Influence of Nutrient Intake after Weigh-In on Lightweight Rowing Performance

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ABSTRACT

SLATER, G. J., A. J. RICE, K. SHARPE, D. JENKINS, and A. G. HAHN. Influence of Nutrient Intake after Weigh-In on Lightweight Rowing Performance. *Med. Sci. Sports Exerc*., Vol. 39, No. 1, pp. 184–191, 2007. **Purpose:** The aim of the present study was to compare the effectiveness of different nutritional recovery strategies between weigh-in and racing on 2000-m rowing ergometer performance among oarsmen undertaking short-term weight loss before competition. **Methods:** Competitive rowers (N = 12) completed four ergometer trials, each separated by 48 h. No weight restrictions were imposed for the first trial (TR1). Thereafter, athletes were required to reduce their body mass by 5.2% in the 24 h before trial 2 (TR2), again reaching this body mass before the final two trials (TR3 and TR4). Athletes were provided with one of three nutritional recovery strategies in the 2 h between weigh-in and racing in a counterbalanced fashion according to a Latin square design: fluid (2.8 kJ·kg^{-1}, 0.0 g·kg^{-1} carbohydrate, 0.6 mg·kg^{-1} sodium, 28.5 mL·kg^{-1} fluid; FLU), carbohydrate/sodium (45.3 kJ·kg^{-1}, 2.2 g·kg^{-1} carbohydrate, 32.9 mg·kg^{-1} sodium, 7.2 mL·kg^{-1} fluid; CHO), and a combination of water and carbohydrate/sodium (44.8 kJ·kg^{-1}, 2.3 g·kg^{-1} carbohydrate, 33 mg·kg^{-1} sodium, 28.5 mL·kg^{-1} fluid; COM). **Results:** Performance was slower for CHO compared with both COM (mean difference, 4.13; 95% CI, 1.37–6.88 s; P = 0.003) and FLU (2.88; 95% CI, 0.13–5.63 s; P = 0.039). However, FLU was not significantly slower than COM (1.24; 95% CI, −1.41 to 3.90 s; P = 0.474). **Conclusions:** The present investigation has shown that although carbohydrate and sodium intake may be important in the recovery period between weigh-in and 2000-m rowing ergometer performance, fluid intake has a greater influence on performance among lightweight male rowers who undertake short-term weight loss to achieve specified body-mass limits. **Key Words:** MAKING WEIGHT, RECOVERY, REHYDRATION, NUTRITION

Elite athletes are encouraged to pay particular attention to dietary intake in the days and hours before competition, under the assumption that precompetition nutritional strategies can influence competitive outcomes. Indeed, among athletes in endurance-based sports, dietary intake in the hours before competition can influence performance (8). For athletes competing in weight-category sports, the precompetition meal also offers an opportunity to recover, at least partially, from the physiological effects of any short-term weight-loss strategies they may have undertaken before weigh-in. The intake of fluid, electrolytes, and carbohydrate are particularly important during this time (29).

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The importance of adequate nutrient intake in the recovery period after dietary restriction has been recognized in anaerobic sports (30) and may be of even greater significance for lightweight rowers, considering that aerobic capacity is compromised by hypohydration (21). Despite this, recovery practices of rowers in the 2 h between weigh-in and racing do not generally comply with current guidelines, especially for dietary sodium and fluid intakes, which may only approach 50% of current recommendations (24).

We have previously shown that short-term weight loss (approximately 4% during 24 h), when combined with aggressive nutritional recovery strategies after weigh-in, has only a small impact on rowing ergometer performance (23,26) and remains largely unidentifiable when assessed while rowing on water (25). This contrasts with earlier research that has examined the performance implications of short-term weight loss (5.2% during 24 h) among lightweight oarsmen in which large performance decrements were observed when only water was provided after weigh-in (2). Although the contrasting literature likely reflects our use of aggressive recovery strategies, this remains speculation because no direct comparison has been

made between different nutritional strategies implemented during the 2-h recovery period between weigh-in and racing. Furthermore, the impact of variance in the extent of short-term weight loss required in the 24 h before weigh-in can not be discounted when comparing investigations.

