Whey Protein Addition to a Carbohydrate-Electrolyte Rehydration Solution Ingested After Exercise in the Heat

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Context: Many active people finish exercise hypohydrated, so effective rehydration after exercise is an important consideration.

Objective: To determine the effects of a rehydration solution containing whey protein isolate on fluid balance after exercise-induced dehydration.

Design: Randomized controlled clinical trial.

Setting: University research laboratory.

Patients or Other Participants: Twelve healthy men (age = 21 ± 1 years, height = 1.82 ± 0.08 m, mass = 82.71 ± 10.31 kg) participated.

Intervention(s): Participants reduced body mass by $1.86\% \pm 0.07\%$ after intermittent exercise in the heat and rehydrated with a volume of drink in liters equivalent to 1.5 times their body mass loss in kilograms of a solution of either 65 g/L carbohydrate (trial C) or 50 g/L carbohydrate and 15 g/L whey protein isolate (trial CP). Solutions were matched for energy density and electrolyte content. Urine samples were collected before and after exercise and for 4 hours after rehydration.

Main Outcome Measure(s): We measured urine volume,

drink retention, net fluid balance, urine osmolality, and subjective responses. Drink retention was calculated as the difference between the volume of drink ingested and urine produced. Net fluid balance was calculated from fluid gained through drink ingestion and fluid lost through sweat and urine production.

Results: Total cumulative urine output after rehydration was not different between trial C (1173 ± 481 mL) and trial CP (1180 ± 330 mL) ($F_1 = 0.002$, $P = .96$), and drink retention during the study also was not different between trial C ($50\% \pm 18\%$) and trial CP ($49\% \pm 13\%$) ($t_{11} = -0.159$, $P = .88$). At the end of the study, net fluid balance was negative compared with baseline for trial C (-432 ± 436 mL) ($t_{11} = 3.433$, $P = .03$) and trial CP (-432 ± 302 mL) ($t_{11} = 4.958$, $P = .003$).

Conclusions: When matched for energy density and electrolyte content, a solution of carbohydrate and whey protein isolate neither increased nor decreased rehydration compared with a solution of carbohydrate.

Key Words: milk, water balance, dehydration, hypohydration, recovery

Key Points

- Rehydration after exercise was not different between solutions of isoenergetic carbohydrate and of carbohydrate and whey protein isolate.
- The inclusion of whey protein isolate in a rehydration solution did not interfere with rehydration.
- When both protein intake and rehydration are needed, the addition of whey protein isolate to rehydration solutions might be advantageous.

The human sweat response to exercise demonstrates large interindividual variability in sweat rate and electrolyte composition. Whereas some people adequately replace sweat losses during exercise, others do not, resulting in a hypohydrated state at the end of exercise.^{1–3} When 2 bouts of exercise are completed in close proximity, finishing the first bout in a hypohydrated state means adequate rehydration is necessary to maintain performance in the second bout of exercise.⁴

Rehydration after exercise-induced dehydration has been well investigated, and the most important factors for effective rehydration appear to be the volume and composition of the ingested drink.⁵ Researchers⁶ have shown that, for fluid balance to be restored, a volume of drink greater than the volume of fluid lost must be ingested to account for ongoing urine losses after drink ingestion. Whereas ingesting a sufficient volume of drink is vital for ensuring a return to positive fluid balance after exercise, the

composition of the rehydration drink determines how well the ingested drink is retained over the subsequent period.

Researchers^{7–12} have investigated many different drink formulations consumed after exercise-induced dehydration and have identified several compositional factors that are important for the retention of a rehydration solution. The electrolyte content, and particularly the sodium content, of the ingested solution has been shown to affect its retention.^{7–9} Addition of sodium to a rehydration solution prevents the rapid fall in plasma osmolality and arginine vasopressin associated with the ingestion of large volumes of sodium-free solutions^{13,14} and consequently reduces urine production.^{8,9} The addition of potassium to a rehydration solution might increase the retention of the solution,⁷ possibly by increasing water retention in the intracellular space,^{5,15} but some investigators¹⁶ have found no effect of adding potassium to a rehydration solution.

