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Consumption of an Oral Carbohydrate-Protein Gel Improves Cycling Endurance and Prevents Postexercise Muscle Damage

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Abstract. Saunders, M.J., N.D. Luden, and J.E. Herrick. Consumption of an oral carbohydrate-protein gel improves cycling endurance and prevents postexercise muscle damage. *J. Strength Cond. Res. 21(3):678–684. 2007.*—Investigators have reported improved endurance performance and attenuated postexercise muscle damage with carbohydrate-protein beverages (CHO+P) versus carbohydrate-only beverages (CHO). However, these benefits have been demonstrated only when CHO+P was administered in beverage-form, and exclusively in male subjects. Thus, the purposes of this study were to determine if an oral CHO+P gel improved endurance performance and post-exercise muscle damage compared to a CHO gel, and determine if responses were similar between genders. Thirteen cyclists (8 men, 5 women; $\dot{V}O_2$peak = 57.9 ± 7.0 ml·kg^{-1}·min^{-1}) completed two timed cycle-trials to volitional exhaustion at 75% of $\dot{V}O_2$peak. At 15-minute intervals throughout these rides, subjects received CHO or CHO+P gels, which were matched for carbohydrate content (CHO = 0.15 g CHO·kg BW^{-1}; CHO+P = 0.15 g CHO + 0.038 g protein·kg BW^{-1}). Trials were performed using a randomly counterbalanced, double-blind design. Subjects rode 13% longer ($p < 0.05$) when utilizing the CHO+P gel (116.6 ± 28.5 minutes) versus the CHO gel (102.8 ± 25.0 minutes). In addition, men (101.8 ± 24.6; 114.8 ± 26.2) and women (104.4 ± 28.6; 119.6 ± 34.9) responded similarly to the CHO and CHO+P trials, with no significant treatment-by-gender effect. Postexercise creatine kinase (CK) was not significantly different between treatments. However, CK increased significantly following exercise in the CHO trial (183 ± 116; 267 ± 214 U·L^{-1}), but not the CHO+P trial (180 ± 133; 222 ± 141 U·L^{-1}). Therefore, to prolong endurance performance and prevent increases in muscle damage, it is recommended that male and female cyclists consume CHO+P gels rather than CHO gels during and immediately following exercise.

Key Words. performance, creatine kinase, substrate utilization, gender

Introduction

It is estimated that protein contributes approximately 5–15% of total energy demands during prolonged exercise (9, 17). Because this contribution is considerably less than that of carbohydrates, protein traditionally has been ignored as a potential ingredient in sports beverages consumed during endurance activities. However, 2 recently published studies (23, 33) have reported significant improvements in endurance performance when athletes consumed carbohydrate plus protein (CHO+P) beverages vs. carbohydrate-matched (CHO) beverages. In addition, CHO+P beverages consumed during or immediately after exercise have been associated with improved muscle recovery. Specifically, CHO+P beverages reportedly accelerate muscle glycogen replenishment (20, 37, 38) and reduce postexercise muscle damage (32, 33) following heavy exercise.

Despite a growing body of evidence which suggests that CHO+P beverages improve endurance performance and postexercise recovery, a variety of specific issues require further clarification. For example, because previous studies have used CHO+P exclusively in beverage form, it is unclear whether similar benefits result from CHO+P administered in oral gels or solid feedings. Earnest and colleagues (18) observed that CHO gels produce comparable physiological and performance benefits previously demonstrated for traditional CHO beverages (11, 12, 16, 22). Thus, recommendations for carbohydrate gel usage are consistent with those for carbohydrate beverages. Based on the evidence presented above, it seems reasonable to expect that a CHO+P gel may produce performance and recovery benefits that exceed those of a CHO gel. However, this remains an untested hypothesis.

Another limitation of CHO+P research is that all existing data have been collected from men. Some researchers have reported that men oxidize higher proportions of carbohydrates than women do during exercise (19, 20, 35), although others have not observed these differences (31). Despite reports of lower endogenous carbohydrate oxidation during endurance activity in women, Riddell and associates (30) observed that women used higher proportions of exogenous carbohydrates, and others have reported that women derive performance benefits from carbohydrate ingestion similar to benefits reported in men (3, 10). Collectively, these data suggest that women may derive benefits from CHO+P treatments comparable to those observed in men. However, data must be collected on women to support this hypothesis.

