Postexercise Carbohydrate-Protein-Antioxidant Ingestion Decreases Plasma Creatine Kinase and Muscle Soreness

Nicholas D. Luden, Michael J. Saunders, and M. Kent Todd

The authors investigated the effects of postexercise carbohydrate-protein-antioxidant (CHO+P+A) ingestion on plasma creatine kinase (CK), muscle soreness, and subsequent cross-country race performance. Twenty-three runners consumed 10 mL/kg body weight of CHO or CHO+P+A beverage immediately after each training session for 6 d before a cross-country race. After a 21-d washout period, subjects repeated the protocol with the alternate beverage. Postintervention CK (223.21 ± 160.71 U/L; 307.3 ± 312.9 U/L) and soreness (medians = 1.0, 2.0) were significantly lower after CHO+P+A intervention than after CHO, despite no differences in baseline measures. There were no overall differences in running performance after CHO and CHO+P+A interventions. There were, however, significant correlations between treatment differences and running mileage, with higher mileage runners having trends toward improved attenuations in CK and race performance after CHO+P+A intervention than lower mileage runners. We conclude that muscle damage incurred during training was attenuated with postexercise CHO+P+A ingestion, which could lead to performance improvements in high-mileage runners.

Key Words: muscle damage, recovery, sport nutrition, endurance performance

Although recent studies have reported improvements in endurance performance with carbohydrate-protein (CHO+P) administration during exercise (12, 26), athletes might not derive these benefits if they perform activities of relatively short duration (<60–90 min) or when consuming CHO+P during the event is not practical. However, postexercise CHO+P ingestion might also enhance various aspects of muscle recovery, providing improvements in subsequent exercise performance. Investigators have observed augmented insulin levels (21, 32, 35) and increased rates of muscle-glycogen resynthesis (11, 35, 36) with postexercise CHO+P feedings, although others have reported no differences between CHO+P and CHO treatments (6, 31). Williams et al. (35) and Niles et al. (21) observed significant improvements in subsequent performance when athletes consumed CHO+P after an exhaustive bout of exercise, which were associated with elevated postexercise...

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insulin levels (21, 35) and muscle-glycogen restoration (35). Limitations in each of these studies, however, such as varying carbohydrate levels between treatments (35) and preexercise glycogen depletion (21), make direct generalization to athletic settings difficult.

CHO+P feedings might also improve muscle recovery by attenuating muscle damage after heavy endurance exercise. A few recent studies have reported reductions in postexercise plasma creatine-kinase (CK) levels (25, 26) and muscle soreness (18, 25) with CHO+P ingestion. Saunders et al. (26) observed improved subsequent performance with CHO+P versus CHO consumption and later reported that individuals with the greatest attenuations in plasma CK after an initial exhaustive exercise bout were the best performers in a subsequent exercise bout (7). CHO+P beverages were provided during and after exercise in that study, however, so it is unclear whether these benefits would have been elicited with postexercise feedings alone. In addition, 2 recent studies reported no improvements in subsequent performance with postexercise CHO+P administration (4, 18), making it difficult to provide clear recommendations regarding CHO+P ingestion.

Another nutritional strategy used to improve recovery in endurance athletes is ingestion of antioxidants, which are included in some commercially available recovery beverages. Evidence supporting their presumed ability to protect muscle from free-radical-induced muscle damage remains equivocal, however. At least 3 studies support that antioxidant consumption provides some protective effect from muscle damage with relatively long duration of treatment (10, 17, 29). It generally appears, however, that the effects of antioxidant supplements are negligible when administered over periods of less than 1 wk (20, 28), especially in highly trained subjects (24) or in subjects without vitamin deficiencies (27). It is possible, however, that regular use of antioxidants might augment the putative benefits of CHO+P beverages.

