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# Effect of menstrual cycle phase on carbohydrate supplementation during prolonged exercise to fatigue

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**Bailey, Stephen P., Cristine M. Zacher, and Karen D. Mittleman.** Effect of menstrual cycle phase on carbohydrate supplementation during prolonged exercise to fatigue. *J. Appl. Physiol.* 88: 690–697, 2000.—The effects of menstrual cycle phase and carbohydrate (CHO) supplementation were investigated during prolonged exercise. Nine healthy, moderately trained women cycled at 70% peak O<sub>2</sub> consumption until exhaustion. Two trials were completed during the follicular (Fol) and luteal (Lut) phases of the menstrual cycle. Subjects consumed 0.6 g CHO · kg body wt<sup>-1</sup> · h<sup>-1</sup> (5 ml/kg of a 6% CHO solution every 30 min beginning at min 30 of exercise) or a placebo drink (Pl) during exercise. Time to exhaustion during CHO increased from Pl values ( $P < 0.05$ ) by 14.4 ± 8.5 (Fol) and 11.4 ± 7.1% (Lut); no differences were observed between menstrual cycle phases. CHO attenuated ( $P < 0.05$ ) the decrease in plasma glucose and insulin and the increase in plasma free fatty acids, tryptophan, epinephrine, and cortisol observed during Pl for both phases. Plasma alanine, glutamine, proline, and isoleucine were lower ( $P < 0.05$ ) in Lut than in Fol phase. CHO resulted in lower ( $P < 0.05$ ) plasma tyrosine, valine, leucine, isoleucine, and phenylalanine. These results indicate that the menstrual cycle phase does not alter the effects of CHO supplementation on performance and plasma levels of related substrates during prolonged exercise. oxygen consumption; endurance; estrogen; progesterone

CARBOHYDRATE (CHO) supplementation during moderately intense exercise [ $\sim 70\%$  maximal oxygen consumption ( $\dot{V}O_{2\max}$ )] has been shown to consistently improve exercise time to fatigue by 24–32% in men (6, 8, 40). Fewer data concerning the beneficial effects of CHO supplementation on endurance performance in women are available. Tarnopolsky et al. (37) reported that the ingestion of a high-CHO diet did not influence endurance performance in the women studied. These authors and others (14, 37, 38) suggest that women oxidize lipid to a greater extent and CHO to a lesser extent than do men during moderately intense exercise. Consequently, it is possible that CHO supplementation during exercise may not have the same effects in women as in men.

Differences between men and women in substrate utilization during moderately intense exercise may be related to the reproductive hormones estrogen and progesterone. Elevated concentrations of estrogen and progesterone that occur during the luteal (Lut) phase of the menstrual cycle have been associated with enhanced glycogen storage (14, 32) and fat utilization during rest and exercise (14). Although this shift in

substrate metabolism may be beneficial during prolonged low-intensity exercise (12), higher intensity endurance exercise in the absence of glucose feedings (7) may be adversely affected.

Although several investigations have described variations in athletic performance during different phases of the menstrual cycle (5, 22, 23), there is no consistent evidence to suggest that the potential shift in substrate utilization described above has any effect on endurance performance during prolonged exercise. Furthermore, the effects of menstrual cycle phase on the potential positive effect of CHO supplementation on endurance performance during prolonged exercise are unknown. Consequently, the purpose of this investigation was to determine whether menstrual cycle phase influences the effect of CHO supplementation on substrate metabolism and fatigue during prolonged exercise.

## METHODS

**Subjects.** Eleven healthy, moderately trained women volunteered to participate in the study. All procedures were approved by the University's Institutional Review Board for the Protection of Human Subjects in Research, and participants provided their informed consent. Subjects completed a medical history questionnaire to rule out any contraindications to participation and an activity questionnaire to document current exercise patterns. Although subjects were not trained cyclists, all had previous experience with endurance cycling. The women were eumenorrheic and were not using oral contraceptives (OCs). Cycle phases were validated by measurement of serum estrogen and progesterone. Two women were excluded from the study due to Lut-phase progesterone values below 16 nmol/l (20).

Before experimental trials, subjects performed a graded exercise test for the determination of peak oxygen consumption ( $\dot{V}O_{2\text{peak}}$ ) and the relative work rate ( $70\% \dot{V}O_{2\text{peak}}$ ) used in subsequent experimental sessions. A Schwinn Velodyne ergometer was used to enable subjects to ride their own bicycles during exercise. Oxygen consumption ( $\dot{V}O_2$ ) was measured online with a computerized metabolic measurement system (MAX-1, FITCO, Farmingdale, NY). Body composition was assessed from skinfold thicknesses (Lange Skinfold Caliper, Creative Health Products, Plymouth, MI). Body density was calculated by the equation of Jackson et al. (17) for athletic women, and percent fat was determined by Siri's equation modified for age- and gender-specific estimates of fat-free mass (25).

**Experimental protocol.** Experimental sessions were conducted on four separate occasions, twice during the follicular (Fol) phase (cycle days 1–8) and twice during the Lut phase (cycle days 19–24) of the menstrual cycle. Before each session,

subjects were asked to refrain from caffeine and alcohol ingestion for at least 12 h and to refrain from strenuous exercise for 24 h.

On the morning of each trial, subjects reported to the laboratory at 8:00 AM, at which time they were fed a meal consisting of 840 kcal (67% CHO, 11% protein, and 22% fat). Subjects then returned to the laboratory at 11:00 AM, and body weight was determined after they voided. An indwelling venous catheter was placed into the brachial vein for subsequent blood draws, and the subject was instrumented for physiological measurements.