Therefore, the current study was designed to address 3 research questions. First, is endurance performance improved when subjects consume an oral CHO+P gel vs. a CHO gel? Second, does consumption of a CHO+P gel attenuate postexercise muscle damage compared with a CHO energy gel? Third, are the putative benefits of CHO+P gels observed consistently between men and women?

Methods

Experimental Approach to the Problem

For practical purposes, many endurance athletes prefer transporting and consuming gel packets in lieu of conventional sports beverages. The primary aim of this study was to determine if recently reported benefits of CHO+P beverages (improved performance, attenuated postexercise muscle damage) were observed when CHO+P gels were used instead of beverages. To allow a meaningful comparison to published data, a protocol was chosen that was very similar to Saunders et al. (33), because this was

TABLE 1. Subject demographics.

Variable	Overall group	Men	Women
Age (y)	24.2 ± 6.8	23.8 ± 7.4	24.8 ± 6.4
Weight (kg)	69.5 ± 11.1	74.8 ± 10.1	61.1 ± 7.0
$\dot{V}O_2$peak ($L \cdot min^{-1}$)	4.0 ± 0.8	4.5 ± 0.4	3.2 ± 0.4
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.6 ± 6.7	61.5 ± 4.2	51.3 ± 4.9

the only published study that examined both endurance performance and postexercise plasma creatine kinase (CK) between CHO and CHO+P beverages matched for carbohydrate content.

Investigators comparing CHO and CHO+P interventions encounter the issue of whether to match their treatments for carbohydrate calories or total calories. The energy gels compared in the present study were matched for total carbohydrate content. As a result, the CHO+P gel contained 25% more calories (from protein) than the CHO gel did. There are a number of rationales for this comparison. First, it is the most generalizable approach; commercially available CHO+P gels and beverages contain amounts of carbohydrate comparable to those of traditional CHO gels and beverages, and thus athletes would be most interested in knowing whether the addition of protein to their carbohydrate gel is effective. Second, most investigators and guidelines observe that 6–10% concentrations of carbohydrate are optimal (1, 13). Above this level, gastrointestinal discomfort is more likely and additional performance benefits are not expected to occur. Both gels in the present study were administered with water such that the relative concentration of carbohydrate was 7.3% in both trials. This was identical to the beverage concentrations used by Saunders et al. (33).

The measure of performance chosen for this comparison was a ride to exhaustion at 75% $\dot{V}O_2$peak. Although time to exhaustion has been criticized as a measure of endurance performance (24), it was a highly relevant measure in this study for 2 reasons. Firstly, time-to-exhaustion protocols at around 70% of $\dot{V}O_2$peak ensure that intramuscular glycogen availability is a contributing factor to fatigue (4), thus maximizing the putative effects of energy gels. In addition, this measure of performance allowed a direct comparison of findings to recently published data on CHO+P beverages (33).

Gel feedings were administered every 15 minutes after the onset of exercise, followed by a larger feeding immediately postexercise. This feeding pattern replicated commonly recommended protocols for subjects engaged in endurance exercise. The postexercise feeding was relatively large, with the intention of maximizing the effect of the treatment on muscle recovery/damage without the concern of gastrointestinal distress playing a role in the volitional fatigue of the subject. Past research has suggested that postexercise feedings of CHO+P within 30 minutes of exercise cessation are critical to optimize the recovery process (21, 26, 38).

A secondary purpose of the present study was to assess gender differences in responses to the gel treatments. Although the small subsets of men and women precluded broad generalizability of these findings, this study was designed to establish a preliminary comparison of the effects of CHO+P treatments between men and women. The observation of similar responses between genders may justify mixed-gender samples in subsequent studies. Conversely, the observation of gender differences between treatments may suggest the need for more comprehensive examinations of gender effects with CHO+P interventions.

