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The Performance Enhancing Ration Components (PERC) project supports the Army Science and Technology Objective "Nutritional Strategies to Enhance Soldier Performance." The focus of the PERC project is to demonstrate, through nutrition intervention, enhancement of physical and/or mental performance in extreme environmental conditions or during sustained high-intensity work. In this PERC study, we examined the effects of a liquid carbohydrate (CHO) supplement on exercise endurance of Special Operations Forces (SOF) soldiers.

The results of this study have encouraging implications in that they demonstrate that the sustainability and survivability of our combat forces can be enhanced through nutrition intervention. By tailoring the nutrient composition of the diet, environmental and battlefield stress may be attenuated and decrements in performance may be prevented.

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PERFORMANCE ENHANCING RATION COMPONENTS PROGRAM: SUPPLEMENTAL CARBOHYDRATE TEST

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
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UNITED STATES ARMY
MEDICAL RESEARCH & MATERIEL COMMAND

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PERFORMANCE ENHANCING RATION COMPONENTS PROGRAM: SUPPLEMENTAL CARBOHYDRATE TEST

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EXECUTIVE SUMMARY

The Performance Enhancing Ration Components (PERC) project supports the Science and Technology Objective "Nutritional Strategies to Enhance Soldier Performance." The focus of the PERC project is to demonstrate, through nutrition intervention, enhancement of physical and/or mental performance in extreme environmental conditions or during sustained high-intensity work. In this PERC study, we examined the effects of a liquid carbohydrate (CHO) supplement on exercise endurance of Special Operations Forces (SOF) soldiers.

On each of three test days during an 11-day experimental period, 18 SOF soldiers performed a high-intensity, two-hour treadmill run in the morning. After a seven-hour rest, the subjects then performed a treadmill run-to-exhaustion. During the two days separating test days, subjects performed lower intensity treadmill running and stationary cycling for a total time of one hour in the morning and one hour in the afternoon. Dietary intake of CHO and protein (PRO) was controlled to simulate the average daily intake in a field setting (4 $g \cdot kg^{-1}$ body weight [BW] and 1.5 $g \cdot kg^{-1}$ BW, respectively, or approximately 300 $g \cdot day^{-1}$ CHO and 112 $g \cdot day^{-1}$ PRO); fat intake was set at a level to maintain BW. The effect of this diet was a transition from a CHO-predominant to a fat-predominant metabolism, as is normally seen in a field setting. A placebo (CHO-0) and two CHO treatments were provided to each subject: a 2.2 $g \cdot kg^{-1}$ BW bolus immediately after the morning exercise (CHO-1), a 1.0 $g \cdot kg^{-1}$ BW bolus immediately after the morning exercise, and a 0.4 $g \cdot kg^{-1}$ BW bolus three times at 20-minute intervals during the afternoon exercise (CHO-2).

Time-to-exhaustion was 6% longer for the CHO-1 ($p=0.045$) and 17% greater for the CHO-2 ($p=0.0001$) trials compared with the CHO-0 trial (114.1 ± 2.2, 120.5 ± 2.2, and 133.9 ± 2.2 min for CHO-0, CHO-1, and CHO-2, respectively). Additionally, CHO-2 mean time-to-exhaustion was greater than CHO-1 ($p=0.0002$).

The results of this study demonstrate how one nutritional intervention, CHO supplementation, can enhance physical performance in a carefully controlled setting. This suggests that this intervention may have application in field combat settings to increase soldier sustainability.

PERFORMANCE ENHANCING RATION COMPONENTS PROGRAM: SUPPLEMENTAL CARBOHYDRATE TEST

INTRODUCTION

The Performance Enhancing Ration Components (PERC) project supports the Army's Science and Technology Objective (STO): "Define and develop nutritional strategies and biotechnologies to enhance soldier performance in all environments" (Army Science and Technology Master Plan, 1993). The focus of the PERC project is to demonstrate, through nutrition intervention, enhancement of physical and/or mental performance in extreme environmental conditions or during sustained high-intensity work. Subject matter experts presented current perspectives in this field at a November 1992 workshop hosted by the National Academy of Sciences Committee on Military Nutrition Research entitled "An Evaluation of Potential Performance Enhancing Food Components for Operational Rations." Utilizing the information reviewed at this workshop, scientists at the U.S. Army Research Institute of Environmental Medicine (USARIEM) and Natick Research, Development, and Engineering Center, Natick, Mass., formed a Joint Working Group and selected the most promising components for studies within a military context. Potential performance enhancing ration supplements chosen for further study were carbohydrate, glucose-electrolyte beverage, caffeine, glutamine, and tyrosine. In addition, food discipline (the timing of food and nutrient consumption in relationship to total food intake and performance) was identified as a potential "tool" to enhance performance. Supplemental carbohydrate was selected as the initial PERC item to test.

BACKGROUND

As exercise intensity increases, muscle glycogen becomes the primary fuel source. It is well known that carbohydrate is the rate limiting fuel for prolonged, high-intensity exercise. As glycogen levels decrease, perception of fatigue increases and capacity to perform exercise above 70% $\dot{V}O_2$max declines (Ivy, 1991). Subsequent replenishment of glycogen stores is dependent upon an adequate dietary carbohydrate intake. After exercise that significantly lowers glycogen levels, rapid synthesis of glycogen occurs in response to carbohydrate feeding (Bergstrom & Hultman, 1967). However, timing of the carbohydrate feeding is important. Maximum glycogen

synthesis occurs when carbohydrate is supplied immediately post-exercise as compared to two hours post-exercise (Ivy et al., 1988). The amount of carbohydrate provided is also important. Consumption of 0.7-1.5 $g \cdot kg^{-1}$ body weight (BW) immediately post-exercise allows for maximum glycogen storage (Blom et al., 1987 and Ivy & Lee, 1988). The rate of storage is decreased by about half when the amount of carbohydrate provided immediately post-exercise is reduced to 0.35 $g \cdot kg^{-1}$ BW (Blom et al., 1987).

Several studies have demonstrated that carbohydrate supplementation during cycling enhances physical performance in subjects consuming a diet adequate in calories and carbohydrate (Wright et al., 1991, Coyle et al., 1986, and Hargreaves et al., 1984). One cycling study also demonstrated increased performance when supplemental carbohydrate was provided to subjects on a carbohydrate restricted diet (Neufer et al., 1987). Further, it has been shown in subjects consuming their usual training diet that provision of carbohydrate before and during cycling exercise enhances performance to a greater degree than when carbohydrate is eaten only before exercise (Wright et al., 1991). Several studies of runners, however, have failed to show an improvement in performance with supplemental carbohydrate (Riley et al., 1988, Noakes et al., 1988, and Sasaki et al., 1987). The work of Riley et al. (1988) was of particular interest as they studied subjects who had fasted for 21 hours before the performance trials, presumably resulting in lowered glycogen stores.

On average, soldiers in the field receiving military rations consume only about 300 $g \cdot day^{-1}$ of carbohydrate, with a total daily caloric intake of approximately 2500 calories (Jones et al., 1990). This amount of carbohydrate is significantly lower than that recommended for glycogen repletion (Costill et al., 1981, and Robergs, 1991). The Committee on Military Nutrition Research, National Academy of Sciences, recognizing that an optimum intake is difficult to achieve in a field setting, recommends a carbohydrate intake of at least 400 $g \cdot day^{-1}$ for soldiers (1988).

Most of the previous work demonstrating an ergogenic effect with supplemental carbohydrate has been performed with subjects consuming a carbohydrate-adequate diet. The objectives of this study were to determine the following: (1) if supplemental carbohydrate would enhance the performance of soldiers consuming a diet with a macronutrient composition similar to that eaten in a field setting; and (2) if timing of

carbohydrate consumption would alter the magnitude of any performance enhancing effects of carbohydrate.