In summary, endurance athletes might derive the putative benefits of enhanced muscle-glycogen resynthesis, attenuated muscle damage, and improved athletic performance from CHO+P beverage ingestion. It is also possible that including antioxidants might enhance muscle recovery in some situations. It is unclear, however, whether these benefits are observable in athletes who consume CHO-protein-antioxidant (CHO+P+A) beverages only postexercise, perform events of moderate duration, and perform in a practical setting in which treatment effects are not artificially maximized (e.g., pretrial glycogen depletion, short durations between exercise bouts). Therefore, the aim of this study was to compare the effects of 6 d of postexercise CHO and CHO+P+A beverage consumption on muscle damage, soreness, and subsequent performance in college cross-country runners.

**Methods**

**Subjects and Experimental Design**

Thirty-six NCAA Division I cross-country runners volunteered as subjects for this study after a complete explanation of procedures. Over the course of the study, 5 subjects failed to provide complete data for analysis, and 8 subjects did not comply with instructions to exclude vigorous activity independent of their prescribed
training. Furthermore, these 8 subjects exhibited high baseline plasma CK levels (>500 IU), indicating high levels of muscle damage at the onset of at least 1 of the study’s intervention periods. Data from these subjects were excluded, resulting in 23 subjects (11 men, 12 women) who were included in data analysis. Before the study, all subjects signed an informed consent and were considered apparently healthy individuals according to ACSM guidelines (1). All subjects were recruited from James Madison University’s (JMU) cross-country teams. Permission to recruit these athletes was obtained from the head coach before individual subject consent was obtained. The JMU Institutional Review Board approved all procedures. Descriptive statistics defining the subjects are presented in Table 1.

Procedures

Physical-Fitness Assessment (Body Mass and VO₂max). All subjects who met inclusion criteria for the study completed a body-mass measurement and cardiovascular-fitness test at the onset of the study. During this assessment, subjects were weighed to the nearest kilogram on a digital physician’s scale. Subjects then performed a graded exercise test on a treadmill to determine their maximum oxygen uptake (VO₂max). Subjects began the test by running at a self-selected velocity that they predicted they could maintain for 30 min. Treadmill grade was then increased 1% each minute of exercise until subjects reached volitional fatigue. Oxygen uptake was assessed continuously throughout the test using a SensorMedics Vmax Spectra metabolic cart (Yorba Linda, CA). The VO₂max test occurred 3 d before the first study intervention. A second VO₂max test was administered 3 days before the second study intervention in order to monitor changes in aerobic conditioning during the course of the study.

Intervention Protocol. Subjects completed two 6-d intervention periods in the study. During the first intervention period, subjects performed normal team-training procedures as prescribed by the head cross-country coach (see Table 2). Throughout the 6-d training phase, athletes consumed either a CHO or a CHO+P+A beverage within 30 min after each running bout. Training information (i.e., distance, time, rating of perceived exertion [RPE]) was recorded for selected training sessions that occurred during the week. On the final day of the week, athletes competed in a 5-km (women) or 8-km (men) cross-country race.

The second 6-d intervention period began 3 wk after the first cross-country race. The only variable that differed between trials was the postexercise beverage.

Table 1 Subject Demographics, Mean ± SD

<table>
<thead>
<tr>
<th></th>
<th>Male (n = 11)</th>
<th>Female (n = 12)</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>19.4 ± 1.0</td>
<td>19.3 ± 1.4</td>
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<tr>
<td>Weight (kg)</td>
<td>68.1 ± 6.8</td>
<td>55.3 ± 4.5</td>
</tr>
<tr>
<td>VO₂max (mL·kg⁻¹·min⁻¹)</td>
<td>66.2 ± 5.2</td>
<td>55.0 ± 7.3</td>
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treatment. Testing was randomly counterbalanced so that subjects who consumed the CHO+P+A beverage during the first trial would consume the CHO beverage during the second trial, and vice versa.

**Control of Variables During Training Periods.** To maintain consistency in training levels during the study, similar training regimens were prescribed during the 2 treatment periods (Table 2). Specific training levels for each individual were determined by the head coach and varied between individual athletes according to previous training experience and ability. Consistent training levels were maintained within subjects, however, during the 2 treatment periods. In addition, training intensity was compared between intervention weeks by examining RPE during 3 training days.