Subjects

Thirteen recreationally competitive cyclists (8 men, 5 women) volunteered to participate in this study. To be included in the study, subjects were required to be training at least 3 days per week and to record a $\dot{V}O_2$peak of >40 $ml \cdot kg^{-1} \cdot min^{-1}$ (women) or >45 $ml \cdot kg^{-1} \cdot min^{-1}$ (men). Subject demographics are provided in Table 1. According to American College of Sports Medicine (ACSM) guidelines (1), mean $\dot{V}O_2$peak values were well above the 90th percentile for cardiorespiratory fitness among U.S. adults, ages 20–29. The $\dot{V}O_2$peak values in this group were consistent with recreationally competitive athletes, but considerably lower than those of elite-level athletes. Typical training levels among subjects in this study varied from 3–6 cycling sessions per week, 1–5 hours per session. Some subjects were performing additional resistance training 2–3 days per week, but were asked to refrain from resistance training or other heavy exercise for at least 48 hours prior to all testing (as described below). Prior to testing, all subjects signed an informed consent form and a comprehensive medical questionnaire to determine the presence of any risk factors associated with coronary artery disease. All subjects were asymptomatic and possessed fewer than 2 risk factors using ACSM guidelines (2). All procedures and protocols were approved by the James Madison University Institutional Review Board.

Procedures

Phase I: Physical Fitness Assessment Screening Test. Potential subjects who met the inclusion criteria completed a physical fitness assessment. This included a $\dot{V}O_2$peak test and body mass measurement. These 2 measurements were used to determine the intensity of the exercise bout and the amount of fluid/gel to be administered in phase II.

Body Mass. A digital physician's scale was used to determine body weight to the nearest 0.1 kg. Each subject was weighed in his or her cycling clothing without shoes and socks.

Cardiorespiratory Test ($\dot{V}o_2$peak). Before testing, subjects performed a 3-minute warm-up on an electronically braked cycle ergometer (Ergoline 800S; SensorMedics, Yorba Linda, CA) at a self-selected pace to prepare for maximal exercise. Subjects then performed a graded exercise test on the same device to determine their peak oxygen uptake. The initial workload for the test was determined subjectively during the warm-up as a wattage the rider felt he or she could maintain for a prolonged ride of easy–moderate intensity. In previous studies, this self-selected wattage produced an initial workload that was consistently below lactate threshold but minimized excessive test duration that can occur in extremely standardized protocols. From this starting wattage, workload was increased uniformly by 25 W each minute during the

test. Subjects were encouraged to cycle at a self-selected cadence of >50 rev·min^{-1} until they were unable to maintain this minimum cadence for a 30-second period, at which point the test was terminated. The following measurements were obtained during this test.

Metabolic Measures. Metabolic measurements including oxygen uptake ($\dot{V}O_2$), CO_2, respiratory exchange ratio (RER), and ventilation were obtained continuously throughout this test using a Vmax Spectra metabolic cart (SensorMedics). Subjects expired air through a 2-way rebreathing valve, which was connected to the metabolic cart. The metabolic cart was calibrated before each use using medical-grade gasses of known concentrations and a 3.0-L calibration syringe.

Heart Rate and Ratings of Perceived Exertion. Heart rate and ratings of perceived exertion (RPE) were obtained at the end of each 60-second period during the $\dot{V}O_2$peak test. Heart rate was acquired via a Polar heart rate monitor (Polar, Brooklyn, NY). The RPE was obtained using Borg's 6- to 20-point RPE scale (8).

Phase II. Experimental Ride With Blinded Treatment A. Each subject performed a prolonged bout of cycling exercise at a self-selected cadence of >50 rev·min^{-1} at an intensity corresponding to 75% of $\dot{V}O_2$peak. The bout was terminated when the subject could no longer maintain 50 rev·min^{-1} for a period of 30 seconds. Time to exhaustion during this test was used to compare endurance performance between gel treatments. A previous examination of this protocol in our laboratory produced an intraclass correlation for repeated time-to-exhaustion measures of 0.817. As discussed later, this consistency was deemed adequate to provide a power level of >0.80 to determine differences between treatments (27).