Manipulating the macronutrient composition of a rehydration solution also has been shown to affect its retention.^{10–12,17} The addition of carbohydrate to a rehydration solution consumed after exercise-induced dehydration has been shown to increase fluid retention compared with carbohydrate-free solutions, but the difference between these solutions appears to be small.^{10,11} The greater fluid retention with consumption of carbohydrate-containing solutions appears to result from a reduction in the rate of gastric emptying of the high carbohydrate solutions, which reduces the rate of water uptake into the circulation¹⁸ and offsets the decline in serum osmolality observed with ingestion of large volumes of dilute solutions.^{10,11}

Researchers have investigated the effects of protein-containing solutions on rehydration after exercise.^{12,17,19} Seifert et al¹⁷ observed that retention of a carbohydrate-protein solution was greater than that of a carbohydrate solution and water, but because they did not match the energy density of the solutions, determining whether the additional protein or the increased energy density increased fluid retention is difficult. Increased energy density might reduce the rate of gastric emptying,^{20,21} reducing the rate of water uptake into the circulation,¹⁸ and might offset the reduction in serum osmolality that occurs after the ingestion of a large volume of a dilute solution.¹³ Shirreffs et al¹⁹ observed that low-fat milk (containing 36 g/L protein) was retained better than either a commercially available carbohydrate-electrolyte solution or water after exercise-induced dehydration. More recently, James et al¹² demonstrated that fluid retention was greater after ingestion of a solution of carbohydrate and milk protein than after ingestion of a solution of carbohydrate; rehydration solutions were matched for energy density and electrolyte content. Although the mechanisms are not known, the beneficial effects of milk protein on postexercise rehydration probably result from a slowing of gastric emptying^{22–25} caused by the coagulation of the casein fraction of milk protein in the acid environment of the stomach.²³ Whereas milk protein might increase fluid retention after exercise in a hot environment, the effects of the ingestion of other protein types remain unknown.

Therefore, the purpose of our study was to investigate the effects of whey protein isolate on rehydration after exercise-induced dehydration by comparing the energy density and electrolyte content-matched solutions of carbohydrate and of carbohydrate and whey protein isolate consumed in a volume equivalent to 1.5 times body mass lost during an exercise session.

METHODS

Participants

Twelve healthy men (age = 21 ± 1 years, height = 1.82 ± 0.08 m, mass = 82.71 ± 10.31 kg) volunteered to participate. Participants were *recreationally active*, which was defined as taking part in exercise for recreation only, and were not heat acclimated at the time of the study. They completed a medical screening questionnaire. All participants gave written informed consent, and the Nottingham Trent University Ethical Advisory Committee approved the study.

Experimental Protocol

Each participant completed a familiarization trial followed by 2 experimental trials, which were separated by at least 6

days. Experimental trials began in the morning after an overnight fast. Participants were instructed to ingest approximately 500 mL of plain water about 1.5 hours before arriving at the laboratory. This helped ensure that participants were in a consistently adequate hydrated state at the start of the trial. In the 24 hours before the first experimental trial, participants recorded their dietary intakes and physical activities and were instructed to repeat these patterns of dietary intake and physical activity in the 24 hours preceding the second trial. Participants also were instructed to refrain from any strenuous physical activity and the consumption of alcohol in the 24 hours before each trial. During the familiarization trial, participants completed all experimental procedures, except recovery after drinking was monitored for only 1 hour.