Systematic differences in fitness levels between treatment periods could also affect some physiological measures. Therefore, this study used a randomly counterbalanced, double-blind design so that any changes in fitness or performance as a result of time would be randomly distributed within treatment periods. Furthermore, VO$_{2\text{max}}$ levels were assessed 3 d before each treatment phase to determine whether fitness levels within the subjects were similar across treatment periods. Similarly, nutritional intake was assessed on Sunday, Tuesday, and Thursday of each treatment period to confirm that diet was consistent between trials. Logs were analyzed by Diet Analysis Plus software for total caloric intake, protein, carbohydrate, and vitamins C and E (Thomson Higher Education Inc., 2005).

**Treatments.** The 2 beverage treatments included a CHO+P+A beverage and a CHO beverage matched in carbohydrate content (PacificHealth Laboratories, Inc.). Each beverage provided 10 mL/kg body weight of water mixed with 1.46 g/kg body weight of CHO. The primary differences between the beverages were an additional 0.365 g/kg body weight of whey protein and vitamins C and E added to the CHO+P+A beverage. Because the beverages were matched for carbohydrates, the CHO+P+A beverage delivered more total calories (from protein) to the athletes.

### Table 2 Sample Training Week

<table>
<thead>
<tr>
<th>Day</th>
<th>Prescribed training bout</th>
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<tr>
<td>Sunday</td>
<td>15- to 32-km run</td>
</tr>
<tr>
<td>Monday</td>
<td>30 min of light resistance training, 10 km easy running</td>
</tr>
<tr>
<td>Tuesday</td>
<td>Intervals of varied length on a rolling cross-country course</td>
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<tr>
<td>Wednesday</td>
<td>10 km easy or alternative training (i.e., pool or bike)</td>
</tr>
<tr>
<td>Thursday</td>
<td>30 min of light resistance training, 15 km moderate running on hilly terrain</td>
</tr>
<tr>
<td>Friday</td>
<td>8–10 km easy running</td>
</tr>
<tr>
<td>Saturday</td>
<td>5- to 8-km cross-country race</td>
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Three subjects (2 male and 1 female) also completed 3 morning runs (8 km easy running). Training volumes and intensities were consistent within subjects across the 2 intervention periods (see “Control of Variables During Training Periods” in Methods section for details).
Both drinks were vanilla flavored and white in color to ensure a blinded design. A complete comparison of beverage ingredients is displayed in Table 3.

### Dependent Variables

**Muscle Soreness.** Subjective ratings of muscle soreness were obtained before the first run of each intervention period (i.e., long run on Sunday morning). The Sunday measurement was considered a baseline measurement with respect to the dietary intervention but was not considered a true resting baseline measure, because the athletes were training heavily before the onset of the study. Ratings of muscle soreness were again obtained after 5 d of training and treatments (i.e., before Friday’s run). Subjects indicated their overall level of muscle soreness using a scale ranging from 0 to 6, with a score of zero indicating a complete absence of muscle soreness and a score of 6 corresponding to movement being compromised as a product of muscle soreness (33). This scale was used to enable comparison with a similar study by Romano-Ely et al. (25).

**Plasma CK.** Plasma CK was obtained as an indicator of muscle damage. Approximately 4 mL of blood were collected using venous-blood draws from the antecubital vein, and whole blood was spun in a centrifuge at 7000 rpm to separate plasma. Plasma samples were frozen at <-18 °C, brought to room temperature (22 °C), and mixed through gentle inversion before analysis. Plasma CK was analyzed using a Johnson and Johnson Vitro DT 6011. Before analyses, the measurement device was calibrated using a reconstituted lyophilized calibration standard purchased.
from the manufacturer. In addition, CK controls were analyzed at room temperature using CK standards containing low (112–176 U/L) and high (843–1095 U/L) CK concentrations, to confirm an accurate calibration. Blood draws were obtained before the first run of each intervention period (i.e., long run on Sunday morning) and after 6 d of training and treatments (i.e., after Friday’s run). Friday’s blood draw was timed to occur 24 h after Thursday’s run, in order to capture an elevated postexercise level of CK (8) that would allow comparison with similar studies on this topic (25, 26).