Twelve to 15 hours after the exercise bout, the subject returned for venous blood collection. The following measurements were obtained during the ride.

Oxygen Uptake, Respiratory Exchange Ratio, Heart Rate, and Perceived Exertion. The $\dot{V}O_2$ and RER were obtained at 30-minute intervals after the onset of exercise using a Vmax Spectra metabolic cart (SensorMedics), as described above. Heart rate and RPE also were obtained every 30 minutes during the trial.

Blood Glucose, Lactate, and Creatine Kinase. Fingerstick blood samples were obtained at rest and every 30 minutes during the exercise bout to determine glucose and lactate levels (YSI 2300 STAT; YSI Inc., Yellow Springs, OH). A venous blood sample was obtained immediately prior to and 12–15 hours after the exercise bout. These samples were analyzed for plasma CK (Vitro DT 60II; Johnson and Johnson, New Brunswick, NJ) as an indirect marker of muscle damage. Prior to analyses, the measurement device was calibrated using a reconstituted lyophilized calibration standard purchased from the manufacturer. Concentrations of CK in the standard were 45, 525, and 1,700 U·L^{-1}. For consistency with previous CHO+P research (33), subjects returned for postexercise blood samples 12–15 hours following their exercise bout. The exact postexercise duration within this time frame was held constant for each subject. A previous examination of the above protocols in our laboratory produced an intraclass correlation for repeated postexercise CK measures of 0.759. As discussed later, this consistency was deemed adequate to provide a power level of >0.80 to determine differences between treatments (26).

Gel/Fluid Protocol. Subjects consumed a commercially-available CHO or CHO+P energy gel (GuSports, Berkeley, CA, and PacificHealth Laboratories, Inc., Matawan, NJ, respectively) with 2 ml·kgBW^{-1} of water every 15 minutes during exercise. Gels were purchased in commercially-available packets and were transferred into flasks marked A or B by a volunteer who was not involved with data collection in the study. All treatments were administered in a counterbalanced, double-blind design. Subjects received 0.146 g CHO·kgBW^{-1} each feeding, such that the concentration of carbohydrate relative to the fluid was 7.3% by volume (i.e., 2 ml·kgBW^{-1} × 0.073). Both CHO and CHO+P gels comprised maltodextrin and fructose carbohydrate sources. The CHO+P gel was matched for total carbohydrate content with the CHO gel, but also had 0.0365 g P·kgBW^{-1}. Therefore, a theoretical 70-kg subject received 140 ml of water, 10.22 g of carbohydrate, and 2.56 g of protein (if present) per 15-minute feeding.

Gel feedings were measured by weight and were fed to the subject by a serving spoon every 15 minutes throughout exercise. Immediately upon completion of the ride, subjects ingested a postexercise feeding of energy gel and water. This feeding consisted of 5 ml·kgBW^{-1} of water, 0.73 g CHO·kgBW^{-1}, and 0.183 g P·kgBW^{-1} (if present).

Phase III: Experimental Ride With Blinded Treatment B. Subjects returned after a 7- to 14-day recovery/washout period and repeated the cycling protocol described in phase II. The only difference in the aforementioned protocol was the administration of the alternate gel. For example, if the subject consumed the CHO+P gel during phase II they received the CHO gel during phase III.

Diet/Exercise Controls. Prior to phases II and III, subjects completed dietary (24-hour) and exercise (48-hour) logs. To minimize the effects of diet and outside exercise on study results, subjects were instructed to maintain their normal exercise and dietary habits throughout the course of the study but to refrain from heavy exercise and resistance training for 48 hours prior to the treatment rides. Following phase II, copies of dietary and exercise logs were provided to the subjects with instructions to repeat pre–phase II diet and exercise habits as consistently as possible before phase III. No significant differences in total calories, carbohydrate calories or protein calories were observed between trials.