The purpose of the present study was to examine the influence of different nutritional recovery strategies after weigh-in on subsequent performance among competitive lightweight oarsmen who had to make weight repeatedly during several days of racing. We hypothesized that an aggressive nutritional recovery strategy focusing on the combination of sufficient sodium, fluid, and carbohydrate would result in the best performance outcome.

METHODS

Experimental approach. To replicate the demands of a multiday regatta, experienced lightweight oarsmen undertook three body mass–restricted 2000-m ergometer time trials, each separated by 48 h. For each trial, there was a 2-h recovery period between weigh-in and racing. Different nutritional recovery strategies were used after weigh-in at each time trial in an effort to ascertain optimal nutritional recovery strategies. As the performance response was of primary interest, every effort was made to create a competitive environment. Six athletes raced alongside each other at any one time, all competing for performance incentives based on personal-best ergometer times. An array of physiological parameters was also monitored in an effort to identify possible mechanisms for any variation in performance.

Subjects. Twelve nationally competitive male lightweight rowers participated in this investigation. An overview of the investigation is shown in Figure 1. Volunteers were fully informed of the nature and possible risks of the investigation before giving their written informed consent, which was consistent with the human subject policy of the American College of Sports Medicine. The investigation was approved by the human research ethics committee of the Australian Institute of Sport.

All athletes were required to adhere to a standardized training program for the 4 wk before the study to prepare them for racing. Athletes maintained a daily log of duration, mode, intensity, and frequency of training beginning 4 wk before and continuing throughout the experimental period. The diary was used to assess compliance to the training program and to monitor body mass–management strategies during the simulated regatta. On their first visit to the laboratory, athletes performed a progressive maximal test on a rowing ergometer (Concept 2D, Morrisville, VT). The test protocol was modified from one that has been previously described (7) and consisted of three submaximal workloads and one maximal workload, each 4 min in duration and separated by 1-min recovery intervals. Submaximal steady-state workloads equated to 50, 65, and 80% of average power output from the maximal 2000-m ergometer time trials conducted in the 4-wk lead-in period. The ergometer was secured firmly to the ground and placed no closer than

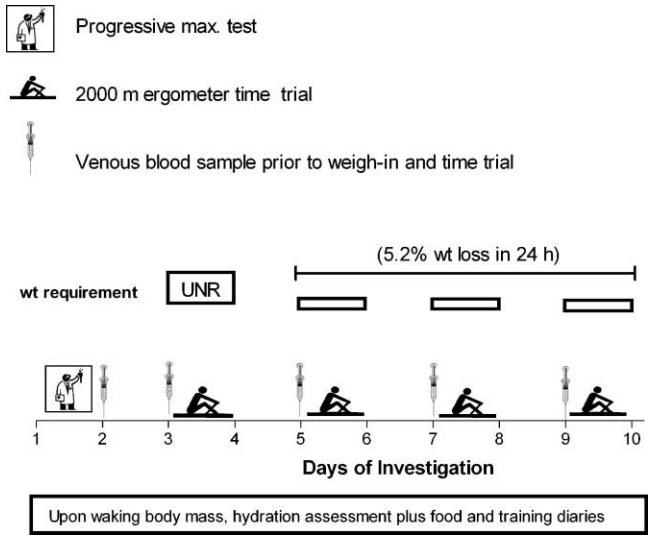

FIGURE 1—An overview of the investigation. No weight restrictions were enforced for the first time trial. Thereafter, athletes were required to reduce their body mass by 5.2% during the 24 h before their second ergometer trial and to reach this again before the remaining two trials. UNR, unrestricted body mass.

