjects' Diets (% of Total Calories) for 3 Days Prior to Each Treatment

	Chocolate milk	Fluid replacement drink	Carbohdrate replacement drink
% Carbohydrate*	61.9 ± 7.7	62.6 ± 4.4	67.2 ± 5.8
% Protein*	21.1 ± 5.3	21.3 ± 2.9	16.9 ± 3.6
% Fat*	16.7 ± 3.9	15.9 ± 2.8	15.7 ± 3.7

Note. Values are means ± standard deviation. *No significant difference between treatments ($P > 0.05$).

Table 5 Average Workloads for Glycogen Depleting Exercise

% P_{max}	Workload (Watts)
50	184.1 ± 19.1
60	220.8 ± 23.0
70	257.7 ± 26.7
80	294.3 ± 30.7
90	331.2 ± 34.4

Note. Values are means ± standard deviation.

In contrast to the findings of the present and above-mentioned studies are the findings of Williams et al. (36), who reported that subjects exercised an average of 55% longer following ingestion of CR (Endurox) compared to FR (Gatorade) (31.1 vs. 20.0 min, respectively). The contrasting results may be due to methodological differences. The subjects in the study of Williams et al. (36) cycled at 85% VO_{2max}, while those in the present study and in other studies (14, 38) exercised at 70% VO_{2max}. Williams et al. (36) suggest that their contrasting results with these other studies (14, 38) may be due to a greater reliance on muscle glycogen at 85% versus 70% VO_{2max}. However, muscle glycogen is but one of many variables that affect time to exhaustion at higher exercise intensities. For instance, at exercise intensities above the lactate threshold, fatigue is also associated with acidosis and the accumulation of metabolites. It is generally agreed that the lactate threshold occurs at an intensity greater than 70% VO_{2max} in endurance-trained athletes (11, 16). Therefore, in the present study, 70% VO_{2max} was chosen as the intensity for the endurance performance trial to ensure that the exercise remained aerobic in nature, and that time to exhaustion was more a result of the muscles' glycogen content rather than acidosis. Given the aerobic characteristics of the subjects in the study of Williams et al. (36) ($VO_{2max} = 62\ mL \cdot kg^{-1} \cdot min^{-1}$), it is possible that some of the subjects were exercising above their lactate threshold. Since Williams et al. (36) did not include lactate measurements following the endurance performance trial, it cannot be determined whether the subjects of their study were exercising above their lactate threshold. Since exercise above the lactate threshold includes a significant contribution from oxygen-independent metabolism, 85% VO_{2max} may not be the most appropriate intensity at which to assess the efficacy of a sports drink on glycogen-dependent endurance performance. In addition, different definitions of time to exhaustion between studies may have contributed to the differences in the results. For example, Williams et al. (36) defined time to exhaustion as a fall in pedal cadence below 60 RPM for 5 s, while subjects in the present study cycled until their average pedal cadence over 60 s fell below 10 RPM of their preset cadence (85 to 100 RPM) after they were given a second chance to maintain the cadence. Taken together, the results of the present study and these other studies, which used different carbohydrate concentrations of the drinks, suggest that something other than, or in addition to, the availability of carbohydrates contributes to muscle glycogen restoration and/or time to exhaustion during endurance exercise.

It is possible that the different types of carbohydrate in the three drinks and/or their different macronutrient compositions contributed to the difference in exercise performance. Chocolate milk and FR are similar in their carbohydrate compositions, containing the monosaccharides glucose and fructose and the disaccharide sucrose (milk also contains the disaccharide lactose, which is composed of glucose and galactose). However, CR contains complex carbohydrates (maltodextrin), in addition to glucose and fructose. Casey et al. (6) found no significant difference in muscle glycogen resynthesis in subjects ingesting either glucose or sucrose, however they did find a greater increase in liver glycogen resynthesis following sucrose ingestion, which also positively influenced subsequent exercise performance. It has also been suggested that the type of carbohydrates ingested may produce different blood glucose and insulin responses (8), which may influence liver glycogen resynthesis. Thus, it is possible that the absence of sucrose in CR in the present study contributed to the shorter time to exhaustion and less total work due to less liver glycogen resynthesis. In addition, given that increases in muscle glycogen content during the first 4 to 6 h post-exercise are greater with ingestion of simple as compared to complex carbohydrates (17), it is possible that the 4-h recovery period in the present study limited the complete digestion of the complex carbohydrates contained in CR. Additionally, since the subjects exercised at an intensity below their lactate thresholds (70% VO_{2max}), there would have been a reliance on free fatty acids as well as carbohydrates. The greater fat content of the chocolate milk may have increased circulating free fatty acids in the blood, delaying glycogen depletion and allowing for an increased time to exhaustion. Alternatively, the fat content of the chocolate milk may have delayed glycogen resynthesis and *decreased* time to exhaustion due to a decreased gastric emptying rate and a consequent decreased carbohydrate absorption rate. It is possible that the use of non-fat chocolate milk may have yielded an increased time to exhaustion compared to FR.