Statistical Analyses

Differences in time to exhaustion between treatments were assessed using a dependent *t*-test. Differences in CK were analyzed using a 2 × 2 (treatment × time) repeated-measures analysis of variance (ANOVA). Simple comparisons also were performed to determine if CK levels increased significantly over time within each treatment. The effects of gender on time to exhaustion and changes in CK were assessed by examining the gender × treatment interaction effect in a 2-way repeated-measures ANOVA.

At 13, the number of subjects exceeded the minimum sample size needed to detect treatment differences in endurance performance and CK with a power of 0.80. This power calculation (27) was based on estimated effect sizes of 1.0 *SD*, a 2-tailed alpha level of 0.05, and intraclass correlations for repeated measures of 0.817 and 0.759 for time to exhaustion and CK, respectively. Intraclass correlations were based on previous data collected in our laboratory, whereas effect sizes were estimated conservatively based on previous data from a similar protocol, in which we observed effect sizes of 1.44 and 2.24 *SD* for

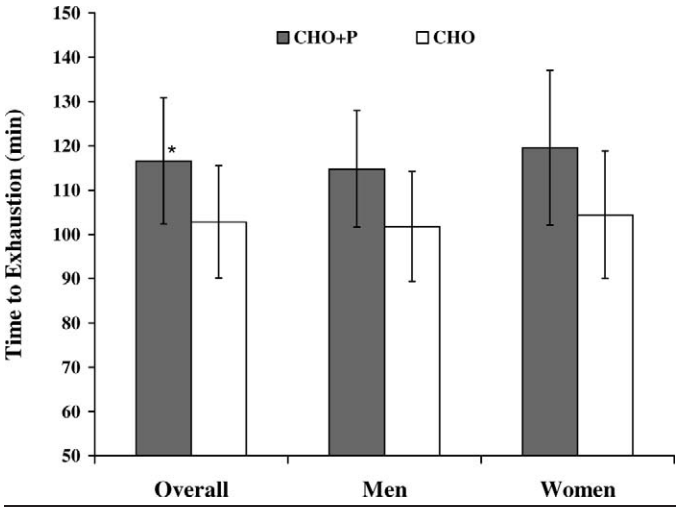

FIGURE 1. Time to exhaustion differences between treatments. * Time to exhaustion significantly longer in carbohydrate + protein (CHO+P) trial ($p < 0.05$).

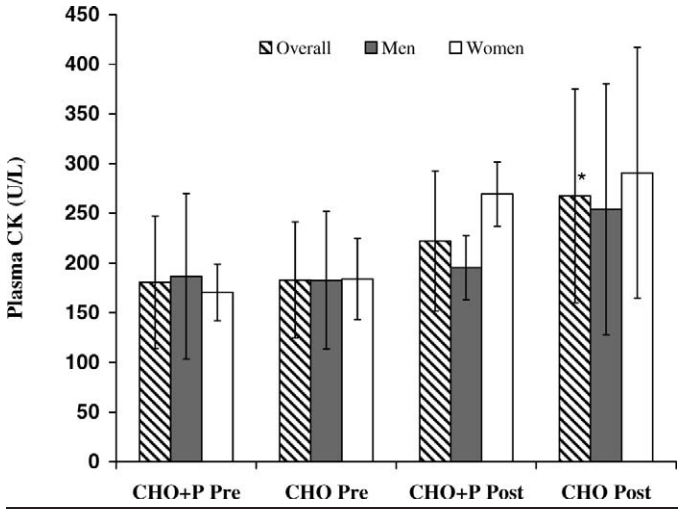

FIGURE 2. Creatine kinase (CK) differences between treatments. * CK significantly increased in the carbohydrate (CHO) trial from pre-exercise level ($p < 0.05$).

treatment differences in time to exhaustion and CK, respectively.

RESULTS

Subjects performed 13% longer ($p < 0.05$) in the CHO+P trial (116.6 ± 28.5 minutes) than in the CHO trial (102.8 ± 25.0 minutes) (Figure 1). Responses between treatments were very similar between men (114.8 ± 26.2 and 101.8 ± 24.6 minutes) and women (119.6 ± 34.9 and 104.4 ± 28.6 minutes). As a result, there was no significant treatment × gender interaction ($p = 0.980$).