A baseline blood sample (25 ml) was taken after 25 min of seated rest in a comfortable room (ambient temperature =  $22.7 \pm 1.6^\circ\text{C}$ ; relative humidity =  $38 \pm 19\%$ ), and then subjects mounted the cycle ergometer and exercised at 70%  $\dot{V}O_{2\text{peak}}$  until fatigue. Fatigue was determined as the time point at which the subjects were unable to maintain the desired workload for 1 continuous min or they requested to stop. Blood samples (20 ml) were collected every 30 min during the trial and at fatigue.

Immediately after the blood draws during exercise, subjects received 5 ml/kg body wt of a drink that contained either a 6% CHO solution or a nonnutritive placebo (PI). This procedure resulted in subjects receiving 0.6 g CHO · kg body wt<sup>-1</sup> · h<sup>-1</sup> during the CHO trial. Subjects received their first drink after the first blood draw during exercise (i.e., after 30 min of exercise). Drinks were formulated to be indistinguishable in taste and appearance (Gatorade Sports Science Institute, Barrington, IL) and were administered in a double-blind fashion by using a Latin-square design.

**Physiological measures.** Heart rates (beats/min) were measured continuously with a heart rate monitor (Vantage XL, Polar) and were recorded every 10 min. Blood pressure was monitored by auscultation using a sphygmomanometer every 20 min during the trials. Mean arterial pressure (mmHg) was calculated from systolic and diastolic pressures ( $\frac{1}{3}$  pulse pressure + diastolic pressure).  $\dot{V}O_2$  was measured for a 5-min period every 20 min during the trials by using the system described in *Subjects*. Total body water loss was calculated from the change in body weight corrected for ingested fluid and urine volume.

**Psychological measures.** To assess the potential influence of CHO supplementation on subjective feelings of fatigue, ratings of perceived exertion (RPE) (4) were recorded every 30 min.

**Blood analyses.** Aliquots of plasma were drawn from centrifuged blood containing either heparin (amino acids and cortisol) or EDTA [free fatty acids (FFA) and glucose]. Blood samples for determination of plasma catecholamines [norepinephrine (NE) and epinephrine (Epi)] were collected into chilled heparinized vacutainers containing 100  $\mu\text{l}$  of a reduced-glutathione and EGTA solution before centrifugation. Aliquots of serum were drawn for estradiol and progesterone. Samples were frozen at  $-70^\circ\text{C}$  for subsequent analyses.

Plasma glucose and FFA were assayed in triplicate by using spectrophotometric methods (16, 33). For amino acids, plasma samples were sent to an established laboratory for analysis by HPLC according to procedures previously described (8, 29). During these procedures, plasma samples are filtered under a vacuum via centrifugation. Consequently, the amino acid concentration values described here are representative of the portion not bound to (or free from) albumin. A commercially available <sup>125</sup>I radioimmunoassay (Coat-A-Count, Diagnostic Products) was used to analyze estradiol and progesterone. All samples were done in one assay, and intra-assay coefficients of variation (CV) were 5.9 and 5.0% for estradiol and progesterone, respectively. Plasma cortisol

was also measured by <sup>125</sup>I radioimmunoassay (Coat-A-Count, Diagnostic Products). Intra- and interassay CVs were 5.5 and 9.1%, respectively. Plasma NE and Epi were isolated by using an alumina-extraction technique (Chromosystems), and HPLC (Waters Millipore) with electrochemical detection was used to determine plasma concentrations according to the procedure of Schneider et al. (36). The sensitivity of the assay for NE and Epi was 5 pg/ml (27 pmol/l) with a signal-to-noise ratio of 4:1. The within-day CV was <1% and the between-day CV <3.0% for standards in the range of 5.0–5,000 pg/ml.

**Statistical analyses.** Data were evaluated for differences among menstrual cycle phases, drink treatments, and time by using a three-way (phase  $\times$  drink  $\times$  time) repeated-measures analysis of variance (SuperANOVA, Abacus Concepts, Berkeley, CA). Significance was set a priori at the  $P < 0.05$  level. When significant main effects were observed, standard contrast procedures were performed by using least squares means. For all values, means  $\pm$  SE are reported.

## RESULTS

Physical characteristics and reproductive hormone data for the nine subjects included in the study are presented in Table 1. Although these women were not trained athletes, their percent body fat and percent  $\dot{V}O_{2\text{peak}}$  values placed them in the “excellent” and “superior” categories, respectively, for their age group (1).

Cycling time to exhaustion at 70%  $\dot{V}O_{2\text{peak}}$  for all four trials are shown in Fig. 1. A significant increase in endurance time was observed during CHO compared with PI trials ( $P < 0.05$ ); menstrual cycle phase had no effect. Improvements in endurance time during CHO treatments were similar for Fol ( $14.4 \pm 8.5\%$ ) and Lut ( $11.4 \pm 7.1\%$ ) phases. Only one woman failed to improve her endurance time with CHO treatment in both cycle phases.