Upon arrival at the laboratory, participants voided their bladders (pre-exercise), and their body mass was measured to the nearest 10 g (Adam CPW 150 scale; Adam Equipment Co Ltd, Milton Keynes, UK) while they wore dry boxer shorts only. Participants then exercised in a temperature-controlled ($35^\circ\text{C} \pm 0.1^\circ\text{C}$) and humidity-controlled ($50.9\% \pm 2.1\%$ relative humidity) environmental chamber (Design Environmental Ltd, Ebbw Vale, Gwent, UK) until they had lost approximately 1.7% of their pre-exercise body mass. Because of continued sweating after the cessation of exercise, target body mass loss was 2.0% of pre-exercise body mass. Exercise began at an intensity corresponding to 2 W/kg body mass, was the same during both experimental trials ($t_{11} = -0.170$, $P = .87$), and amounted to 1.8 ± 0.3 W/kg body mass. Exercise was performed on a friction-braked cycle ergometer (Ergonomic 874E; Monark Sports & Medical, Cranlea, Birmingham, UK) in blocks of 10 minutes that were separated by a 5-minute rest in the chamber. With participants wearing boxer shorts only, body mass was monitored in the rest periods, and exercise continued until the required mass loss was achieved. Total exercise time (62 ± 6 minutes) was not different between the trials ($t_{11} = 0.433$, $P = .67$), and total heat exposure, including rest periods, lasted 92 ± 8 minutes. Upon completion of exercise, participants were allowed 15 minutes to shower. Body mass was measured again with participants wearing dry boxer shorts only, and they provided a urine sample (–1 hour). This body mass was used to determine total body mass lost from the pre-exercise mass.

Next, participants ingested a volume of rehydration drink in liters equivalent to 1.5 times the body mass lost in kilograms. This drink was provided in 4 aliquots of equal volume every 15 minutes over a 1-hour period (0, 15, 30, and 45 minutes), and participants consumed each drink within 15 minutes. Drinks were mixed approximately 1 hour before consumption and kept at room temperature. Each drink was mixed thoroughly, and its temperature was measured before serving. Drink temperature was not different between trials ($t_{11} = 0.574$, $P = .30$), and drink temperature at serving was $16.8^\circ\text{C} \pm 1.2^\circ\text{C}$ over all trials. After the 1-hour rehydration period, participants provided a urine sample (0 hours) and rested quietly in the laboratory ($20.6^\circ\text{C} \pm 1.0^\circ\text{C}$) for 4 hours. During this recovery period, participants provided urine samples each hour (1, 2, 3, and 4 hours). After providing the final urine sample (4 hours), participants again were weighed while wearing dry boxer shorts only. In addition, participants completed questionnaires related to their subjective feelings immediately before each urine sample (before exercise and at –1, 0, 1, 2, 3, and 4 hours). Participants were instructed to rate their subjective feelings of thirst, stomach fullness, bloatedness, hunger, tiredness, alertness, concentration, head soreness, dryness of mouth, refreshedness, and

energy using a 100-mm visual analog scale, with 0 mm representing *not at all* and 100 mm representing *very*. After participants drank the rehydration solutions, they answered questions about the sweetness, saltiness, bitterness, and pleasantness of the solutions.

Trials were administered in a randomized, double-blind, counterbalanced order. Drinks were matched for energy and electrolyte content, and the only difference between the drinks was the carbohydrate and protein content and their osmolalities (Table). The carbohydrate drink (C) contained 35 g/L glucose and 30 g/L of maltodextrin, whereas the carbohydrate-protein drink (CP) contained 34.9 g/L glucose, 15 g/L maltodextrin, 0.1 g/L lactose (contributed by the protein supplement), and 15 g/L whey protein isolate in the form of a commercially available protein supplement (Impact whey protein isolate; Myprotein, Inc, Manchester, UK). Because the protein supplement contributed a small amount of fat, an amount of olive oil providing the same amount of fat (0.1 g/L) was added to drink C. Both drinks had a small amount (100 mL/L) of sugar-free squash added to mask the contents of the drinks. Furthermore, small amounts of sodium chloride and potassium chloride were added to the drinks to give a final sodium concentration of 20 mmol/L and a final potassium concentration of 5 mmol/L for each solution.

For each urination, participants were instructed to completely empty their bladders and collect the entire volume in the containers provided. The volume of each urine sample was measured, and a small sample (approximately 5 mL) was retained for subsequent analysis. A sample (approximately 5 mL) of each drink also was retained for subsequent analysis.