Physiological data were obtained for $\dot{V}O_2$, heart rate, RER, blood lactate, blood glucose, and RPE (Table 2). Data presented were obtained at 30 minutes of exercise because it was the only common time point for all subjects on all treatment rides. No differences between CHO and CHO+P trials were observed for any of these variables. In addition, there were no significant treatment × gender interactions.

Postexercise muscle damage was assessed indirectly by analyzing plasma CK concentrations. Two subjects were omitted from this analysis (1 man, 1 woman). One subject was unable to provide a posttest blood sample, and another subject was omitted due to a baseline CK value of >800 $U \cdot L^{-1}$. Pretrial exercise logs revealed that this abnormally high baseline level was likely the result of heavy resistance training that was completed 24 hours before testing, despite pretest instructions to refrain from vigorous exercise for 48 hours prior to test sessions. A repeated-measures ANOVA revealed a significant main effect for time ($p < 0.05$), but no treatment × time interaction for CK ($p = 0.294$). However, CK significantly increased ($p < 0.05$) from pre-exercise to postexercise in the CHO trial (183 ± 116 and 267 ± 214 $U \cdot L^{-1}$, respectively), but not in the CHO+P trial (180 ± 133 and 222 ± 141 $U \cdot L^{-1}$, respectively) (Figure 2). There were no significant treatment × gender ($p = 0.916$) or time × treatment × gender ($p = 0.751$) interactions in CK responses.

DISCUSSION

This study was the first to examine if the ingestion of an oral CHO+P energy gel provided benefits in endurance performance comparable to those of a CHO energy gel. The primary finding was that cyclists performed 13% longer at 75% $\dot{V}O_2$peak when receiving a CHO+P gel than when consuming a CHO gel. These findings are comparable to a recent report from Saunders et al. (33), who observed 29% improvements in cycling endurance when athletes consumed CHO+P beverages vs. CHO beverages during a similar protocol. Ivy et al. (23) also observed improvements in variable-intensity cycling performance when cyclists consumed CHO+P beverages vs. CHO and placebo beverages.

The CHO and CHO+P energy gels used in this study were matched at 7.3% carbohydrate content, which is similar to beverages used in studies by Saunders et al. (33) and Ivy et al. (23). Therefore, the CHO+P gels contained 25% more calories than the CHO gels did, exclusively in the form of protein. As described in the "Experimental Approach to the Problem" section, it has been widely observed that 6–10% concentrations of carbohydrate are optimal for sports beverages (1, 13). Thus, the

TABLE 2. Physiological responses during rides with CHO and CHO+P treatments.*

Variable	Overall		Men		Women	
	CHO+P	CHO	CHO+P	CHO	CHO+P	CHO
$\dot{V}O_2$ ($L \cdot min^{-1}$)	3.0 ± 0.63	3.0 ± 0.65	3.4 ± 0.40	3.5 ± 0.38	2.3 ± 0.18	2.4 ± 0.23
Heart rate ($b \cdot min^{-1}$)	156.5 ± 14.8	159.5 ± 12.7	155.4 ± 17.6	158.0 ± 15.3	158.2 ± 10.6	161.8 ± 8.1
RER	0.96 ± 0.04	0.97 ± 0.03	0.95 ± 0.02	0.97 ± 0.04	0.97 ± 0.06	0.97 ± 0.03
Lactate ($mmol \cdot L^{-1}$)	2.9 ± 1.5	3.7 ± 1.4	2.4 ± 1.15	3.7 ± 1.6	3.56 ± 2.0	3.7 ± 1.3
Glucose ($mg \cdot dl^{-1}$)	79.0 ± 14.9	75.2 ± 14.0	82.1 ± 17.9	82.9 ± 13.3	76.0 ± 12.1	67.1 ± 9.8
RPE	13.9 ± 1.8	13.9 ± 1.8	14.3 ± 2.3	14.7 ± 2.1	13.8 ± 1.1	13.0 ± 1.0

* No significant differences between CHO+P and CHO treatments; no significant treatment × gender interactions. CHO = carbohydrate; CHO+P = carbohydrate and protein; RER = respiratory exchange ratio; RPE = rating of perceived exertion.