**Performance Measures.** At the end of each 6-d treatment period, all athletes performed a cross-country race of 5 km (women) or 8 km (men). Direct comparison of these times was not practical, because cross-country race times can be affected by a variety of extraneous factors. To offset differences in race-day performance resulting from differing courses, distances, and environmental factors, a standardized performance variable was derived for this study. Performance was assessed as the number of seconds that each athlete varied from the average time of all subjects (within their gender) over the course. Athletes performing better than the group mean received negative scores, and athletes performing slower than the group mean received positive scores. For example, an athlete that ran 20 s faster than the mean was given a score of –20. For overall analyses, performance scores for both genders were combined.

Reliability and validity of this performance measure were obtained using JMU team-performance results from the same racecourses during competitions in 2003 and 2004. Intraclass correlations of 0.862 (2003) and 0.933 (2004) were established for repeat measurements between the 2 racecourses in the 2 y measured, indicating a high correlation between standardized performance measures when no nutritional intervention was conducted. The standard error of the estimate for predicting the standardized performance time in the second race from the performance time in the first race was 17–19 s in the 2 y measured, suggesting that a moderate treatment effect could produce differences in performance that were greater than the measurement error between trials. In addition to the described measure, performance was also assessed using race rankings (finishing position) within each gender group. Six subjects were withheld from at least 1 of the races at their coach’s discretion. As a result, all race-performance analyses were conducted with a sample size of 17. The omission of these subjects also affected the counterbalancing of this measure—the omitted subjects included 1 subject who consumed the CHO beverage in the first race and 5 subjects who consumed CHO+P+A in their first race.

**Statistical Analyses**

This study employed a within-subject, repeated-measures design that contrasted the impact of 2 nutritional treatments on plasma CK levels, muscle soreness, and racing performance. Differences in plasma CK levels were assessed using a 2 × 2 (treatment × time) repeated-measures ANOVA. Differences in muscle soreness between treatments were assessed using Wilcoxon signed-ranks tests. A dependent t-test was used to analyze differences in standardized performance measurements between races, and a Wilcoxon signed-ranks test was used to examine potential differences between performance-rank scores. A significance level of $P < 0.05$ was used for all statistical analyses.
To determine whether responses to the beverage treatments for CK and race performance were different between men and women, repeated-measures ANOVAs were conducted, with treatment (and time, for CK) as the within-subject factors and gender as the between-subjects factor. Muscle soreness and performance rank were examined using a Mann–Whitney U test to compare treatment-difference scores (i.e., $\Delta$ Soreness$_{CHO+P+A}$ – $\Delta$ Soreness$_{CHO}$) between genders.

It was hypothesized that the subjects performing the highest running mileages would experience the greatest muscle damage and thus derive greater treatment effects during the study. To determine whether treatment effects were influenced by training mileage, correlation coefficients were calculated for the relationships between treatment-difference scores and running mileage during the 6-d treatment period. In addition, to provide a quantitative illustration of the impact of training mileages on treatment effects, the subject pool was divided into high-mileage (>65 km, $n = 12$ [9 men, 3 women], mean = 86 ± 18 km) and low-mileage (<65 km, $n = 11$ [2 men, 9 women], mean = 49 ± 10 km) training groups. Because of the applied nature of this study, it was not possible to randomly assign subjects into the high- and low-mileage groups. Thus, the 65-km cutoff point was established as the mileage that split the subjects into 2 relatively equal groups with the largest natural break between groups. Treatment-difference scores for CK and race performance were assessed between high- and low-mileage groups using repeated-measures ANOVAs, with treatment as the within-subject factor and mileage group as the between-subjects factor. Treatment-difference scores for soreness were compared between high- and low-mileage groups using a Mann–Whitney U test.

Training distance, RPE, VO$_{2\text{max}}$, and nutritional intake were obtained during both observation periods, as described previously. Dependent $t$-tests were used to compare training distance, VO$_{2\text{max}}$, and nutritional intake between treatments. A Wilcoxon signed-ranks test was used to examine potential differences in RPE between treatments.