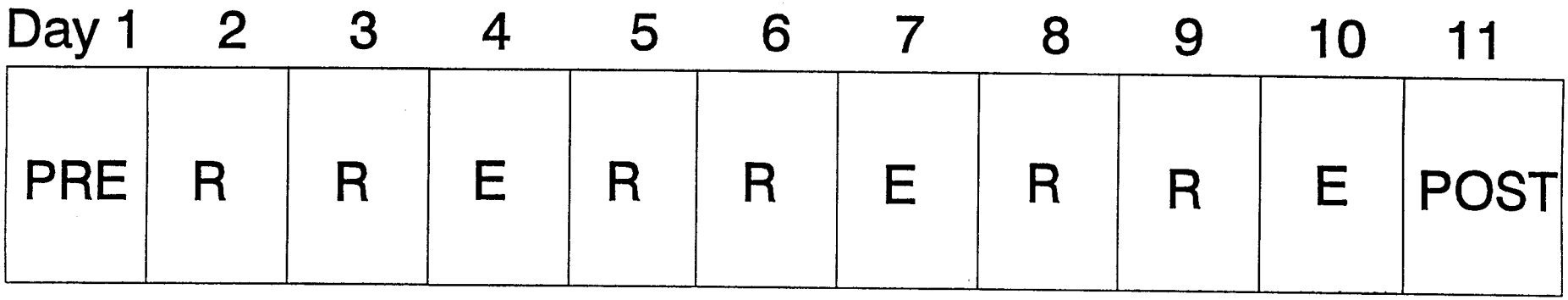
METHODS

SUBJECTS

Eighteen highly motivated male Special Operations Forces (SOF) soldiers volunteered to participate in the study after giving informed written consent. Their mean (±SD) age, height, weight, % body fat, and $\dot{V}O_2max$ were 30 ± 3 yr, 178 ± 8 cm, 83.2 ± 8.7 kg, 18.5 ± 5.8%, and 4.31 ± 0.44 $L \cdot min^{-1}$, respectively. This study was approved by the Human Use Review Committees at USARIEM and the U.S. Army Medical Research and Materiel Command.

EXPERIMENTAL DESIGN

During the experiment, the subjects lived on an inpatient metabolic ward. The experimental timeline is shown in Figure 1. At the start (day 1) and at the end (day 11) of the experiment, these measurements were taken: height, weight, body composition, and maximum aerobic capacity ($\dot{V}O_2max$). Exercise testing was performed three times, on test days 4, 7, and 10, with two rest days (R) preceding each exercise test day (E). On each exercise day, in the morning the subjects engaged in endurance exercise and in the afternoon, the subjects engaged in exercise consisting of prolonged, submaximal treadmill exercise to exhaustion (Figure 2). Using a counterbalanced, single-blind, repeated measures design, the subjects were given a placebo, or one of two carbohydrate treatments after the morning exercise and during the afternoon run-to-exhaustion. The placebo (CHO-0) was a non-nutritive solution provided at both exercise sessions. CHO-1 provided 2.2 $g \cdot kg^{-1}$ BW of carbohydrate in a single bolus immediately after the morning exercise and placebo during the afternoon exercise. CHO-2 provided 2.2 $g \cdot kg^{-1}$ BW of carbohydrate in a divided dose: 1.0 $g \cdot kg^{-1}$ BW immediately following the morning exercise and 0.4 $g \cdot kg^{-1}$ BW at 20, 40, and 60 min time points during the afternoon exercise. Ambient temperature and relative humidity were 17 ± 1° C and 82 ± 6%, respectively.



Pre/post = measurement day; R = rest day; E = exercise day

Figure 1. Experimental design

ANTHROPOMETRIC DATA

Pre-test vertical height was measured in duplicate to the nearest 0.1 cm using a stadiometer (Holtain Stadiometer, Holtain, Ltd.). Body weight was measured in the morning, after the subject voided but before breakfast, using an electronic scale (model 6800, Cardinal Detecto) accurate to 0.1 kg. Body composition was determined by dual energy X-ray absorptiometry (DEXA)(Hologic, Waltham, MA) soft tissue and bone mass analyses, as previously described (Mazess et al., 1990).

RESTING ENERGY EXPENDITURE

Resting energy expenditure (REE) was determined on all R-Days. $\dot{V}O_2$ and $\dot{V}CO_2$ were measured using a metabolic cart with a ventilated hood system (SensorMedics, 2900z, Anaheim, CA), which was calibrated against gases of known concentration before each test session. Measurement was made on supine subjects over a 30-min period, and the values were averaged over the last 10-min . Subjects' REE and respiratory exchange ratio (RER) for this 10 min period were calculated using the equations derived by Weir (1949).

AEROBIC POWER ($\dot{V}O_2$max)

A continuous, treadmill exercise protocol was employed to elicit $\dot{V}O_2$max; the protocol was a modified version of that described by Costill and Fox (1969). After a 3-minute warm-up at 1.56 $m \cdot sec^{-1}$ (3.5 miles per hour) and 0% grade, the speed was increased to 2.5 $m \cdot sec^{-1}$ (5.6 miles per hour) for 3 minutes (0% grade). The grade was maintained at 0% for the following 3-minute stage while the speed was increased to 3.35 $m \cdot sec^{-1}$ (7.5 miles per hour). Thereafter, the speed was held constant while the grade was increased by 2% every 2 minutes beginning with a 4% grade, until $\dot{V}O_2$max was achieved. Previously established criteria were used to determine attainment of $\dot{V}O_2$max (Thoden et al., 1983). Respiratory gas exchange was continuously monitored via an open circuit spirometry system (Sensor Medics, 2900Z, Anaheim, Calif.), which was calibrated using gases of known concentration before each test.

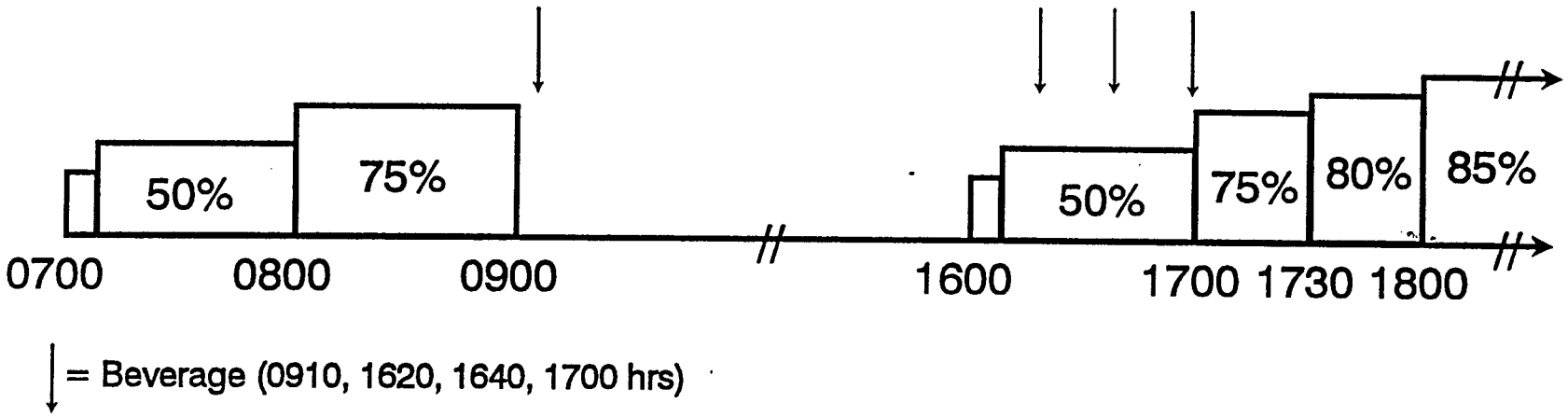


Figure 2. Exercise day schedule.

ENDURANCE EXERCISE TESTING

Exercise Days

Exercise days were comprised of a morning and an afternoon treadmill session. During the morning session, subjects completed a two-hour treadmill run (Q-55, Quinton Instrument Co., Seattle, Wash.) during which exercise intensity was 35% of $\dot{V}O_2$max for five min, 50% for 55 min, and 75% for one hr. Following a 7-hr rest period, a treadmill run to exhaustion was performed. Exercise intensity for this afternoon exercise session was 35% of $\dot{V}O_2$max for five min, 50% for 55 min, 75% for 30 min, 80% for 30 min, and 85% until exhaustion.

Rest Days

During rest days, the subjects exercised one hour in the morning and one hour in the afternoon. Each of these exercise sessions consisted of 30 min on a cycle ergometer and 30 min on a treadmill, both performed at 50% of $\dot{V}O_2$max. These exercise sessions were supervised and intensity was continuously monitored by heart rate response (Polar Pacer, Polar CIC, Port Washington, N.Y.).