Plasma FFA and glucose are shown for all four trials over the course of exercise in Fig. 2. Main effects were noted in FFA responses for drink treatment and time ( $P < 0.05$ ). In addition, the changes in FFA over time were influenced by drink treatment ( $P < 0.05$ ) and menstrual cycle phase ( $P < 0.05$ ). As shown in Fig. 2A, FFA increased above baseline at 90 min of exercise and continued to increase until fatigue (90 min < 120 min < fatigue;  $P < 0.05$ ) for both drinks. This rise in FFA was significantly greater during the PI compared with CHO trials ( $P < 0.05$ ). At 120 min of exercise and fatigue,

Table 1. *Physical characteristics and reproductive hormones of subjects*

Variable	Means $\pm$ SD
Age, yr	27.0 $\pm$ 6.8
Weight, kg	58.3 $\pm$ 6.8
Height, cm	164.5 $\pm$ 5.2
Body fat, %	19.2 $\pm$ 4.1
$\dot{V}O_{2\text{peak}}$ , ml · kg <sup>-1</sup> · min <sup>-1</sup>	49.6 $\pm$ 4.3
Fol E <sub>2</sub> , pmol/l	135.94 $\pm$ 18.20*
Lut E <sub>2</sub> , pmol/l	310.09 $\pm$ 20.70*
Fol P, nmol/l	1.85 $\pm$ 0.22*
Lut P, nmol/l	25.26 $\pm$ 3.41*

Values are for 9 subjects.  $\dot{V}O_{2\text{peak}}$ , peak oxygen consumption; Fol, follicular phase; Lut, luteal phase; E<sub>2</sub>, estradiol; P, progesterone. \*Values are means  $\pm$  SE.

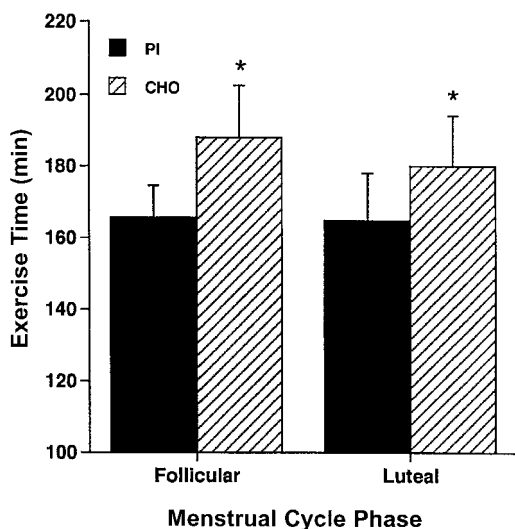


Fig. 1. Exercise time to fatigue during cycle ergometry at 70% peak  $O_2$  consumption in 9 trained women. Values (means  $\pm$  SE) are for placebo (PI) and carbohydrate (CHO) trials over both phases of the menstrual cycle. \*Significant difference between drink treatments (PI vs. CHO),  $P < 0.05$ .

FFA levels were significantly lower during Lut compared with Fol phases ( $P < 0.05$ ).

As expected, plasma glucose was significantly greater during CHO compared with PI trials ( $P < 0.05$ ). No

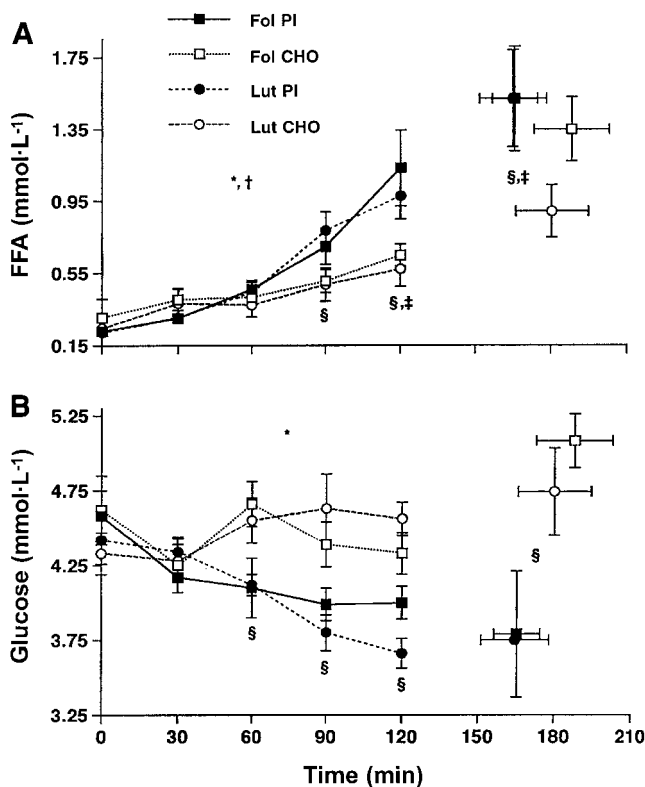


Fig. 2. Plasma free fatty acids (FFA; A) and glucose (B) over the 4 exercise trials: CHO, PI, luteal phase (Lut), and follicular phase (Fol). \*Significant difference between drink treatments (PI vs. CHO),  $P < 0.05$ . †Significant differences over time,  $P < 0.05$ . ‡Significant interaction between drink and time,  $P < 0.05$ . §Significant interaction between menstrual phase and drink,  $P < 0.05$ .

differences were observed between menstrual cycle phases (Fig. 2B). Although the change in glucose over time was not significant ( $P > 0.05$ ), a drink by time interaction was evident ( $P < 0.05$ ). From 60 min of exercise until fatigue, plasma glucose during CHO was significantly greater than during PI trials ( $P < 0.05$ ). At fatigue, plasma glucose was elevated above baseline values during CHO trials ( $4.78 \pm 0.21$  vs.  $4.48 \pm 0.15$  mmol/l;  $P < 0.05$ ). In contrast, a significant reduction from  $4.52 \pm 0.12$  to  $3.74 \pm 0.26$  mmol/l ( $P < 0.05$ ) occurred during PI trials.