### Results

#### Control Variables

Mean 6-d training distance was not different between CHO (68.9 ± 24.5 km) and CHO+P+A (65.3 ± 24.0 km) treatment periods. In addition, RPE obtained during 3 training days did not differ between CHO and CHO+P+A treatment phases, (Monday 13.1 ± 2.5 vs. 13.0 ± 1.8, Tuesday 17.6 ± 0.9 vs. 17.8 ± 0.9, Thursday 14.3 ± 2.0 vs. 14.1 ± 1.4, respectively). There were no differences in cardiorespiratory fitness between CHO (61.5 ± 9.1 mL·kg$^{-1}$·min$^{-1}$) and CHO+P+A (62.1 ± 8.7 mL·kg$^{-1}$·min$^{-1}$) treatment periods. Similarly, nutritional intake analyzed for total caloric intake, protein, carbohydrate, and vitamins C and E was not significantly different between treatment periods (Table 4).

#### Plasma CK

The CHO+P+A beverage significantly attenuated plasma CK levels compared with the CHO beverage, as demonstrated by a significant ($P < 0.05$) treatment × time interaction. There was no significant difference in baseline (day 1, Sunday) plasma CK levels between treatments, but CK was significantly lower in the CHO+P+A
treatment on day 6 (Friday; \( P < 0.05 \); Figure 1). In addition, responses to the beverage treatments were similar between men and women—there were no significant treatment × gender or treatment × time × gender interactions in CK responses. CK attenuation (\( \Delta \text{CK}_{\text{CHO}} - \Delta \text{CK}_{\text{CHO+P+A}} \)) was 149.7 ± 250 and 32.6 ± 97.3 U/L for men and women, respectively.

### Muscle Soreness

Muscle soreness was significantly lower after 5 d of CHO+P+A treatment (\( P < 0.05 \); Figure 2), with a median score of 1 and a range of 0 to 3, compared with the CHO treatment, which elicited a median of 2 and a range of 0 to 5. Treatment differences in muscle soreness (\( \Delta \text{Soreness}_{\text{CHO}} - \Delta \text{Soreness}_{\text{CHO+P+A}} \)) were not different between men (1.1) and women (1.3).

### Table 4 Dietary Intake

<table>
<thead>
<tr>
<th></th>
<th>CHO trial</th>
<th>CHO+P+A trial</th>
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<tbody>
<tr>
<td>Energy (kcal)</td>
<td>2,270 ± 573</td>
<td>2,224 ± 479</td>
</tr>
<tr>
<td>Carbohydrates (kcal)</td>
<td>1,260 ± 336</td>
<td>1,293 ± 328</td>
</tr>
<tr>
<td>Protein (kcal)</td>
<td>341 ± 95</td>
<td>323 ± 75</td>
</tr>
<tr>
<td>Vitamin C (mg)</td>
<td>91 ± 51</td>
<td>83 ± 42</td>
</tr>
<tr>
<td>Vitamin E (mg)</td>
<td>9 ± 7</td>
<td>7 ± 5</td>
</tr>
</tbody>
</table>

CHO indicates carbohydrate, and CHO+P+A, carbohydrate-protein-antioxidant. Values are mean ± SD, not including nutrients from treatment beverages.

**Figure 1** — Treatment differences in plasma creatine kinase (CK). *Significantly lower than CHO intervention (\( P < 0.05 \)). **Significant treatment × time interaction (\( P < 0.05 \)).
Performance

There were no differences in standardized performance times between treatments, as shown in Figure 3. Similarly, there were no significant differences in mean performance ranks between CHO (4.8 ± 2.5) and CHO+P+A (4.7 ± 2.5).
Influence of Running Mileage on Dependent Measures

Significant correlations ($P < 0.05$) were present between running mileage and treatment-difference scores for CK ($r = 0.479$) and race performance ($r = 0.418$). Similarly, comparison of high- and low-mileage groups revealed significant treatment $\times$ mileage interactions ($P < 0.05$) for CK (high $= 170.4 \pm 216.9$, low $= -0.5 \pm 110.8$) and race performance (high $= 15.5 \pm 31.9$ s faster in the CHO+P+A trial, low $= 41.7 \pm 41.5$ s slower). There was no significant correlation between mileage and muscle soreness and no significant treatment $\times$ mileage interaction.