purpose of the present study was to determine if protein added to a theoretically optimal amount of carbohydrate would produce additional performance benefits. It is possible that the performance benefits observed with CHO+P administration in the present study and aforementioned studies (23, 33) resulted from the additional protein calories in the CHO+P beverages. Saunders et al. (33) suggested that this was unlikely to be the primary mechanism for performance improvements, based on calculations that the additional protein calories from the CHO+P beverage could not explain more than one-third of the additional calories expended during the CHO+P trial. However, it also should be noted that performance improvements with added protein have considerable practical importance even if the ergogenic effects were the result of the additional protein calories. This result would suggest that protein oxidation is upregulated by CHO+P consumption during exercise. This differs from traditionally discussed models of substrate utilization during exercise, in which the contribution from protein is largely ignored. Colombani et al. (14) observed increased plasma levels of amino acids, urinary total nitrogen, and absolute urea with CHO+P ingestion and concluded that supplemental protein was at least partially oxidized during exercise. Similarly, Koopman et al. (25) reported increased protein oxidation when protein was added to a carbohydrate beverage during prolonged endurance activity. Therefore, it is possible that the ergogenic effects of protein may result from an increase in the upper limit of exogenous caloric uptake/oxidation beyond levels attainable with carbohydrate-only treatments.

A number of calorically-independent mechanisms also could explain the observed ergogenic benefits of the CHO+P gel in this study. It is possible that branched-chain amino acids (BCAA) from the CHO+P gel attenuated central fatigue during this trial, because Blomstrand and associates (5, 6) reported improved physical and mental performance with BCAA administration. Protein also may aid endurance performance by facilitating carbohydrate or fluid transport across the lining of the intestine, as implied from hydration studies from Shi et al. (34) in which carbohydrate and total solute absorption appeared to be increased slightly by the addition of glycine to a mixed-carbohydrate beverage. It also has been suggested that improved performance in CHO+P trials may result from augmented insulin stimulation, which has been observed with postexercise CHO+P feedings (36, 37, 39). However, each of the calorically-independent mechanisms discussed above requires further investigation to determine the primary cause of improved endurance performance in CHO+P trials.

A secondary purpose of our study was to compare the relative ergogenic effects of a CHO+P gel between men and women. Previous studies have observed gender differences in substrate utilization during moderate intensity exercise. For example, Tarnopolsky et al. (35) found that, compared with men, women used more lipids and less carbohydrate and protein during a 15.5-km run. Lower carbohydrate oxidation in women has been similarly reported by other investigators (19, 20), although some have observed no gender differences (31). Despite potential differences in substrate utilization between genders, women derive comparable ergogenic effects from carbohydrate feedings to those observed in men. Investigators have reported improvements in time to fatigue (3) and endurance time-trial performance (10) with CHO ingestion in women. The magnitude of CHO improvements vs. water/placebo are comparable to those in men and do not appear to be influenced by menstrual phase (3, 10). Although these data imply that women may derive benefits from CHO+P treatments comparable to those observed in men, the present study is the first to directly address this hypothesis. Although there were small samples of women and men in the present study, the relative improvements in performance in the CHO+P trial (14.6 and 12.8%, respectively) were remarkably similar between genders. This provides preliminary evidence that the ergogenic effects of CHO+P beverages previously observed in men (23, 33) generalize to women.

A variety of recent evidence has suggested that recovery from heavy exercise may be enhanced with CHO+P feedings. For example, the addition of protein to postexercise carbohydrate feedings has been associated with enhanced muscle glycogen replenishment (21, 37, 39). This may be the result of glycogen synthase stimulation due to augmented insulin levels (36, 37, 39), although higher rates of glycogen replenishment with CHO+P feedings have been reported without increases in insulin above levels in CHO trials (21). This finding suggests that protein may enhance glycogen replenishment through mechanisms that are both dependent and independent of insulin concentration. At least 3 studies have reported improvements in subsequent exercise performance with postexercise CHO+P feedings (29, 33, 38), which may be the result of enhanced glycogen replenishment.