The effect of menstrual cycle phase and CHO supplementation on plasma amino acids during exercise are shown in Table 2. Alanine, glutamine, proline, and isoleucine were all reduced during Lut compared with Fol phases ( $P < 0.05$ ). CHO ingestion resulted in significantly lower plasma levels of tyrosine, valine, leucine, isoleucine, and phenylalanine and in significantly elevated levels of plasma alanine compared with PI trials ( $P < 0.05$ ). Exercise at 70%  $\dot{V}O_{2peak}$  resulted in decreases over time in plasma alanine, glutamine, valine, and proline ( $P < 0.05$ ). A significant interaction ( $P < 0.05$ ) was noted between cycle phase and drink treatment for plasma isoleucine and valine. Values were higher during Fol compared with Lut phases in the PI trials, whereas minimal phase differences were noted for the CHO trials.

CHO resulted in significantly lower values for tryptophan (Table 2) by 120 min of exercise ( $P < 0.05$ ). There was a trend for a drink by time interaction for tryptophan, although this was not significant ( $P = 0.10$ ).

Plasma cortisol, insulin, NE, and Epi responses are shown in Fig. 3 for both drink treatments over time. Because neither menstrual cycle phase main effects nor phase interactions with drink or time were observed, data for Fol and Lut phases were combined for each drink treatment. Plasma cortisol increased over time for both drink treatments ( $P < 0.05$ ; Fig. 3A). Although an overall drink effect was not significant, an interaction ( $P < 0.05$ ) was found between drink treatment and time; cortisol was higher at 60 min of exercise during CHO compared with PI trials ( $357 \pm 26$  vs.  $274 \pm 28$  nmol/l). At fatigue, cortisol was suppressed during CHO ( $486 \pm 57$  nmol/l) compared with PI ( $625 \pm 59$  nmol/l). As shown in Fig. 3C, exercise resulted in a significant reduction ( $P < 0.05$ ) in plasma insulin. Plasma insulin levels were greater during CHO compared with PI trials ( $116.6 \pm 16.5$  vs.  $93.9 \pm 8.3$  pmol/l) by 60 min of exercise. Plasma NE increased over time until 120 min of exercise for both drink treatments (0 min  $<$  60 min  $<$  120 min;  $P < 0.05$ ; Fig. 3B). Values at fatigue ( $1,516 \pm 162$  pmol/l) were not different from those at 120 min of exercise ( $1,362 \pm 152$  pmol/l). Exercise at 70%  $\dot{V}O_{2peak}$  resulted in an increase in Epi for both drink treatments ( $P < 0.05$ ; Fig. 3C), although CHO supplementation significantly suppressed the Epi response from 120 min ( $P < 0.05$ ). Plasma Epi at fatigue was over twofold greater during PI compared with CHO trials ( $589 \pm 77$  vs.  $253 \pm 36$  pmol/l).

Table 2. Plasma amino acid concentrations during four exercise trials

Amino Acid	Cycle Phase	Exercise Time, min							
		PI				CHO			
		0	60	120	Fatigue	0	60	120	Fatigue
Alanine <sup>a,b</sup>	Fol	358 ± 44	371 ± 32	299 ± 20 <sup>e,f</sup>	238 ± 20 <sup>e,f,g</sup>	345 ± 30	418 ± 24	338 ± 12 <sup>e,f</sup>	261 ± 21 <sup>e,f,g</sup>
	Lut	300 ± 17	308 ± 17	256 ± 12 <sup>e,f</sup>	205 ± 14 <sup>e,f,g</sup>	327 ± 18	334 ± 13	271 ± 18 <sup>e,f</sup>	254 ± 25 <sup>e,f,g</sup>
Glutamine <sup>a,c</sup>	Fol	317 ± 46	305 ± 30	300 ± 33 <sup>e</sup>	272 ± 39 <sup>e,f,g</sup>	295 ± 32	304 ± 32	294 ± 25 <sup>e</sup>	267 ± 24 <sup>e,f,g</sup>
	Lut	263 ± 16	248 ± 22	233 ± 23 <sup>e</sup>	208 ± 20 <sup>e,f,g</sup>	287 ± 27	260 ± 36	237 ± 25 <sup>e</sup>	244 ± 21 <sup>e,f,g</sup>
Tyrosine <sup>b</sup>	Fol	54 ± 4	53 ± 5	56 ± 4	56 ± 4	47 ± 4	52 ± 3	48 ± 2	53 ± 4
	Lut	48 ± 4	50 ± 4	52 ± 3	55 ± 3	50 ± 3	48 ± 2	47 ± 3	51 ± 4
Proline <sup>a,c</sup>	Fol	256 ± 36	221 ± 34 <sup>e</sup>	194 ± 30 <sup>e,f</sup>	166 ± 27 <sup>e,f,g</sup>	209 ± 19	200 ± 16 <sup>e</sup>	167 ± 12 <sup>e,f</sup>	142 ± 12 <sup>e,f,g</sup>
	Lut	191 ± 13	157 ± 15 <sup>e</sup>	138 ± 9 <sup>e,f</sup>	116 ± 9 <sup>e,f,g</sup>	208 ± 14	171 ± 10 <sup>e</sup>	148 ± 11 <sup>e,f</sup>	138 ± 15 <sup>e,f,g</sup>
Phenylalanine <sup>b</sup>	Fol	47 ± 4	45 ± 3	49 ± 3	48 ± 3	40 ± 3	42 ± 2	42 ± 1	45 ± 1
	Lut	42 ± 2	42 ± 2	45 ± 2	47 ± 2	44 ± 3	42 ± 2	40 ± 3	45 ± 2
Isoleucine <sup>a,b</sup>	Fol	54 ± 4	52 ± 5	53 ± 3	51 ± 3	47 ± 4	48 ± 3	41 ± 2	39 ± 2
	Lut <sup>d</sup>	45 ± 4	45 ± 3	47 ± 2	47 ± 2	46 ± 4	44 ± 2	39 ± 3	40 ± 3
Leucine <sup>b</sup>	Fol	94 ± 7	95 ± 8	95 ± 5	91 ± 6	85 ± 6	87 ± 5	75 ± 4	75 ± 4
	Lut	81 ± 6	83 ± 5	84 ± 3	86 ± 5	81 ± 8	81 ± 4	71 ± 5	74 ± 5
Valine <sup>b,c</sup>	Fol	180 ± 13	169 ± 13	168 ± 9 <sup>e</sup>	155 ± 9 <sup>e,f</sup>	153 ± 9	154 ± 9	136 ± 9 <sup>e</sup>	126 ± 5 <sup>e,f</sup>
	Lut <sup>d</sup>	150 ± 9	141 ± 7	142 ± 6 <sup>e</sup>	140 ± 6 <sup>e,f</sup>	157 ± 10	141 ± 4	126 ± 9 <sup>e</sup>	127 ± 9 <sup>e,f</sup>
Tryptophan <sup>b,c</sup>	Fol	4.7 ± 0.4	4.8 ± 0.4	7.2 ± 0.4 <sup>e</sup>	9.6 ± 0.4 <sup>e,f</sup>	4.1 ± 0.3	4.8 ± 0.4	5.0 ± 0.4 <sup>e</sup>	9.3 ± 1.4 <sup>e,f</sup>
	Lut	4.0 ± 0.4	4.7 ± 0.5	6.1 ± 0.5 <sup>e</sup>	11.0 ± 1.4 <sup>e,f</sup>	4.4 ± 0.4	4.6 ± 0.4	5.0 ± 0.5 <sup>e</sup>	6.9 ± 0.6 <sup>e,f</sup>