1 m from a wall, and the drag factor was set at 120. Throughout the testing period, mixed expired air passed through a fully automated, first-principles, indirect calorimetry system (Australian Institute of Sport, Belconnen, ACT, Australia). The operation and calibration of this system has been described elsewhere (20). $\dot{V}O_{2peak}$ was defined as the highest O_2 uptake athletes attained during two consecutive 30-s sampling periods. In our laboratory, this technique has a typical error (TE), or within-subject standard deviation, of 1.8%.

Treatments. Oarsmen were ranked according to previous 2000-m ergometer time-trial performances. The ranking was used to assign athletes to two fitness-matched groups that were counterbalanced for test order according to a Latin square design. Groups differed only in the order of nutritional recovery strategies provided before each ergometer trial. Athletes performed four 2000-m maximal rowing ergometer time trials, each test separated by 48 h and undertaken on the same ergometer at the same time of day, with the drag factor set at 120. Six performance-ranked athletes raced alongside each other for all trials, with ergometers placed no closer than 1 m apart. For all groups, no weight restrictions were imposed for the first ergometer trial (TR1), which acted as a familiarization. Thereafter, athletes were required to reduce their body mass by 5.2% during a 24-h period (in accordance with Burge and associates (2)) before their second ergometer trial (TR2), and then to reach this body mass again before the remaining two ergometer trials (TR3 and TR4). To encourage athletes to perform maximally, performance incentives were offered for each trial. In our laboratory, the 2000-m time trial has a TE of 1.6% (26).

Training load was prescribed before each of the four ergometer trials, simulating training habitually undertaken in the 24 h before racing at a regatta. However, additional

training was allowed to assist the athletes in achieving body-mass goals. Excluding pharmacological interventions, no limits were imposed on techniques used to induce the specified weight loss. However, athletes were required to replicate weight-loss techniques employed before TR2 for subsequent trials. Food diaries were maintained throughout the investigation and were analyzed by a dietitian using a dietary-analysis program (Foodworks, version 3.02, Xyris Software, Brisbane, Australia).

Urine samples were collected on waking each day of the investigation. Hydration status was monitored throughout the investigation by the measurement of urinary osmolality (OSM), in duplicate, via the freezing-point depression method, using an Osmomat 030-D cryogenic osmometer (Gonotec, Berlin, Germany). Additionally, fresh urine samples were analyzed for the presence of ketones using reagent strips (Ketostix, Bayer Diagnostics Manufacturing Ltd., New South Wales, Australia).

Experimental protocol. An overview of the testing schedule before each ergometer test is presented in Figure 2. Subjects presented at the laboratory 140 min before the start of each 2000-m time trial. After lying supine for 20 min to eliminate the influence of posture on plasma volume, 11 mL of blood was drawn into a tube containing ethylene diaminetetraacetic acid via venipuncture without stasis from a superficial forearm vein using standard phlebotomy procedures. An additional 4-mL blood sample was collected and was allocated to a serum separation tube and centrifuged at 4000 rpm for 5 min. The resultant serum was analyzed for OSM in duplicate using the freezing-point depression method. Serum cortisol was also measured using a competitive chemiluminescent enzyme immunoassay on an Immulite 1000 analyzer (DPC, Los Angeles, CA). Plasma was analyzed for aldosterone (ALD), renin activity (REN), and arginine–vasopressin (ADH) concentrations using radioimmunoassay kits on a 1277 GammaMaster gamma counter (LKB Wallac, Uppsala, Sweden).

Hematocrit (Hct) and hemoglobin (Hb) concentrations were determined in triplicate using an automated flow cytometry hematology analyzer (ADVIA 120, Bayer Diagnostics, Tarrytown, NY), with the mean result used in analysis. Relative changes in plasma volume were calculated using the method employed by Dill and Costill (4). Changes in plasma volume were calculated and expressed relative to Hct and Hb concentrations averaged from the first 3 d of the investigation while volunteers were in a euhydrated state. For all ergometer trials, this procedure was repeated before the subjects began their warm-up on the ergometer.