Carbohydrate-protein feedings also may improve athletic recovery by attenuating muscle damage following heavy endurance training. Two recent studies observed 45% (32) to 83% (33) attenuations in postexercise CK, as well as reduced muscle soreness (32) with CHO+P beverage administration. It also was reported that athletes who observed the largest attenuations in postexercise CK with CHO+P administration in the study by Saunders et al. (33) exhibited the greatest improvements in performance in a subsequent exercise bout (15), suggesting a causal link between attenuated muscle damage and subsequent performance. Reductions in muscle damage with the ingestion of CHO+P may be explained by an improved balance between protein synthesis and degradation during and following exercise. Miller et al. (28) demonstrated that postexercise leg phenylalanine uptake was significantly greater following administration of a CHO+P supplement when compared with a CHO supplement. The authors concluded that carbohydrate-induced hyperinsulinemia was inadequate for protein synthesis without an adequate supply of amino acids. Thus, the presence of both carbohydrate and protein in CHO+P feedings provided an interactive effect that optimized postexercise protein synthesis. The timing of postexercise CHO+P feedings also appears to be important, because higher rates of protein synthesis and net protein balance have been reported when CHO+P supplements were ingested immediately following exercise, as opposed to 3 hours postexercise (26).

Postexercise muscle damage was assessed in the present study by measuring plasma CK levels. Unlike the aforementioned studies, no significant differences in postexercise CK were observed between CHO and CHO+P gels. However, the CHO+P gel prevented a significant increase in CK from pre- to postexercise, as similarly reported by Romano-Ely et al. (32). The present study differed from others in that there were no large elevations in postexercise CK following the CHO trial, although the moderate elevations observed represented a statistically

significant increase in CK. Thus, the CHO+P gel was effective at preventing damage, but the protocol did not elicit enough muscle damage in this group of subjects to be able to demonstrate significant differences in postexercise CK levels between treatments.

There are at least 2 explanations for the low postexercise CK levels in this study. The first possibility is that the relative muscular effort of this group of subjects was lower than in previous studies (i.e., subjects may have self-selected a higher cadence during cycling, minimizing muscular force at a given workload). We are aware of no studies that have examined the effects of varying cycling cadence or load on muscle damage. However, if higher pedaling cadences reduced the overall effect on muscle damage, then it would be impossible to observe differences between treatments without a very large sample size. In general support of this hypothesis is the observation that postexercise CK was elevated significantly from baseline in the CHO trial but not in the CHO+P trial. Theoretically, the smaller postexercise effect that was observed between treatments in the present study (i.e., 0.52 *SD* vs. >1.0 *SD* in previous studies) would require a sample size of approximately 50 subjects to allow adequate statistical power (0.80) to observe differences in postexercise CK (27).

Another possibility for the lower postexercise CK levels is that the subjects in the present study were more highly trained than were those in previous studies. If subjects were training more vigorously, it is possible that a greater protective effect from muscle damage could be present (7). However, although training status can not be directly compared between studies, the reported $\dot{V}O_2$peak values in the subject pools do not support this hypothesis. The $\dot{V}O_2$peak values of the present subjects (overall/male values = 57.9 ± 7.0; 61.5 ± 4.2 ml·kg^{-1}·min^{-1}) were higher than those provided by Saunders et al. (52.6 ± 10.3; men) (33), but they were lower than those reported by Romano-Ely et al. (63.4 ± 10.8 ml·kg^{-1}·min^{-1}; men) (32). Thus, it seems unlikely that potentially small differences in training status between the groups studied can explain the comparably large discrepancies in postexercise CK between studies.

PRACTICAL APPLICATIONS

Supplementation of a CHO+P gel provided significant improvements in cycling endurance compared to a CHO gel, and these performance benefits were consistently observed in men and women. In addition, postexercise CK was not elevated significantly following the CHO+P gel trial, suggesting that CHO+P gels may attenuate postexercise muscle damage. Thus, consumption of CHO+P mixtures during and following endurance activity provides important benefits for both acute endurance performance and muscle recovery in men and women.

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