DIET

Dietary intake of soldiers was controlled to simulate the average daily intake of carbohydrate and protein in a field setting: $4 g \cdot kg^{-1}$ BW carbohydrate and $1.5 g \cdot kg^{-1}$ BW protein (or about $300 g \cdot day^{-1}$ carbohydrate and $112 g \cdot day^{-1}$ protein for a 75 kg soldier) (Jones et al., 1990). Fat intake was set at a level to maintain body weight. The 3-day cycle menu is listed in Appendix A. Subjects began the controlled diet regimen three days before endurance testing began. Test diets were designed using the Extended Table of Nutrient Values (ETNV) (Moore & Goodloe, 1990). Food and beverage items were weighed to the nearest 0.01 g (Mettler balance PM4000, Hightstown, N.J.). Subjects were strongly encouraged to consume all foods and beverages provided; unconsumed foods and beverages were weighed and subtracted from the total. Water and caffeine- and calorie-free beverages were available *ad libitum*. Subjects were asked to limit caffeine intake to one cup of coffee per day for 10 days prior to the

study. Caffeine-containing beverages and medications were not available during the study.

CARBOHYDRATE SOLUTIONS

A placebo (CHO-0) and two carbohydrate treatments (CHO-1, CHO-2) were provided to each subject: CHO-1 = 2.2 $g \cdot kg^{-1}$ BW immediately after the morning exercise session and placebo during the afternoon exercise session; and CHO-2 = 1.0 $g \cdot kg^{-1}$ BW immediately after the morning exercise and 0.4 $g \cdot kg^{-1}$ BW at 20, 40, and 60 min during the afternoon exercise session (Figure 2). In the CHO-1 session, supplemental carbohydrate was administered as a 25% solution of maltodextrin (Maltrin M500, Grain Processing Corporation, Muscatine, Iowa), aspartame, flavoring, and coloring; the CHO-2 beverage was identical except that it was an 11% maltodextrin solution. Formulated and tested to be indistinguishable, the placebo (CHO-0) was sweetened, flavored, and colored to resemble CHO-1 and CHO-2. Total fluid volumes of CHO-0, CHO-1, and CHO-2 consumed were dictated by body weight, but were identical between trials for each subject (range: 1094 to 1280 ml). Additional plain water was provided *ad lib*.

PHYSIOLOGICAL VARIABLES

During the afternoon endurance exercise trials, O_2 consumption ($\dot{V}O_2$) was measured with an on-line metabolic analyzer (Sensor Medics 2900Z, Anaheim, Calif.). Respiratory exchange ratio was determined from $\dot{V}O_2$ and $\dot{V}CO_2$ measurements. Substrate oxidation was calculated using the equation of Weir (1949). Respiratory samples were collected for 5-min intervals at 20, 50, 75, 100 and 120 min of exercise.

Venous blood samples were collected at 0, 40, and 70 min of exercise and immediately post-exercise (IP). Blood samples were acquired from an indwelling venous catheter, which was previously inserted into a superficial forearm vein. The catheter was kept patent with isotonic saline. All samples were collected in the upright posture. The pre-exercise (0 min) sample was preceded by a 20-min postural equilibration period. Blood for glucose, free fatty acid, glycerol, and insulin analyses

was transferred to plain test tubes. Serum was collected after centrifugation and frozen at -80°C until subsequent analysis.

Glucose, glycerol,and free fatty acids were analyzed on the Beckman Synchron CX5 analyzer using Beckman (Brea, Calif.) CX reagents for glucose, Sigma (St Louis, Mo.) reagent for glycerol, and WAKO (Dallas, Tex.) reagent for free fatty acids. The latter two analyses were adapted to the Beckman CX5 at the Pennington Biomedical Research Center (Clinical Research Laboratory Manual, Pennington Biomedical Research Center, Baton Rouge, La.).

Insulin was analyzed by microparticle enzyme immunoassay on the Abbott IMx automated immunochemistry analyzer using Abbott (Chicago, Ill.) reagent. Recovery of spiked samples was 93-106.7%. Inter-assay variance was 3-8%.

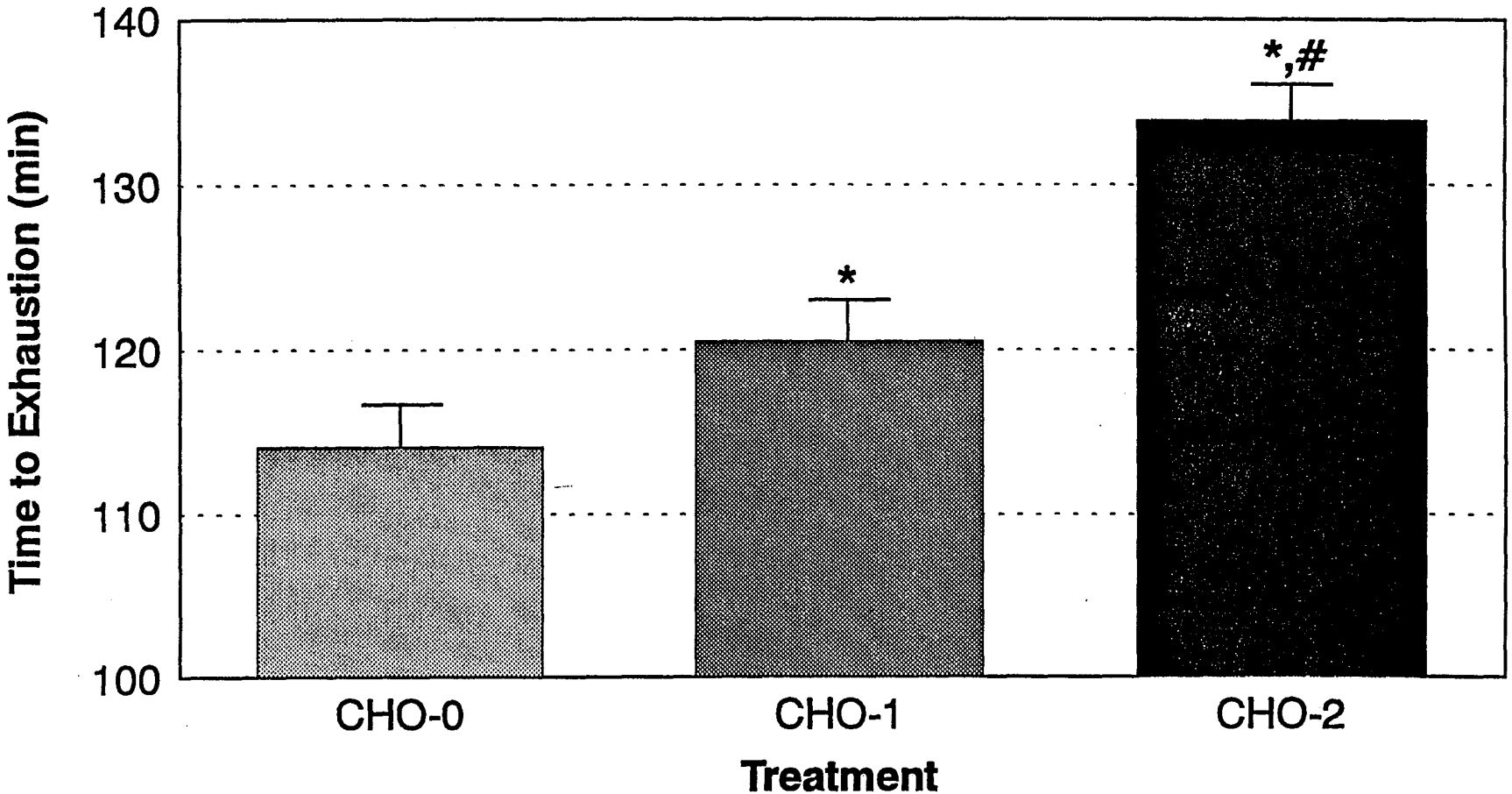
STATISTICAL ANALYSIS

A regression line was calculated for run-to-exhaustion times utilizing least squares estimates. The mean response for each subject was calculated and compared across the five different treatment sequences using ANOVA to test for any interaction between the treatment effect and the order given. A three-way ANOVA, with terms for subject, period, and treatment, was then run to test for treatment effect. Other comparisons were made using one-way analysis of variance for repeated measures. Level of significance was $P<0.05$. Post hoc comparisons were made using the Student-Newman-Keuls test.

RESULTS

PERFORMANCE RESULTS

Mean time-to-exhaustion was significantly higher for CHO-1 (120.5 ± 2.2 min, p=0.045) and CHO-2 (133.9 ± 2.2 min, p=0.0001) compared to the control (CHO-0 = 114.1 ± 2.2 min) (Figure 3). Individual times-to-exhaustion are listed in Appendix B. Additionally, endurance time for CHO-2 was greater than CHO-1 (p=0.0002).