Mileage was significantly different ($P < 0.05$) between genders—men completed significantly more mileage ($79.7 \pm 20.5$km) than did women ($56.0 \pm 20.3$km). Responses to the beverage treatments were similar between men and women, however—there were no treatment $\times$ gender interactions or treatment $\times$ volume $\times$ gender interactions for any of the dependent measures.

Discussion

Our primary finding was that 5 d of postexercise CHO+P+A supplementation significantly attenuated plasma CK and muscle soreness in cross-country runners compared with a CHO supplement. Reductions in postexercise plasma CK (25, 26) and muscle soreness (25) with CHO+P or CHO+P+A ingestion have previously been reported after exhaustive bouts of cycling. It is unclear from these studies, however, whether benefits were the result of treatments consumed during exercise, postexercise, or both. The present study provides evidence that significant attenuations in muscle soreness and plasma CK can be achieved with only postexercise feedings of CHO+P+A during a 6-d training phase. Millard-Stafford et al. (18) recently found that muscle soreness, but not plasma CK, was attenuated as a result of postexercise ingestion of CHO+P. The conflicting CK data might be the result of differences in sample sizes and varying levels of muscle damage. For example, both studies reported relatively low muscle damage after running, resulting in small potential treatment effects. Assuming a mean treatment difference in CK levels comparable to the present study, the small sample size of Millard-Stafford et al. ($N = 8$) produced inadequate statistical power ($\beta < 0.35$) to consistently observe differences between treatments (16).

The specific mechanism by which CHO+P+A might have reduced muscle damage was not addressed in the present study. It is possible that the higher caloric value of the CHO+P+A (because of the added protein) was responsible for the treatment differences in plasma CK and soreness. Romano-Ely et al. (25), however, observed significant reductions in postexercise CK and muscle soreness with CHO+P+A administration, compared with a calorically matched (higher carbohydrate) CHO beverage, suggesting that calories were not responsible for the observed differences between treatments. Miller et al. (19) and Koopman et al. (14) have reported that CHO+P ingestion improves the balance between protein degradation and protein synthesis, which might explain reductions in muscle damage with CHO+P ingestion. We are aware of no studies, however, that have directly
examined whether improvements in muscle damage with CHO+P administration are associated with improvements in protein balance.

The timing of CHO+P+A ingestion also appears to play an important role in the attenuation of muscle damage. Our subjects consumed postexercise feedings of CHO or CHO+P+A immediately after each running bout, throughout the 6-d phase. Total protein intake in the athletes’ daily diets met recommended levels for athletes (>1.5 g/kg body weight) during both treatment periods and was not significantly different between observations (Table 4). Because total dietary protein intake was adequate during both treatments, the attenuations in plasma CK and soreness observed with the CHO+P+A treatment might be related to the timing of protein intake rather than to total daily protein ingestion. In support of this theory, Levenhagan et al. (15) observed that protein synthesis was increased threefold with a feeding of CHO+P provided immediately postexercise, compared with the same treatment provided 3 h after exercise.

Antioxidants were included in the CHO+P+A beverage to maximize the relevance of these findings for athletes who use commercially available recovery beverages, which often include protein and antioxidants. Although some studies have suggested that antioxidants might play a role in attenuating muscle damage after exercise (10, 17, 29), it appears that the effects of antioxidant supplements are negligible when administered over periods of less than 1 wk (20, 28), especially in highly trained subjects (24). The current study design precludes a specific fractioning of benefits derived from additional protein or antioxidants. It seems probable, however, that the reductions in plasma CK and soreness can be primarily attributed to the additional protein because of the relatively short period of antioxidant administration and the observation that the CHO+P+A produced greater attenuations in CK in the subjects performing the greatest training mileages, despite previous observations of improved resistance to oxidation-induced muscle damage in subjects performing higher mileages (24).