The fraction of the ingested drink that had been retained at each time point was calculated from volumes of drink ingested and urine produced up until that time. Net fluid balance was calculated from fluid lost through sweating and urine production and fluid gained through drink ingestion. Metabolic water formed by substrate oxidation was ignored, as in similar studies.^{6,8–10,12}

Sample Analysis

Urine samples were analyzed for osmolality by freezing-point depression (Osmomat 030 cryoscopic osmometer; Gonotec GmbH, Berlin, Germany). Drink samples were analyzed for osmolality and for sodium and potassium concentrations by flame photometry (Corning Clinical Flame Photometer 410C; Corning Ltd, Essex, UK).

Statistical Analysis

All data were checked for normality of distribution using a Shapiro-Wilk test. All data containing 2 variables were

analyzed using a 2-way repeated-measures analysis of variance (ANOVA). The Mauchly test was used, and where it indicated that the assumption of sphericity had been violated, the degrees of freedom for the data set were corrected using Greenhouse-Geisser estimates. Differences were located using Bonferroni-adjusted paired *t* tests for normally distributed data or Bonferroni-adjusted Wilcoxon signed-rank tests for nonnormally distributed data. Variables containing 1 factor (eg, drink perception) were analyzed using paired *t* tests or Wilcoxon signed-rank tests as appropriate. The α level was set at .05. Normally distributed data are presented as means $\pm$ standard deviations, whereas nonnormally distributed data are presented as medians (ranges). All data were analyzed using SPSS (version 16.0; SPSS Inc, Chicago, IL).

RESULTS

We found no difference in the participants' body mass (82.84 ± 10.30 kg [trial C], 83.28 ± 10.32 kg [trial CP]) ($t_{11} = 1.931$, $P = .08$) or urine osmolality (335 mOsm/kg [range, 137–752 mOsm/kg] [trial C], 325 mOsm/kg [range, 137–658 mOsm/kg] [trial CP]) ($z = 0.800$, $P = .47$) at the start of each trial, indicating that participants began each trial in a similar state of hydration. Body mass loss induced by the intermittent exercise protocol was not different between trials ($t_{11} = 0.577$, $P = .585$), and it was 1.54 ± 0.19 kg over both trials, representing $1.86\% \pm 0.07\%$ of participants' pre-exercise body mass. The volume of rehydration drink ingested was not different between trials ($t_{11} = 0.518$, $P = .62$) and was 2.32 ± 0.30 L over both trials.

Urine Output and Fluid Balance

The volume of urine produced after drink ingestion was not different between trials ($F_{1,9} = 0.001$, $P = .98$) (Figure 1). We found a main effect of time ($F_{2,481,27,286} = 33.551$, $P < .001$) for urine volume, and, compared with postexercise (–1 hour), urine volume was higher at 1, 2, and 3 hours during both trials (z range, -3.061 to -3.059 , $P < .001$) and still was higher at 4 hours during trial CP ($z = -2.907$, $P = .01$). Cumulative urine output was not different between trials ($F_{1,9} = 0.002$, $P = .96$), and at the end of the study it was 1173 ± 481 mL during trial C and 1180 ± 330 mL during trial CP (Figure 2). At the end of the study, the fraction of the ingested drinks that had been retained was not different between trials; $50\% \pm 18\%$ of drink C and $49\% \pm 13\%$ of drink CP had been retained ($t_{11} = -0.159$, $P = .88$). We found a main effect of time for net fluid balance ($F_{1,877,20,646} = 170.792$, $P < .001$) (Figure 3). Compared with pre-exercise, net fluid balance was negative at –1 hour for trial C (-1576 ± 181 mL) ($t_{11} = 30.228$, $P < .001$) and trial CP (-1581 ± 201 mL) ($t_{11} = 27.221$, $P < .001$) and became

Table. Energy Density, Osmolality, Protein Content, Carbohydrate Content, Fat Content, Sodium Concentration, and Potassium Concentration of the Carbohydrate and Carbohydrate-Protein Drinks (Mean $\pm$ SD)