* Significantly different from CHO-0. # Significantly different from CHO-1. Values are $\bar{x}$ +SD.

Figure 3. Mean run-to-exhaustion times.

Table 1 Performance Data

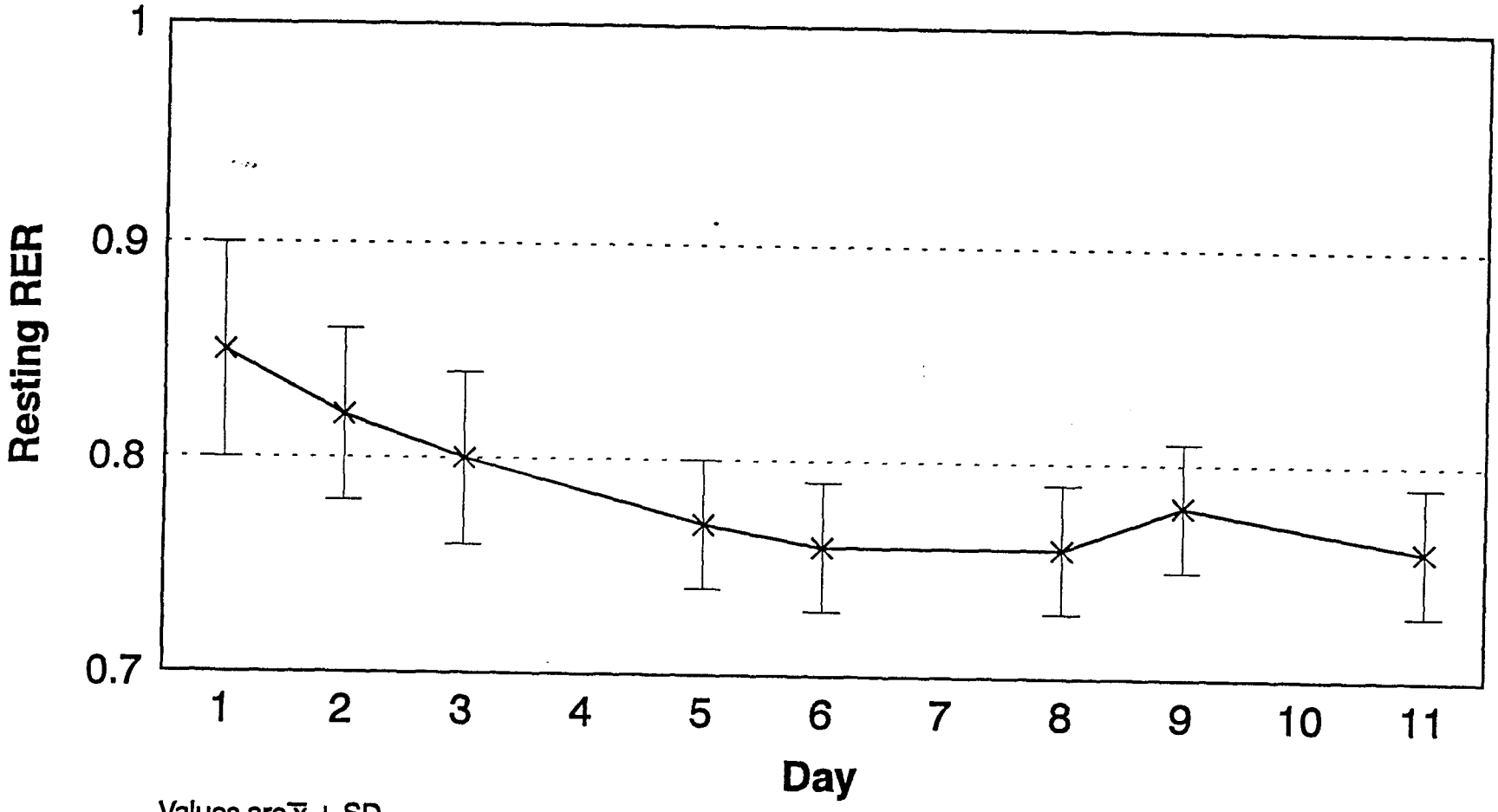
Trial	n	$\bar{x}$ (as calculated)	$\bar{x}$ (LS means)	*p* vs.CHO-0	*p* vs.CHO-1
CHO-0	16	116.9	114.1	-	0.045
CHO-1	17	118.0	120.5	0.045	-
CHO-2	16	135.9	133.9	0.0001	0.0002

RESPIRATORY RESULTS, CARBOHYDRATE OXIDATION

Daily resting RER data (Figure 4) indicated that the physically active soldiers adjusted to a field-type military diet by day 2 (RER 0.82) and remained in a state of fat-predominant metabolism throughout the remainder of the experiment. Resting RER decreased during the study from about 0.86 to 0.77, denoting that the contribution of fat to the resting fuel mix increased from approximately 48% to 76% (Lusk, 1928).

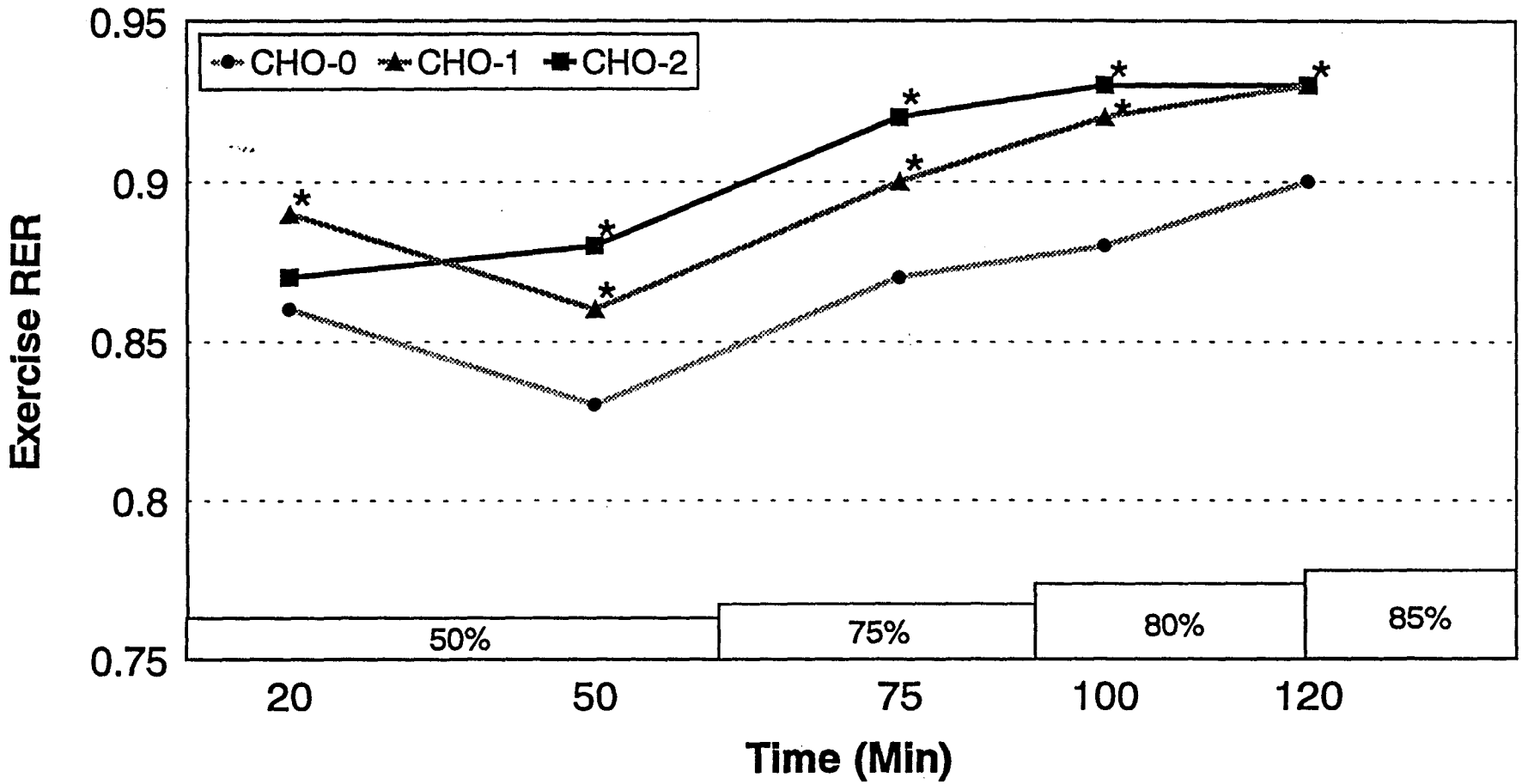
RER values during exercise are shown in Figure 5. The RER during CHO-1 trial was higher than CHO-0 at all time points measured during exercise ($p<0.05$); CHO-2 was greater than CHO-0 at all measurements except at the 20-min mark ($p<0.05$).