Both glycogen restoration and rehydration after exhausting exercise are necessary for optimal substrate availability, cardiovascular function, and thermoregulation during subsequent exercise bouts. For example, Fallowfield et al. (15) found no significant difference in time to exhaustion while running at 70% VO_{2max} between ingestion of FR (6.9% CHO) and a placebo. To keep the subjects equally hydrated across trials, each subject was given the same volume of fluid for each treatment. Total body water, which was calculated from bioelectrical impedance analysis, and body mass were used as indicators of hydration status in this study to determine a possible effect of dehydration on exercise performance. As anticipated, neither measure differed between all three trials, both at rest (prior to any exercise) and following the 4-h recovery period (Table 3). Furthermore, there were no differences between resting and post-recovery total body water and body mass for all three trials. Since rehydration is dependent on the ingestion of adequate fluid and sodium to recover that lost in sweat (31), it was expected that 4 h would be an adequate amount of time for the subjects to rehydrate. With each type of recovery drink given to the subjects (1018 mL) and the ad libitum water ingestion, the subjects met the volume and sodium requirements for rehydration (2).

The subjects commented and noted on their questionnaires (on a scale of 1 to 10, with 1 signifying no symptoms and 10 signifying severe symptoms) at the end of the recovery period that the amount of stomach distress was greater following CR ingestion (2.7 ± 2.1, vs. 2.4 ± 2.4 and 1.8 ± 1.4 for chocolate milk and FR, respectively). While not statistically significant, the practical significance of a slightly greater stomach distress with CR ingestion could have influenced the subjects' performances during the endurance exercise and may indicate a difference in carbohydrate absorption.

There were no significant differences in the macronutrient composition of the subjects' diets for the 3 d prior to each trial in the present study (Table 4). Thus, differences in time to exhaustion and total work cannot be attributed to the carbohydrate content of the subjects' pre-exercise diets. In addition, there were no significant differences between trials in the amount of time the subjects exercised during the initial glycogen depletion exercise, and was similar to that of other studies using the same glycogen depletion protocol (25, 35).

Subjects' exercise heart rates (Figure 2), end-exercise RPE, and post-exercise blood lactate concentration were similar between the three trials in the present study (Table 3), suggesting that all three trials presented similar physiological challenges. Other studies have also found no difference in physiological measurements, such as heart rate, VO_2, minute ventilation, RER, blood lactate, or RPE during endurance exercise after ingesting FR, CR, or placebo during the recovery period between two exercise bouts (3, 7, 36).

Since it was expected that there would be little, if any, accumulation of lactate in the blood when muscle glycogen content is low, blood lactate was measured immediately after both exercise bouts. Mean lactate values following the glycogen depletion exercise and endurance performance trial suggest that fatigue during the exercise bouts was more likely a result of glycogen depletion rather than other metabolic factors associated with a high lactate concentration or acidosis. The pooled lactate values are in agreement with other studies measuring blood lactate after glycogen-depleting exercise (6, 21, 39). For example, Zawadzki et al. (39) reported that blood lactate increased from a pre-exercise value of 0.87 ± 0.05 mmol/L to 3.98 ± 0.18 mmol/L following glycogen-depleting exercise, comparable to that of the present study.

In conclusion, the results of this study suggest that, chocolate milk, with its high carbohydrate and protein content, may be considered an effective alternative to commercial FR and CR for recovery from exhausting, glycogen-depleting exercise.

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