Variable	Carbohydrate Drink	Carbohydrate-Protein Drink
Energy density, kJ/L	1143 $\pm$ 0	1143 $\pm$ 0
Osmolality, mOsm/kg	290 $\pm$ 5	265 $\pm$ 6
Protein, g/L	0 $\pm$ 0	15 $\pm$ 0
Carbohydrate, g/L	65 $\pm$ 0	50 $\pm$ 0
Fat, g/L	0.1 $\pm$ 0	0.1 $\pm$ 0
Sodium, mmol/L	21 $\pm$ 1	22 $\pm$ 2
Potassium, mmol/L	5 $\pm$ 1	5 $\pm$ 1

positive immediately after rehydration (0 hours) for trial C (685 ± 111 mL) ($t_{11} = -21.296$, $P < .001$) and trial CP (697 ± 115 mL) ($t_{11} = -20.972$, $P < .001$). Fluid lost through urine production after rehydration resulted in a negative net fluid balance compared with pre-exercise fluid balance by 4 hours during trial C ($t_{11} = 3.433$, $P = .03$) and by 3 hours during trial CP ($t_{11} = 3.697$, $P = .02$); at 4 hours, it was -432 ± 436 mL for trial C and -432 ± 302 mL for trial CP. Net fluid balance was not different between trials ($F_{1,9} = 0.026$, $P = .88$).

Urine Osmolality

We found a main effect of time for urine osmolality ($F_{6,54} = 20.692$, $P < .001$) (Figure 4). Compared with pre-exer-

cise, urine osmolality increased to 585 mOsm/kg (range, 498–931 mOsm/kg) for trial C ($z = -2.589$, $P = .042$) and 551 mOsm/kg (range, 321–855 mOsm/kg) for trial CP ($z = -2.590$, $P = .042$) after the intermittent exercise-induced dehydration protocol. Compared with pre-exercise, urine osmolality decreased 1 hour after drink ingestion to 106 mOsm/kg (range, 55–437 mOsm/kg) for trial C ($z = -2.981$, $P = .006$) and 124 mOsm/kg (range, 50–419 mOsm/kg) for trial CP ($z = -2.590$, $P = .04$). In addition, urine osmolality was increased to 529 mOsm/kg (range, 137–792 mOsm/kg) during trial CP at 4 hours compared with pre-exercise ($z = -2.590$, $P = .04$). Urine osmolality was not different between trials ($F_{1,9} = 0.066$, $P = .80$).

Figure 1. Urine output for each hour after exercise after ingestion of the carbohydrate and carbohydrate-protein drinks. ^aIndicates the carbohydrate and carbohydrate-protein drink trials were different from -1 hour. ^bIndicates the carbohydrate-protein drink trial was different from -1 hour. Points are median values, and error bars represent ranges.

Figure 2. Cumulative urine output after ingestion of the carbohydrate and carbohydrate-protein drinks. Points are mean values, and error bars represent SDs.

Figure 3. Net fluid balance during the carbohydrate and carbohydrate-protein drink trials. ^aIndicates the carbohydrate and carbohydrate-protein drink trials were different from pre-exercise. ^bIndicates the carbohydrate-protein drink trial was different from pre-exercise. Points are mean values, and error bars represent SDs.

Figure 4. Urine osmolality during the carbohydrate and carbohydrate-protein trials. ^aIndicates the carbohydrate and carbohydrate-protein drink trials were different from pre-exercise. ^bIndicates the carbohydrate-protein drink trial was different from pre-exercise. Points are median values, and error bars represent ranges.