As expected, carbohydrate oxidation increased as exercise intensity increased. In addition, carbohydrate oxidation differed among treatments. Carbohydrate oxidation was greater ($p<0.05$) during CHO-1 than CHO-0 at 20, 50, and 100 min. CHO-2 carbohydrate oxidation was significantly greater ($p<0.05$) than CHO-0 at 50, 75, and 100 min, and was greater ($p<0.05$) than CHO-1 at the 75 min measurement (Table 2). Total carbohydrate oxidation during the exercise test was greater ($p<0.05$) in CHO-1 (241 ± 75g) and CHO-2 (279 ± 89g) compared to CHO-0 (186 ± 63g). $\dot{V}O_2$ and RER were used to estimate the rate of carbohydrate oxidation.



Values are $\bar{x}$ + SD.

Figure 4. Daily resting respiratory exchange ratio.



* Significantly different from CHO-0. Values are $\bar{x}$ + SD.

Figure 5. Exercise respiratory exchange ratio.

Table 2 Carbohydrate oxidation at 20, 50, 75, 100, and 125 min of exercise, expressed as $g \cdot min^{-1}$

	CHO-0	CHO-1	CHO-2
20 min	1.45 ± .32	1.76 ± .42*	1.55 ± .42
50 min	1.19 ± .29	1.53 ± .50*	1.62 ± .35*
75 min	2.16 ± .41	2.52 ± .64	2.67 ± .33*
100 min	2.29 ± .61	2.92 ± .73*	2.95 ± .81*
125 min	2.67 ± .70	2.98 ± .66	3.27 ± .85

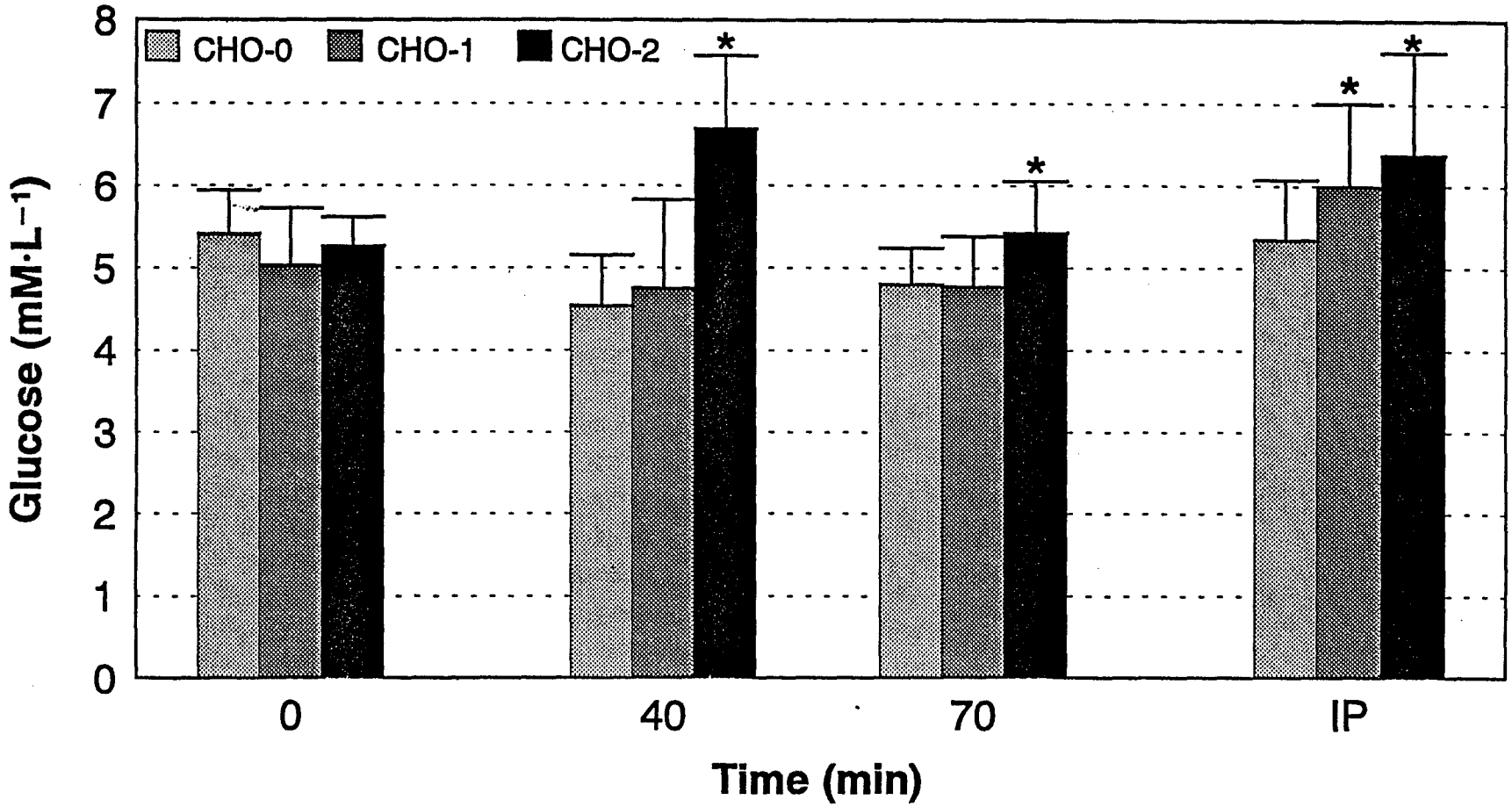
Values are $\bar{x}$ ± SD. *Significantly different than CHO-0 ($P<0.05$).

PLASMA GLUCOSE AND INSULIN

During CHO-1, blood glucose was higher ($p<0.05$) immediately post-exercise (IP) compared to CHO-0 (Figure 6). Compared to CHO-0, blood glucose was greater ($p<0.05$) at 40 min, 70 min, and IP during CHO-2. Plasma insulin was increased during CHO-2 at 70 min compared to CHO-0 and CHO-1 (Figure 7).