Values are means ± SE in μmol/l for 8 subjects. <sup>a</sup>Significant differences for menstrual cycle phase (Fol vs. Lut), *P* < 0.05. <sup>b</sup>Significant differences for drink treatment (PI vs. CHO), *P* < 0.05. <sup>c</sup>Significant differences for time effect, *P* < 0.05. <sup>d</sup>Significant menstrual cycle phase by drink treatment interaction, *P* < 0.05. <sup>e,f,g</sup>*P* < 0.05 vs. 0, 60, and 120 min, respectively (drink treatment and menstrual phases combined).

Cardiorespiratory and hemodynamic responses averaged over each 30-min period during the trials are shown in Table 3. Neither menstrual cycle phase nor drink treatment altered these responses during 70%  $\dot{V}O_{2peak}$  exercise. Responses for respiratory exchange ratio during the course of exercise are displayed in Fig. 4. Neither drink nor menstrual cycle phase had an impact on RPE.

DISCUSSION

The purpose of this investigation was to determine whether menstrual cycle phase influences the effect of CHO supplementation on performance and related plasma substrates during prolonged exercise. The results of this investigation indicate that exercise time to fatigue during prolonged exercise at 70%  $\dot{V}O_{2peak}$  is

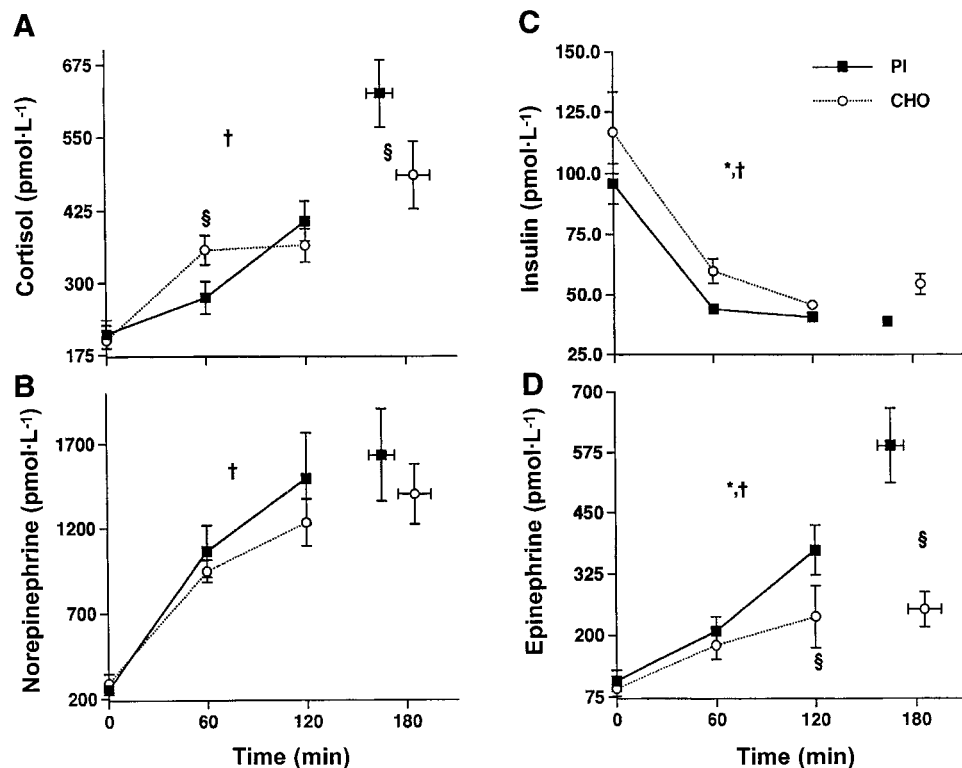


Fig. 3. Plasma hormone responses over time for PI vs. CHO trials. A: cortisol. B: norepinephrine. C: insulin. D: epinephrine. \*Significant difference between drink treatments (PI vs. CHO), *P* < 0.05. †Significant differences over time, *P* < 0.05. ‡Significant interaction between drink and time, *P* < 0.05