Subjective Feelings

We found no main effects of trial ($F_{1,11}$ range, 0.001–2.901, $P>.05$) or any interaction effects ($F_{1,11}$ range, 0.239–2.181, $P>.05$) for the subjective feelings. We found no difference in the perceived sweetness (drink C=79 mm [range, 28–93 mm], drink CP=76 mm [range, 26–100 mm] [$z=-0.824$, $P=.44$]), saltiness (drink C=28 mm [range, 3–70 mm], drink CP=26 mm [range, 4–79 mm] [$z=-0.628$, $P=.56$]), bitterness (drink C=23 mm [range, 2–93 mm], drink CP=25 mm [range, 1–67 mm] [$z=-0.178$, $P=.90$]), or pleasantness (drink C=47 mm [range, 6–97 mm], drink CP=34 mm [range, 21–90 mm] [$z=-0.589$, $P=.58$]) of the drinks.

DISCUSSION

Our main findings indicated that after a $1.86\% \pm 0.07\%$ reduction in body mass via intermittent exercise in a hot environment, fluid balance and drink retention were not different after ingestion of a solution of 65 g/L carbohydrate or of 50 g/L carbohydrate and 15 g/L whey protein isolate when a volume of drink equivalent to 1.5 times the sweat lost during exercise was ingested over 1 hour. After a 4-hour recovery period, $50\% \pm 18\%$ of drink C and $49\% \pm 13\%$ of drink CP had been retained, and net fluid balance was negative compared with pre-exercise for both trials. This indicates that the substitution of 15 g/L carbohydrate (maltodextrin) with 15 g/L protein (whey protein isolate) neither increased nor decreased the retention of the ingested solution.

These findings demonstrate that although ingesting a volume of rehydration solution greater than the volume of sweat lost during exercise means fluid balance initially will be restored, it does not mean that this restoration of fluid balance will be maintained because net fluid balance at the end of the study was negative compared with pre-exercise for both trials ($P<.05$). Other researchers have observed this when investigating the effects of carbohydrate and protein addition to rehydration solutions,^{10,12,19} but the addition of large quantities of sodium to rehydration solutions seems to maintain fluid balance longer.^{8,9} Although a sufficient volume of rehydration solution must be ingested to return the person to euhydration,⁶ the composition of the ingested solution determines how much is retained.^{7–12} However, researchers recently have shown that the rate at which a solution is ingested also might affect the retention of the ingested solution.²⁶

Seifert et al¹⁷ observed that drink retention was greater with a commercially available carbohydrate-protein solution (60 g/L carbohydrate and 15 g/L protein) than with a commercially available carbohydrate solution (60 g/L carbohydrate) after a body mass loss of approximately 2.4% and ingestion of a volume of drink equivalent to the body mass lost, but these solutions were not matched in terms of energy density. Energy density of a solution is one of the main factors affecting the rate at which an ingested solution empties from the stomach.^{20,21} A reduced rate of gastric emptying of an ingested solution has been shown to reduce the rate of water uptake into the circulation,¹⁸ which is likely to affect serum osmolality response and urine production after drink ingestion. In our study, the protein concentration of the drink was identical to that in the study of Seifert et al,¹⁷ but the energy content of the drink was matched between trials. When we matched them for energy content, we found no difference in urine production or drink retention between solutions of carbohydrate and of carbohydrate and whey

protein isolate. This suggests that the difference in drink retention observed between the carbohydrate and carbohydrate-protein drinks in the study of Seifert et al¹⁷ might be attributable to the increased energy density of the carbohydrate-protein drink used.

Shirreffs et al¹⁹ examined the effects of low-fat milk on rehydration after exercise in a hot environment. After a 1.8% reduction in body mass and ingestion of a volume of drink equivalent to 1.5 times the body mass lost over 1 hour, they reported that low-fat milk was retained better than either a commercially available sports drink or bottled water and that adding 20 mmol/L of sodium chloride to the milk did not increase drink retention.¹⁹ The protein content was approximately 36 g/L for low-fat milk and 0 g/L for the sports drink and water, but the compositional differences between the drinks (energy density, carbohydrate content, fat content, sodium concentration, and potassium concentration) make it difficult to determine the specific effects of the protein on fluid retention.