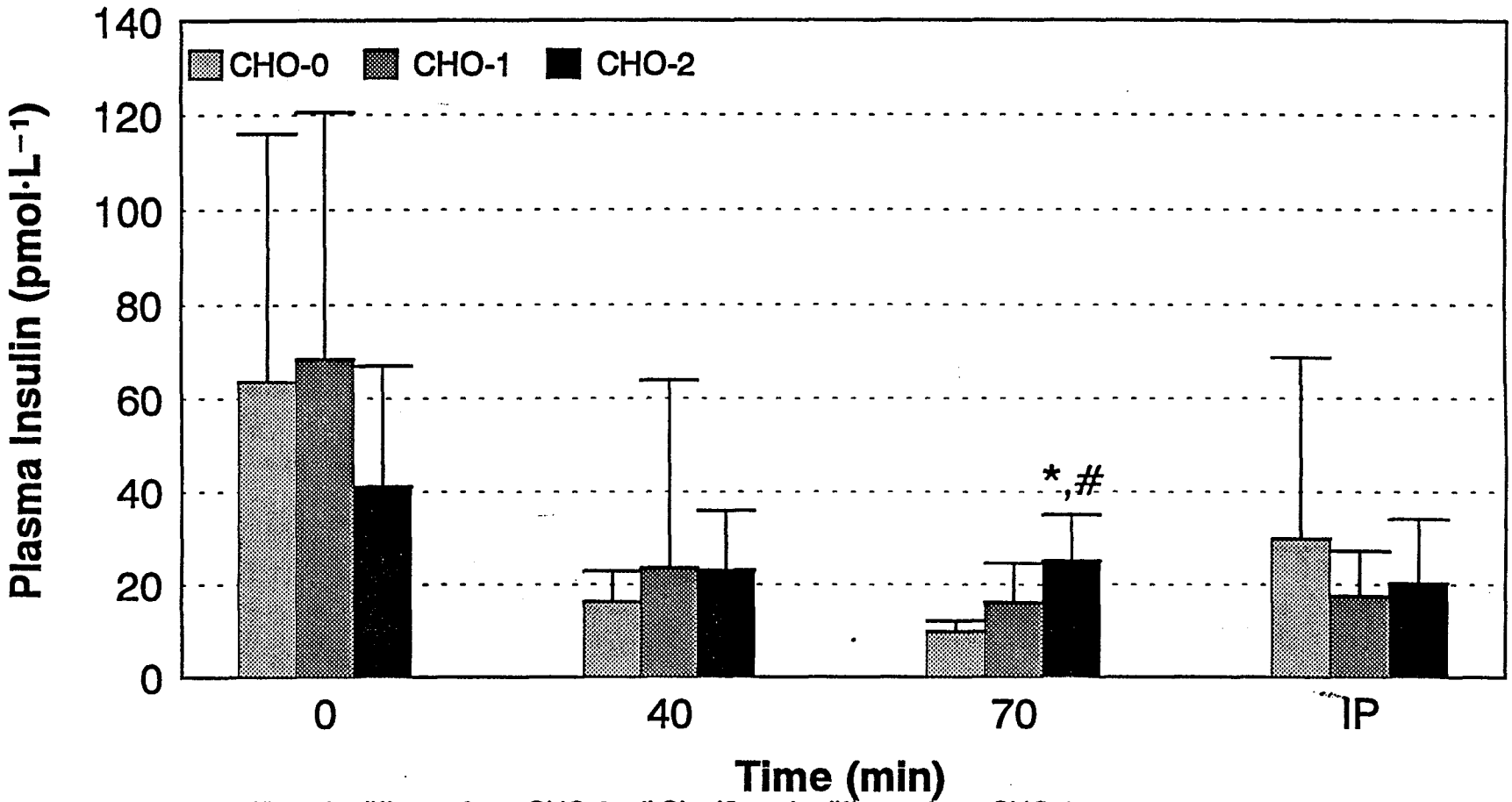
PLASMA FREE FATTY ACIDS, BLOOD GLYCEROL, AND BLOOD LACTATE

During CHO-1, free fatty acids (Figure 8) were lower ($p<0.05$) than CHO-0 at 40 min and 70 min. Plasma-free fatty acids (Figure 8) during CHO-2 were lower ($p<0.05$) than CHO-0 at 40 min, 70 min, and IP. During CHO-2, glycerol (Figure 9) was lower ($p<0.05$) than CHO-0 at 40 min and 70 min, and lower ($p<0.05$) than CHO-1 at 70 min.



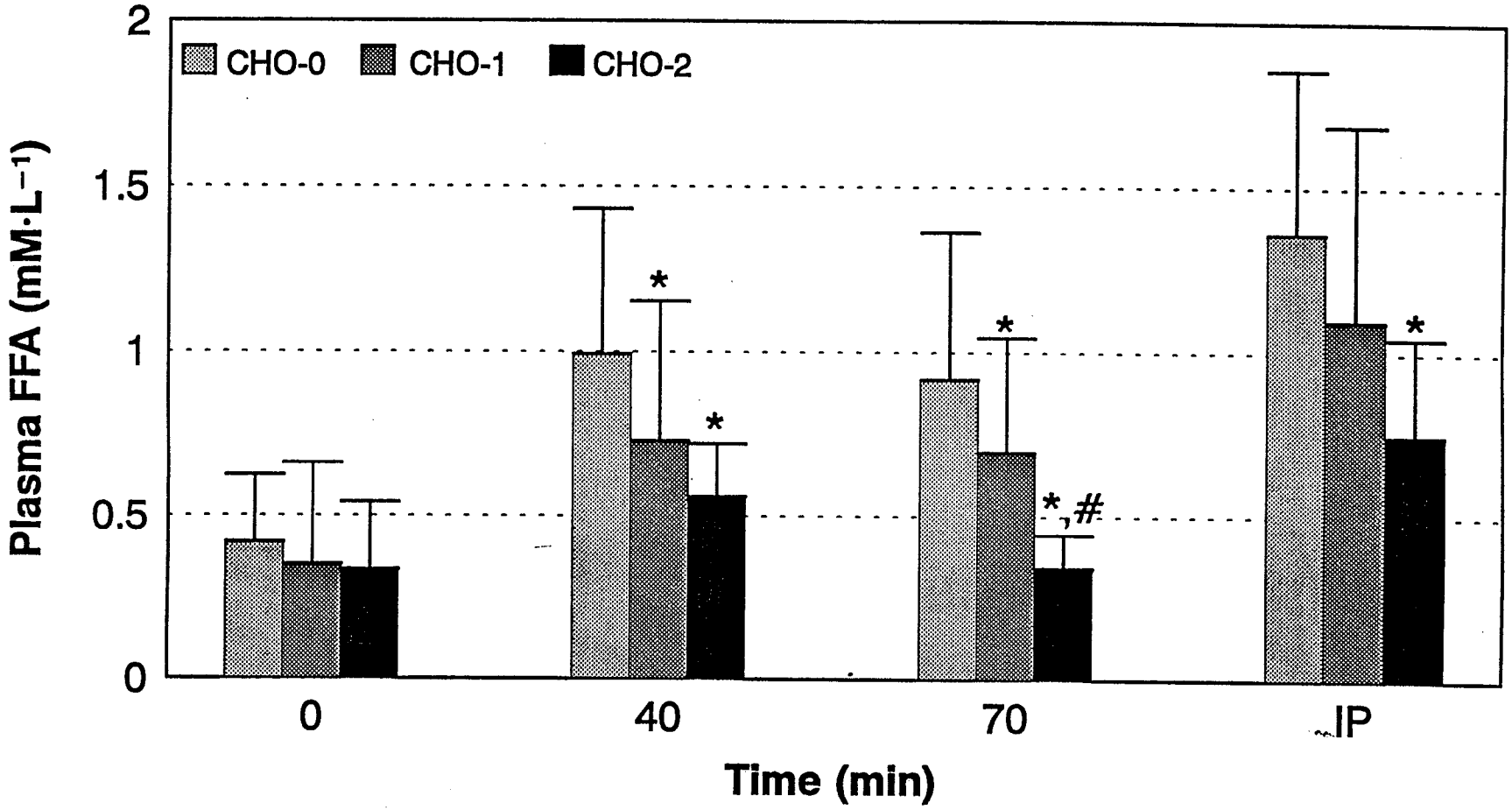
* Significantly different from CHO-0. Values are $\bar{x}$ + SD.

Figure 6. Blood glucose at 0 min, 40 min, and 70 min of exercise and immediately post-exercise (IP).