A limitation of the present study is the absence of direct markers of muscle damage. CK has been criticized as a quantitative measure of muscle damage because of reports of poor correlations to direct measures of muscle damage (3). In addition, changes in plasma CK concentrations might be affected by altered enzyme-clearance rates (9), which can affect the interpretation of CK changes. For these reasons, it has been suggested that multiple measures of muscle damage should be included in studies when direct measures of muscle damage are not feasible. Because of the highly applied nature of the present study, it was not possible to obtain biopsies for direct measurements of muscle damage. Thus, muscle soreness was also examined to provide a secondary indicator of muscle damage. Although muscle-soreness ratings have also been criticized as a measure of muscle damage (34), the observation that both plasma CK and muscle-soreness ratings were attenuated by the CHO+P+A beverage provides preliminary evidence of the benefits of these beverages on muscle damage. Similar studies should be conducted in the future using direct measures of muscle damage to support these findings.

A related purpose of our study was to determine the effects of a CHO+P+A recovery beverage on subsequent cross-country race performance. It was hypothesized that the CHO+P+A treatment would significantly attenuate markers of muscle damage after 5 d of training, allowing the athletes to begin their subsequent cross-country race in a more “recovered” state, potentially improving race performance,
as shown previously in short-term cycling studies (7, 26). Although plasma CK and muscle soreness were significantly reduced after the CHO+P+A treatment, there were no treatment differences in cross-country race performance, when expressed as a standardized time or as a performance rank. It appears that the level of muscle damage in the CHO trial was not large enough to negatively affect subsequent performance over this relatively short training period.

Posttreatment CK levels in the CHO trial were much lower than those previously reported to be associated with improvements in subsequent performance after exhaustive cycling (7, 26). Explanations for the low CK levels after this training period are not clear, because it has been shown that running generally elicits more muscle damage than cycling because of accentuated eccentric muscle contractions involved in the running gait (13). Because of the highly trained status of the subjects in this study, however, it is possible that they received a prophylactic effect from their training, as illustrated by Byrnes et al. (5). It is also possible that some of the subjects were not running enough mileage to elicit high levels of muscle damage—running distance has been positively correlated with muscle damage or CK levels (22, 23). This concept is supported by a significant correlation between running mileage and treatment differences in CK.

There was also a significant correlation between treatment differences in race performance and running mileage, with the higher mileage runners having a greater tendency toward improved performance after the CHO+P+A treatment than the lower mileage runners. The finding of a significant treatment × mileage interaction for both CK and race performance suggests that athletes who run the highest mileages might benefit the most from CHO+P+A recovery beverages. It should be noted, however, that the high-mileage group did not race statistically faster after the CHO+P+A treatment than after the CHO treatment. This suggests that the total amount of muscle that was protected from damage during the treatment period was not great enough to elicit a significant benefit in performance in either mileage group. For example, it could be roughly estimated that the high-mileage group protected less than 1 g of skeletal muscle during the CHO+P+A treatment, based on a CK difference of 170 U/L and assumed levels of 2.7 L plasma and >1000 U of active CK per gram of skeletal muscle (2, 30). Therefore, the impact of postexercise CHO+P+A should be examined during training periods that are longer, harder, or over a greater time period than the present study to determine whether the attenuations in plasma CK and soreness ultimately lead to improved subsequent performance.

In summary, our study demonstrated that a 6-d period of postexercise CHO+P+A-beverage consumption significantly attenuated markers of muscle damage (plasma CK and muscle soreness) in college cross-country runners. The magnitude of CK reductions with CHO+P+A was greatest in the athletes completing higher training mileages during the treatment period. Postintervention cross-country race performance was not affected by the treatments. There was a greater tendency, however, for a positive treatment effect on race performance in the higher mileage athletes, perhaps because of the greater reductions in muscle damage. We conclude that the small amounts of muscle damage incurred during this training period were attenuated with postexercise CHO+P+A ingestion. Future investigations should examine whether these changes might lead to performance
improvements in those performing high volumes of training or when treatment interventions are implemented over longer periods of time.

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