Table 3. *Cardiorespiratory and hemodynamic responses over time*

Variable	Drink	Exercise Time, min					
		0	30	60	90	120	Fatigue
$\dot{V}O_2$ , <sup>a</sup> l/min STPD	PI	0.23 ± 0.01	1.79 ± 0.08 <sup>b</sup>	1.82 ± 0.07 <sup>b</sup>	1.84 ± 0.06 <sup>b</sup>	1.85 ± 0.06 <sup>b</sup>	1.86 ± 0.06 <sup>b</sup>
	CHO	0.23 ± 0.01	1.82 ± 0.08 <sup>b</sup>	1.85 ± 0.08 <sup>b</sup>	1.87 ± 0.07 <sup>b</sup>	1.84 ± 0.06 <sup>b</sup>	1.82 ± 0.07 <sup>b</sup>
$\dot{V}E$ , <sup>a</sup> l/min BTPS	PI	10.41 ± 0.48	60.41 ± 2.78 <sup>b</sup>	61.38 ± 3.15 <sup>b</sup>	60.90 ± 2.91 <sup>b</sup>	62.11 ± 2.78 <sup>b</sup>	63.56 ± 2.54 <sup>b</sup>
	CHO	10.17 ± 0.48	61.50 ± 2.42 <sup>b</sup>	61.98 ± 2.54 <sup>b</sup>	62.83 ± 2.78 <sup>b</sup>	62.95 ± 2.78 <sup>b</sup>	62.71 ± 2.66 <sup>b</sup>
RER <sup>a</sup>	PI	0.85 ± 0.02	0.92 ± 0.01 <sup>b</sup>	0.90 ± 0.02 <sup>b,c</sup>	0.87 ± 0.01 <sup>b,c</sup>	0.85 ± 0.01 <sup>c,d</sup>	0.83 ± 0.01 <sup>c,d,e,f</sup>
	CHO	0.86 ± 0.02	0.92 ± 0.01 <sup>b</sup>	0.90 ± 0.02 <sup>b,c</sup>	0.89 ± 0.01 <sup>b,c</sup>	0.88 ± 0.01 <sup>c,d</sup>	0.85 ± 0.01 <sup>c,d,e,f</sup>
MAP, <sup>a</sup> mmHg	PI	85.3 ± 1.5	94.0 ± 1.0 <sup>b</sup>	93.1 ± 1.1 <sup>b</sup>	93.1 ± 1.3 <sup>b</sup>	91.1 ± 1.2 <sup>b</sup>	91.0 ± 1.1 <sup>b,c,d,e</sup>
	CHO	86.6 ± 1.4	96.2 ± 1.4 <sup>b</sup>	94.6 ± 0.8 <sup>b</sup>	94.7 ± 1.0 <sup>b</sup>	93.9 ± 0.9 <sup>b</sup>	90.4 ± 1.4 <sup>b,c,d,e</sup>
HR, <sup>a</sup> beats/min	PI	65 ± 2	142 ± 2 <sup>b</sup>	150 ± 2 <sup>b,c</sup>	152 ± 2 <sup>b,c</sup>	154 ± 3 <sup>b,c</sup>	158 ± 3 <sup>b,c,d,e,f</sup>
	CHO	66 ± 2	143 ± 2 <sup>b</sup>	152 ± 2 <sup>b,c</sup>	153 ± 2 <sup>b,c</sup>	154 ± 3 <sup>b,c</sup>	158 ± 3 <sup>b,c,d,e,f</sup>

Values are means ± SE for 9 subjects.  $\dot{V}O_2$ , oxygen consumption;  $\dot{V}E$ , minute ventilation; RER, respiratory exchange ratio; MAP, mean arterial pressure; HR, heart rate. <sup>a</sup>Significant differences for time effect,  $P < 0.05$ . <sup>b,c,d,e,f</sup> $P < 0.05$  vs. 0, 30, 60, 90, and 120 min, respectively (drink treatment and menstrual cycle phases combined).

equally improved by CHO supplementation (0.6 g CHO · kg body wt<sup>-1</sup> · h<sup>-1</sup>) during the Fol and Lut phases of the menstrual cycle.

Although the improvements in endurance performance with CHO supplementation (14% during the Fol phase and 11% during the Lut phase) are consistent with the trends observed by other investigators, the magnitude of improvement is less than that observed in men under similar conditions. For example, Wright and colleagues (40) observed a 32% increase in exercise time to fatigue during cycling at 70%  $\dot{V}O_{2\max}$  when CHO was supplied at a rate of 0.6 g CHO · kg body wt<sup>-1</sup> · h<sup>-1</sup>. Similarly, Davis and colleagues (8) observed a 24% increase in exercise time to fatigue during cycling at ~68%  $\dot{V}O_{2\max}$  when CHO was supplied at a rate of 0.6 g CHO · kg body wt<sup>-1</sup> · h<sup>-1</sup>. Although these potential differences between men and women are intriguing, subtle differences in exercise intensity or training status cannot be discounted as potential reasons for the lower relative improvement in performance observed here in women. An appropriate comparison of the effects of CHO supplementation on endurance performance between men and women can only be made by an investigation that includes both genders.