Using the same experimental design as we did, James et al¹² demonstrated greater retention of a solution of 40 g/L carbohydrate and 25 g/L milk protein compared with a solution of 65 g/L carbohydrate after exercise-induced dehydration by 1.9% body mass. The reasons for the difference in findings between our study and that of James et al¹² are not known but might be related to the gastric-emptying properties of the different proteins used in the studies. We used whey protein isolate, whereas James et al¹² used milk protein. Although not measured, this difference in protein type might have affected the gastric-emptying properties of the ingested solutions.^{22–25} Bovine milk protein comprises 2 fractions: a micellar fraction (casein protein) and a soluble whey protein fraction.²⁷ The casein fraction composes approximately 80% of the protein, and the whey fraction composes the remaining 20%. In the presence of gastric acid in the stomach, this casein fraction in milk protein clots,²³ which results in a reduced rate of gastric emptying for milk or casein protein compared with other protein fractions^{22–24} and glucose or lactose.^{22,25} The reduction in the rate of gastric emptying with the ingestion of casein or milk protein might influence the retention of a rehydration solution containing either casein or milk protein by reducing the rate at which the drink enters the circulation,¹⁸ thus offsetting the decline in serum osmolality that occurs with the ingestion of large volumes of low-sodium solutions that empty rapidly from the stomach.¹⁰

The results of this study and other studies suggest that fluid composition can be altered by 2 main methods to ensure that fluid retention is maximized. These methods are altering micronutrient composition and macronutrient composition. When micronutrient, and in particular sodium, concentration is altered, fluid balance appears to be influenced by the effect of ingestion on intracellular or extracellular fluid composition.^{7–9,13–15} When macronutrient composition is altered by the addition of carbohydrate,^{10,11} fluid balance appears to be affected because of changes in the rate at which fluid is absorbed from the intestinal lumen by reducing the gastric-emptying rate or intestinal absorption.¹⁸ Although this effect has not been demonstrated with protein-containing solutions, it is a potential mechanism that might account for the increased retention of some protein-containing solutions.^{12,16,17} The cumulative effect of increasing micronutrient and macronutrient content of rehydration solutions has not been examined.

Whereas the specific rehydration effects of carbohydrate-protein solutions ingested after exercise have not been well documented, the effects of the coingestion of carbohydrate and

protein on muscle glycogen resynthesis^{28,29} and muscle protein synthesis³⁰ after exercise have been investigated. Researchers have shown that the rate of muscle glycogen resynthesis is greater with the coingestion of carbohydrate and protein than with an isoenergetic amount of carbohydrate.^{28,29} However, ingestion of carbohydrate at a rate greater than 1.2 g/kg body weight per hour appears to negate the effects of additional protein on muscle glycogen resynthesis after exercise.³⁰ In our study, rates of carbohydrate ingestion were 1.8 ± 0.1 g/kg per hour for trial C and 1.4 ± 0.1 g/kg per hour for trial CP during the rehydration hour, so, although not measured in our study, the rates of muscle glycogen resynthesis are unlikely to have been different between the C and CP trials. When the rehydration drink is ingested at a slower rate, a solution of carbohydrate and whey protein isolate might be more beneficial for muscle glycogen resynthesis than a carbohydrate-only solution. Muscle protein synthesis after exercise has been shown to be greater with the coingestion of protein and carbohydrate than with ingestion of an isoenergetic amount of carbohydrate.³⁰ Therefore, our findings suggest that although retention did not differ between a solution of whey protein isolate and carbohydrate and a solution of isoenergetic carbohydrate, the potential benefits for muscle glycogen resynthesis and muscle protein synthesis might make the addition of whey protein isolate to a rehydration solution attractive in some athletic situations.²⁸⁻³⁰

CONCLUSIONS

The substitution of 15 g/L carbohydrate for 15 g/L whey protein isolate did not affect the amount of the ingested solution that was retained after exercise in a hot environment. Although the addition of whey protein isolate to a rehydration solution did not increase rehydration, the finding that it also did not impair rehydration means its addition to rehydration solutions consumed after exercise might confer some benefits for muscle protein synthesis or muscle glycogen resynthesis when postexercise carbohydrate ingestion is suboptimal (<1.2 g/kg per hour).

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