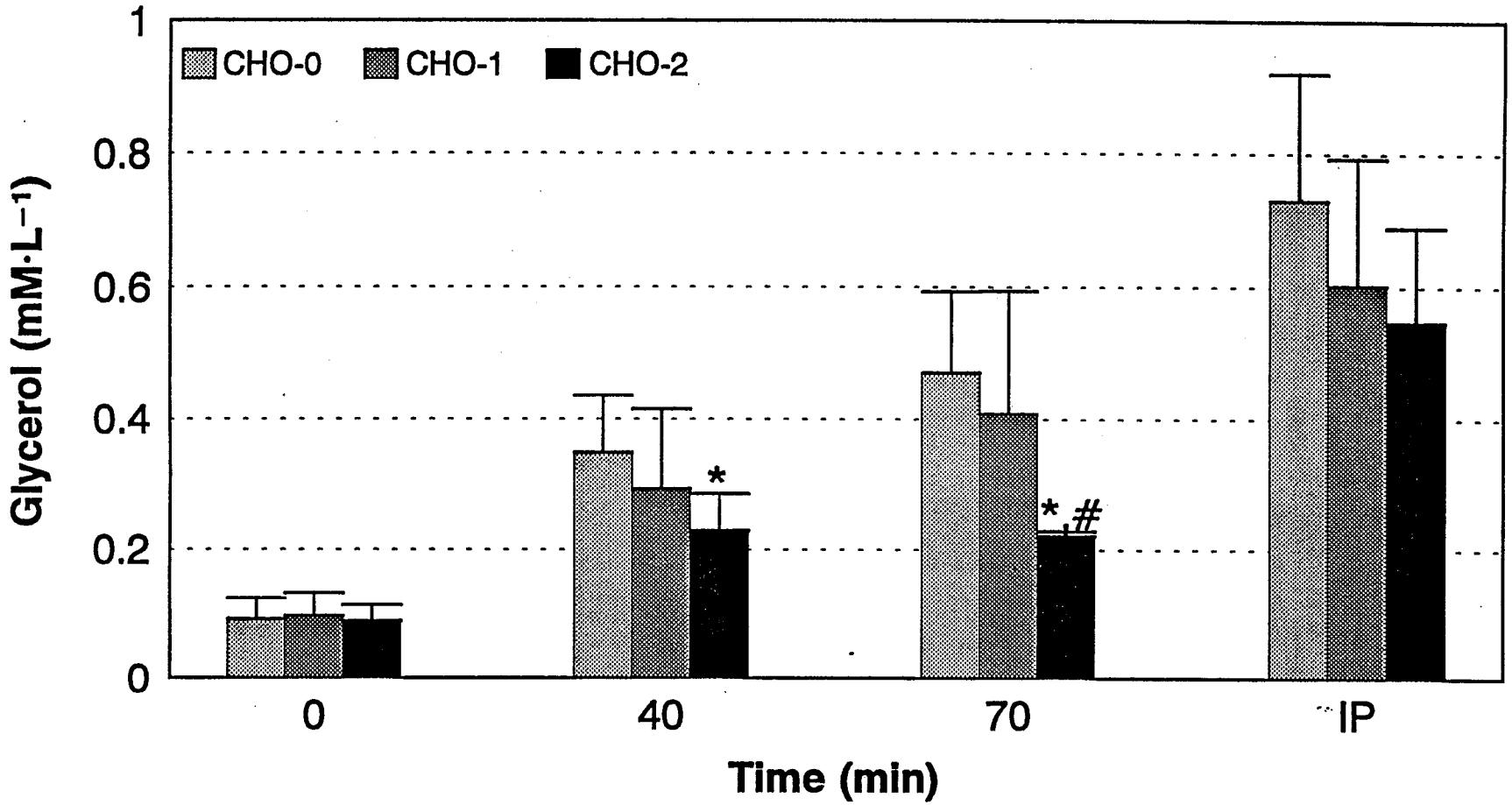
* Significantly different from CHO-0. # Significantly different from CHO-1.
Values are $\bar{x}$ + SD.

Figure 7. Plasma insulin at 0 min, 40 min, and 70 min of exercise and immediately post-exercise (IP). * Significantly different from CHO-0.



* Significantly different from CHO-0. # Significantly different from CHO-1.
Values are $\bar{x}$ + SD.

Figure 8. Plasma free fatty acids at 0 min, 40 min, and 70 min of exercise and immediately post-exercise (IP).



* Significantly different from CHO-0. # Significantly different from CHO-1.
Values are $\bar{x}$ + SD.

Figure 9. Plasma glycerol at 0 min, 40 min, and 70 min of exercise and immediately post-exercise (IP).

DISCUSSION

There were several important findings in this study. The first was that a liquid carbohydrate supplement increased treadmill run-to-exhaustion time in physically active soldiers. A significant increase in endurance time (6%) was also observed when the entire allocation of carbohydrate (2.2 $g \cdot kg^{-1}$) was consumed in the morning immediately after a routine exercise bout. These results are consistent with reports of the effects of CHO supplementation on cycle exercise endurance. Wright et al. (1991) demonstrated a significant 18% increase in endurance of subjects who consumed 5 $g \cdot kg^{-1}$ carbohydrate 3 hr before exercise. Similarly, Sherman et al. (1991) reported a 12% improvement in endurance time when subjects were fed 1.1 $g \cdot kg^{-1}$ carbohydrate 1 hr prior to exercise.

A dramatic increase in treadmill endurance time (17%) was achieved when carbohydrate was consumed (a) immediately after a morning treadmill run (1.0 $g \cdot kg^{-1}$) and (b) at 20 min intervals during the afternoon test of exercise endurance capacity (0.4 $g \cdot kg^{-1}$, at 15, 35, and 50 min of exercise). These data agree with those of Wright et al. (1991) who found endurance time increased by 44% in subjects fed carbohydrate both 3 hr before exercise (5 $g \cdot kg^{-1}$) and during exercise (0.2 $g \cdot kg^{-1}$). In addition, Neufer et al. (1987) showed a significant 22% increase in work output after 45 min of cycling at 77% $\dot{V}O_2max$ when subjects ingested 200 g carbohydrate 4 hr before exercise and 45 g carbohydrate 5 min before exercise.

Total carbohydrate oxidation during the endurance exercise test was 30% higher during CHO-1 and 50% higher during CHO-2 compared to CHO-0 ($p<0.05$). The mean amount of supplemental carbohydrate provided to each subject was 182 g. An additional 55 g and 93 g of carbohydrate was oxidized during CHO-1 and CHO-2, respectively. Thirty percent of the supplemental carbohydrate provided during CHO-1 was utilized during the run-to-exhaustion compared with 51% of that supplied during CHO-2.

As was found by other investigators (Coyle et al., 1986, and Hargreaves et al., 1984), carbohydrate ingestion during exercise was associated with higher blood glucose levels and lower free fatty acid and glycerol levels. The decrease in glycerol and free fatty acids during the CHO-2 trial suggests an inhibition of lipolysis (Wolfe et

al., 1990, and Wolfe and Peters, 1987). A similar pattern was evident during CHO-1, although glycerol was not significantly different from CHO-0. The significant decrease in free fatty acids, combined with an insignificant decrease in glycerol, could be attributed to increased free fatty acid utilization (Hurley et al., 1986, and Nurjhan et al., 1988).

The exercise routine in the present study involved exercise at progressively greater intensities (Figure 2). The larger contribution of carbohydrate to fuel oxidation at the higher intensities resulted in an elevation of the RER. As compared to CHO-0, the increase ($p<0.05$) in the RER for CHO-1 at all measurement times, and for CHO-2 at all measurement times except the 20-min mark, likely reflects the increased availability and metabolism of carbohydrate (Pirnay et al., 1977). These findings are consistent with the results of other investigators (Wright et al., 1991, Coyle et al., 1986, and Neufer et al., 1987). The RER at the 20-min measurement was higher for CHO-1 than CHO-2 ($p<0.05$); thereafter, the RER for CHO-2 tended to be higher (NS). The higher intake of carbohydrate after the morning exercise during CHO-1 (2.2 $g \cdot kg^{-1}$ vs. 1.0 $g \cdot kg^{-1}$ for CHO-2) may have resulted in increased glycogen repletion compared to CHO-2. Although previous work has shown no significant difference in glycogen repletion at these levels of carbohydrate intake in subjects consuming a high-carbohydrate diet (Ivy et al., 1988, and Blom et al., 1987), there may have been differences in glycogen deposition in these CHO-restricted subjects. Pre-exercise elevations in muscle glycogen facilitate increased glycogen utilization and carbohydrate oxidation during exercise (Coyle et al., 1985), and this could have resulted in the higher RER during CHO-1 at the 20-min measurement. The carbohydrate supplement consumed during the CHO-2 run-to-exhaustion would have been available for rapid oxidation (Pirnay et al., 1977), and may have resulted in the tendency for the higher CHO-2 RER during subsequent measurements (Flatt et al., 1985).

The work by Flatt et al. (1985) provides a possible explanation for our results. The addition of fat to a meal does not result in a concomitant increase in the RER. In contrast, carbohydrate oxidation is closely tied to carbohydrate availability. In Flatt's study, oxidation of carbohydrate increased with the ingestion of carbohydrate and then decreased as the available carbohydrate was oxidized or stored. Similarly, when our subjects consumed all the carbohydrate after the morning exercise session (CHO-1),

an increase in carbohydrate oxidation, as well as utilization for glycogen repletion probably occured. This would result in less carbohydrate being available as fuel at the subsequent treadmill run. Providing a portion of the carbohydrate after the morning run and the remainder during the afternoon run (CHO-2) was clearly a more effective method of delivery. In CHO-2, the carbohydrate consumed during the run-to-exhaustion was, in all probability, available for use as fuel. Indeed, Pirnay et al. (1977) demonstrated that a 100-g load of carbohydrate administered during exercise is completely oxidized during a 4-hr exercise bout.