Numerous investigations have addressed the differences in physical performance during various phases of the menstrual cycle [see Lebrun (22) for review]. The

results of these investigations have greatly varied. For example, Jurkowski and co-workers (18) observed nearly a 100% greater exercise time to fatigue during the Lut phase (2.97 ± 0.63 min) compared with the Fol phase (1.57 ± 0.32 min) during cycling at 85–90%  $\dot{V}O_{2\max}$ . Similarly, Nicklas and colleagues (32) observed a small but significantly greater exercise time to fatigue during the Lut phase (139.2 ± 14.9 min) compared with the Fol phase (126 ± 17.5 min) during cycling at 70%  $\dot{V}O_{2\max}$ . Although the two investigations cited above suggest that endurance performance is greater in the Lut phase, the bulk of the investigations in this area report no difference in endurance performance between the menstrual cycle phases (5, 22). In the present investigation, the finding that exercise time to fatigue was similar in the Lut and Fol phases during PI and CHO conditions is in agreement with these latter studies.

Differences in endurance performance during the phases of the menstrual cycle have been postulated to be due to differences in substrate availability and metabolism. Elevated concentrations of estrogen and progesterone during the Lut phase have been associated with altered muscle glycogen and FFA utilization during rest and submaximal exercise (37, 38). These differences in substrate utilization may influence performance during prolonged exercise by altering the availability of muscle glycogen. For example, Lavoie and colleagues (21) found plasma glucose was lower and plasma FFA was higher during cycling at 63%  $\dot{V}O_{2\max}$  for 90 min during the Lut phase. In the present investigation, menstrual cycle phase appeared to have no effect on plasma glucose and FFA during exercise. Although our results differ from those described by Lavoie and co-workers (21), they are consistent with several other reports (5, 19, 32). For example, Nicklas and colleagues (32) found blood glucose, plasma FFAs, and respiratory exchange ratio to be similar during the Lut and Fol phases of the menstrual cycle during cycling at 70%  $\dot{V}O_{2\max}$ . The lack of consistency of results among investigations may be related to small differences in exercise intensity. In an investigation completed by Hackney and co-workers (14), lipid utilization and oxidation were found to be greater during the

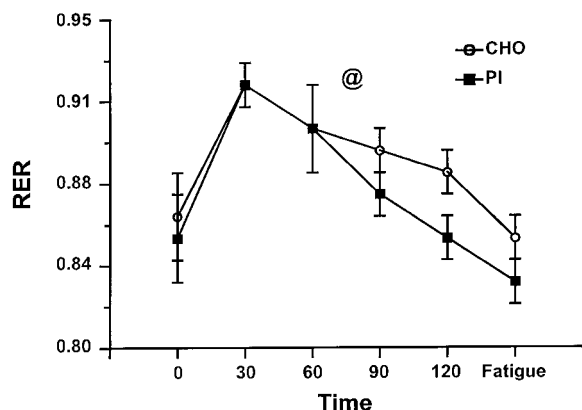


Fig. 4. Respiratory exchange ratio (RER) responses during exercise for PI vs. CHO trials. @Significant differences over time,  $P < 0.05$ .

Lut phase at exercise intensities equal to 35 and 60%  $\dot{V}O_{2\max}$ ; however, differences between the Lut and Fol phases were not present at 75%  $\dot{V}O_{2\max}$ . Support for the evidence that menstrual phase differences in substrate utilization during exercise varies according to exercise intensity is seen in recent work by Friedlander et al. (11). Results from these investigations indicate that, whereas glucose use during exercise is directly related to exercise intensity in women, FFA use is not. Because the exercise intensity used in this investigation (70%  $\dot{V}O_{2\max}$ ) was at a level at which CHO metabolism may become exponentially more important to energy production than FFA oxidation, it would be inappropriate to extend our findings to lower exercise intensities. It is important to note, however, that it is unlikely that our subjects would have been able to exercise for >2.5 h during PI if FFA oxidation was not playing an important role in energy production.

The perception that substrate availability and utilization differs during the Lut and Fol phases of the menstrual cycle has been perpetuated by findings from investigations that describe the effects of OC use on metabolism and plasma substrates (2, 35). Because OC use elevates plasma estrogen levels, and estrogen levels are higher during the Lut phase of a "normal" menstrual cycle, OC use and the Lut phase are often expected to have similar metabolic results. Although these investigations are extremely valuable in the attempt to understand the metabolic events associated with the specific population under examination, these findings should not be extrapolated to normally cycling women. For example, an investigation completed by Ruby and associates (35) suggests that application of a transdermal estrogen patch for 72 and 144 h in amenorrheic women does not affect "whole body" lipid metabolism during 90 min of treadmill running at 65%  $\dot{V}O_{2\max}$ . The results of this investigation are extremely important when women with amenorrhea are considered; however, extrapolation to women who are normally cycling is inappropriate for two reasons. First, the pharmaceutical treatment increased estradiol to a level that was >10-fold lower than that seen in normally menstruating women. Second, the physiological events that result in women becoming amenorrheic and/or the ensuing state of hypoestrogenism could very well result in adaptations that would impact the metabolic consequences of increasing and decreasing estrogen levels in the blood.