It is likely that the performance enhancement of the CHO-1 and CHO-2 regimens is related to hepatic energy reserves. Due to the activity level and limited carbohydrate intake of subjects in this study, muscle glycogen stores were presumably lowered (Kirwan et al., 1988); it is likely that liver stores were also reduced. Ingestion of carbohydrate after the morning exercise would have resulted in partial replenishment of muscle (Ivy et al., 1988) and, presumably, liver glycogen stores. Increased carbohydrate would have therefore been available during the run-to-exhaustion for CHO-1 and CHO-2 compared to CHO-0. The oxidation of the carbohydrate ingested during the afternoon session in CHO-2 (Pirnay et al., 1977) probably spared hepatic glycogen.

Previously, it had been shown that a carbohydrate intake of 300 $g \cdot day^{-1}$ was associated with a transition to a fat-predominant state of metabolism in soldiers during four days of moderate exercise (Jones et al., 1990). In this study, administration of 514 $g \cdot day^{-1}$ of carbohydrate to soldiers engaged in heavy exercise did not prevent a transition from a carbohydrate-predominant to a fat-predominant metabolism.

During field maneuvers, food intake of soldiers is often limited to the amount of food they can carry. The size and weight of military rations is tightly regulated; carbohydrate content of rations is, therefore, limited by size and weight restrictions. The average daily carbohydrate intake for soldiers in a field setting is 300 $g \cdot day^{-1}$ (Jones et al., 1990). When two or more bouts of high-intensity physical activity are expected during the day, consumption of a large amount of carbohydrate immediately after an exercise session appears to enhance performance at a subsequent session. Ivy et al. (1988) demonstrated the importance of consuming carbohydrate as soon as possible after exercise completion for maximum glycogen resynthesis. However,

when supplies are limited, it may be more effective to spread consumption of the available carbohydrate over the entire day. Ingestion of carbohydrate during exercise period(s) may provide for the most efficient utilization of carbohydrate as an exercise fuel for the soldier in a field setting.

In future studies, different exercise intensities and durations than those examined in this study need to be assessed. Also, this study does not address the effects of glycemic index characteristics of different carbohydrates. Future research should examine the relationship of carbohdrate intake to hepatic glycogen stores and human performance. Non-invasive ^{13}C magnetic resonance spectroscopy techniques may provide information in this arena.

CONCLUSIONS

1. Consumption of a liquid carbohydrate supplement enhances exercise performance. Maximum performance is observed when the carbohydrate is divided and consumed partially after the morning and the remainder during subsequent exercise. When the same amount of carbohydrate is ingested immediately after a morning exercise bout, endurance during a subsequent exercise session is also significantly increased but the beneficial effects are not as great.

2. Dietary carbohydrate intake of 465 $g \cdot day^{-1}$ is insufficient to prevent a transition from a carbohydrate-predominant to a fat-predominant metabolism in soldiers performing heavy exercise.

3. The transition to a fat-predominant metabolism can have a negative impact on physical performance of soldiers, especially high-intensity physical performance.

RECOMMENDATIONS

1. Develop and type-classify liquid and solid carbohydrate supplements suitable for consumption during physical activity.

2. Develop nutrition education tools to instruct soldiers on methods to achieve maximum ergogenic potential of rations.

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APPENDIX A: THREE-DAY MENU

MENU 1: R DAY

AMOUNT	BREAKFAST	WEIGHT (g)
4 oz.	Orange Juice	118.0
1 oz.	Raisin Bran	28.4
2 pats	Margarine	10.0
2 ea.	Biscuits	122.8
2 ea.	Sausage Patties	77.1
8 oz.	Whole Milk	226.8
	LUNCH	
1 ea.	Ham and Cheese Sandwich:	
2 oz.	White Bread	50.0
2 oz.	Ham	56.7
1 oz.	American Cheese	28.4
	Lettuce Leaves	20.0
	Tomato Slices	28.4
1 pc	Mayonnaise	9.0
1 oz.	Doritos	28.4
2 ea.	Chocolate Chip Cookies	34.4
12 oz.	Diet Decaf. Soft Drink	369.6
	DINNER	
4 oz.	Beef Brisket	113.6
3 oz.	Mashed Potatoes	85.2
2 pats	Margarine	10.0
1 oz.	Beef Gravy	28.4
3 oz.	Broccoli Au Gratin	85.2
2 ea.	Croissants	113.6
4 pats	Margarine	20.0
1/2 cup	French Vanilla Ice Cream	72.6
12 oz.	Diet Decaf. Soft Drink	369.6
	SNACK	
6 ea.	Peanut Butter/Cheese Crackers	85.2
12 oz.	Diet Decaf. Soft Drink	369.6

MENU 2: R DAY

AMOUNT	BREAKFAST	WEIGHT (g)
8 oz.	Orange Juice	236.0
5 oz.	Scrambled Eggs	142.0
2 ea.	Sausage Patties	113.1
2 ea.	Biscuits	122.8
2 pats	Margarine	10.0
1 oz.	Grape Jelly	28.4
4 oz.	Whole Milk	113.4
	LUNCH	
3 oz.	Hamburger Patty	85.2
	Lettuce Leaves	20.0
	Tomato Slices	42.5
1 pc	Mayonnaise	9.0
1 ea.	Hamburger Bun	40.0
1 oz.	Doritos	28.4
2 oz.	Pound Cake	56.8
12 oz.	Diet Decaf. Soft Drink	369.6
	DINNER	
3 oz.	Chicken Breast	85.2
4 oz.	Rice Pilaf	113.6
1/2 cup	Green Beans	68.0
1 pat	Margarine	5.0
2 ea.	Dinner Rolls	61.2
2 pats	Margarine	10.0
2 ea.	Brownies	56.6
4 oz.	Whole Milk	113.4
	SNACK	
5 ea.	Ritz Crackers	
1 oz.	Cheddar Cheese	28.4
12 oz.	Diet Decaf. Soft Drink	369.6

MENU 3: E DAY

AMOUNT	BREAKFAST	WEIGHT (g)
4 oz.	Orange Juice	118.0
1 oz.	Corn Flakes	28.4
2.5 oz	Banana Slices	85.2
1 ea.	Biscuit	61.4
2 pats	Margarine	10.0
1 pc	Grape Jelly	14.2
8 oz.	Whole Milk	226.8
	SNACK	
1 ea.	Cheese Sandwich:	
2 oz.	American Cheese	56.8
1 pc	Mayonnaise	9.0
2 sl.	White Bread	50.0
1 oz.	Corn Chips	28.4
12 oz.	Diet Decaf. Soft Drink	369.6
	DINNER	
	Spaghetti with Meatballs	
6 oz.	Spaghetti	170.4
2 pats	Margarine	10.0
6 oz.	Spaghetti Sauce	170.4
6 oz.	Meatballs	170.4
1 oz.	Parmesan Cheese	28.4
	Tossed Salad	
2.5 oz.	Iceberg Lettuce	71.0
1 oz.	Diced Tomato	28.4
1 oz.	Cheddar Cheese	28.4
3 oz.	Avocado Slices	85.2
3 Tbsp	Bacon Bits	1.1
4 Tbsp	Ranch Salad Dressing	60.5

MENU 3: E DAY (cont.)

AMOUNT	DINNER	WEIGHT (g)
	Garlic Bread:	
1 sl.	Italian Bread	28.4
2 pats	Margarine	10.0
.25 tsp.	Garlic Powder	0.03
4 oz.	Whole Milk	113.4
1 cup	Vanilla Ice Cream	145.2
1/2 cup	Strawberries	128.8

APPENDIX B

INDIVIDUAL RUN-TO-EXHAUSTION TIMES (MINUTES)

SUBJECT	CHO-0	CHO-1	CHO-2	ORDER
1st iteration				
10	106	108	115	CHO-2,0,1
02	120	120	135	"
03	104	105	120	"
04	*	100	111	CHO-1,0,2
05	140	124	157	"
06	125	106	135	"
07	119	130	160	CHO-0,1,2
08	130	152	180	"
09	96	125	127	"
2nd iteration				
11	136	123	154	CHO-1,0,2
12	95	90	*	"
13	95	99	*	"
14	123	124	149	CHO-1,2,0
15	91	100	104	"
16	123	129	153	"
17	*	*	129	CHO-2,1,0
18	123	136	125	"
19	145	135	120	"

* - injury; did not start/complete run
CHO-0: placebo
CHO-1: 2.2 g CHO/kg BW 15 minutes post morning exercise session
CHO-2: 1.0 g CHO/kg BW 15 minutes post morning exercise session, and 0.4 g CHO/kg BW at 10, 30, and 50 minutes during the afternoon exercise session

SGRD-UE-OPN

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Second Author

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