Differences in plasma levels of glucose and FFA were observed in this investigation because of the drink treatment. Specifically, blood glucose levels were maintained and increases in FFA were blunted during the CHO trials. These differences are consistent with those described in men exercising under similar experimental conditions (8, 31, 40). One previous investigation has described the effects of CHO supplementation on plasma glucose and FFA levels during various phases of the menstrual cycle. In this investigation, Bonen and colleagues (3) provided women with 1.5 g/kg of CHO 20 min before 1 h of treadmill walking (30 min at 40%  $\dot{V}O_{2\max}$  and 30 min at 80%  $\dot{V}O_{2\max}$ ). Interestingly,

whereas plasma glucose levels were not found to be affected by CHO supplementation or menstrual cycle phase, plasma FFA levels were observed to be lower when CHO was provided before exercise in the Lut phase. The results of this investigation by Bonen and colleagues appear to be contradictory to those investigations (14, 21) that have observed greater plasma FFA levels while exercising during the Lut phase. An explanation for these various results does not appear to be readily apparent; however, it is possible that the procedures utilized by Bonen and colleagues (CHO supplementation before exercise) precipitated a unique physiological response that warrants further study.

Menstrual phase differences were observed for several amino acids. Plasma levels of alanine, glutamine, proline, and isoleucine were all lower in the Lut phase compared with the Fol phase. These general results are consistent with those of Moller and associates (30), who found the sum of neutral amino acids to be 10% lower in the Lut phase compared with the Fol phase. Interestingly, they only found tyrosine to be significantly lower in the Lut phase. Although glutamine and proline were not measured in the investigation by Moller et al., alanine and isoleucine appeared to follow this trend. This difference in plasma levels of neutral amino acids may be related to estrogen and progesterone levels, which have been found to have a catabolic effect on amino acids (30). We also found an effect of menstrual cycle phase on plasma levels of isoleucine, leucine, and valine. Specifically, plasma levels of these amino acids were higher during the Fol-PI trial than the Lut-PI trial. It is unclear why this difference was not also observed in the CHO trials. The subsequent effect of these differences in plasma amino acids as a result of menstrual cycle phase on metabolism and related bodily functions is unknown. Plasma amino acids play important roles in a vast spectrum of functions, including production of various neurotransmitters (7) and CHO metabolism (39).

Prolonged exercise in this investigation resulted in reductions in plasma alanine, glutamine, valine, and proline. Similar findings have been described by other authors in men (13, 15, 34, 39). For example, Graham and colleagues (13) observed decreases in plasma levels of alanine and proline after 3 h of one-legged knee extensor exercise at 60%  $\dot{V}O_{2\max}$  in trained men. Van Hall and associates (39) found significant reductions in plasma valine levels after 90 min of one-legged knee extensor exercise at 60–65%  $\dot{V}O_{2\max}$  in trained men with normal muscle glycogen levels. Furthermore, Rennie and co-workers (34) describe significant decreases in plasma glutamine and alanine as a result of 3.5 h of cycling at 50%  $\dot{V}O_{2\max}$ . Declines in plasma amino acids during exercise may be the result of deamination of existing amino acids or reduced synthesis of amino acids. It is generally believed that these "extra" carbon skeletons are then used for energy production (15). Interestingly, it appears that the present investigation is the first to observe simultaneous declines in the four amino acids: alanine, glutamine, valine, and proline. Mechanisms for this finding and its importance are

unclear. Whether these findings are the result of the slightly greater exercise intensity used in the present study and/or the use of two-legged cycle ergometry vs. one-legged exercise requires further study. It also appears that this is the first investigation to observe this response in women.

In this investigation, CHO supplementation resulted in significantly lower plasma levels of tryptophan and the branched-chain amino acids (BCAA; leucine, isoleucine, and valine) by 120 min of exercise. These results are generally consistent with those described by Davis and colleagues (8). The attenuation in the rise in plasma tryptophan levels is believed to be the result of attenuation in plasma FFA levels as a result of the CHO supplementation. Increasing levels of plasma FFA result in increased plasma levels of tryptophan by displacing tryptophan from albumin (7, 8). Conversely, declines in plasma BCAA levels during CHO supplementation and exercise are thought to be due to the maintenance of plasma insulin levels during exercise (7, 29).

Along with the BCAA, CHO supplementation also resulted in lower plasma levels of tyrosine and phenylalanine. Since movement of these amino acids into muscle and liver can also be enhanced by insulin (8, 27), reduced levels of these two amino acids during the CHO trials are believed to be a result of the same mechanism related to the BCAA.

CHO supplementation also influenced the hormonal responses to exercise. Specifically, CHO supplementation during prolonged exercise attenuated increases in plasma cortisol and Epi and decreases in plasma insulin. These results are generally consistent with previous investigations (26, 28, 31); however, the magnitude of decline in plasma insulin levels during CHO supplementation appears to be greater in women compared with the decline previously described in men. For example, Murray and colleagues (31) observed when subjects received a PI drink that plasma insulin levels decreased up to ~30% during 120 min of cycling at 65–75%  $\dot{V}O_{2\max}$ . In comparison, when subjects were provided a CHO beverage (26 g/h), plasma insulin levels decreased ~15% during the first 20 min of exercise and tended to approximate baseline levels during the remaining 100 min. In this investigation, we observed that plasma insulin levels decreased ~50% during the first 60 min of CHO and PI trials. The significance of this finding is unclear. Several investigations have been completed that describe differences in insulin sensitivity between men and women (9, 10). In one investigation, Donahue and associates (9) observed that premenopausal women have a greater insulin response to an oral glucose tolerance test than do men. In another investigation, these same authors found that glucose uptake at a constant insulin level was greater in women than in men after adjustments were made for differences in body composition (10).

In conclusion, the results of this investigation indicate that the performance-enhancing effects of CHO supplementation during prolonged exercise at 70%  $\dot{V}O_{2\max}$  are not influenced by menstrual cycle phase.

Furthermore, menstrual cycle phase did not alter endurance performance or any hormonal and metabolic factors that could influence endurance performance.

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