After the first blood sample, bladder-voided body mass was measured on a calibrated digital scale with a precision of ± 0.02 kg (A and D Co., Tokyo, Japan). Thereafter, for TR1, subjects consumed a standard meal (toasted bread, Vegemite, Power Bar, Carboshotz, Gastrolyte, Gatorade, water) providing 44.8 $kJ \cdot kg^{-1}$ (2.3 $g \cdot kg^{-1}$ carbohydrate, 33.0 $mg \cdot kg^{-1}$ sodium, and $\geq$ 7.2 $mL \cdot kg^{-1}$ fluid; *ad libitum* water was allowed in addition to the fluid specified). For the remaining three trials, athletes consumed three different meals using similar food/fluid choices to that provided in TR1, but with a focus on either fluid (2.8 $kJ \cdot kg^{-1}$, 0.0 $g \cdot kg^{-1}$ carbohydrate, 0.6 $mg \cdot kg^{-1}$ sodium, 28.5 $mL \cdot kg^{-1}$ fluid; FLU), carbohydrate (45.3 $kJ \cdot kg^{-1}$, 2.2 $g \cdot kg^{-1}$ carbohydrate, 32.9 $mg \cdot kg^{-1}$ sodium, 7.2 $mL \cdot kg^{-1}$ fluid; CHO), or a combination of these nutrients (44.8 $kJ \cdot kg^{-1}$, 2.3 $g \cdot kg^{-1}$ carbohydrate, 33.0 $mg \cdot kg^{-1}$ sodium, 28.5 $mL \cdot kg^{-1}$ fluid; COM). The fluid-only formula was colored and flavored with a sugar-free additive.

Fluid intake was prescribed to maximize plasma volume and fluid-balance restoration. Intake was quantified by weighing drink bottles before and after the recovery

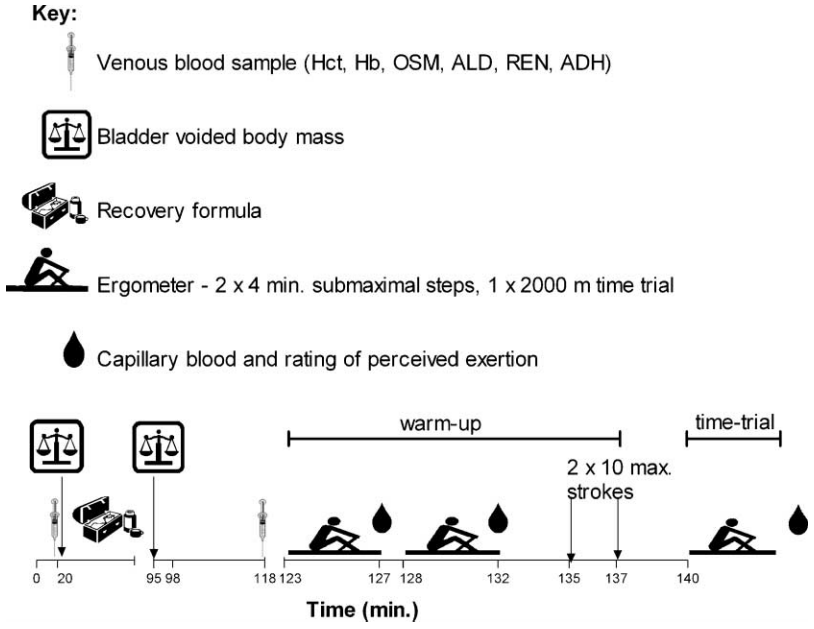

FIGURE 2—An overview of testing commitments undertaken during each 2000-m ergometer time trial. Hct, hematocrit; Hb, hemoglobin; OSM, osmolality; CORT, cortisol; ALD, aldosterone; REN, renin activity; ADH, arginine–vasopressin.

period. During this time, subjects remained within the controlled environment of the laboratory (21.1 ± 0.7°C, 29.0 ± 4.5% relative humidity). Bladder-voided body mass was again recorded before the warm-up. All urine produced during the recovery period was collected into 2-L polyethylene bottles and quantified using a calibrated digital scale with a precision of ± 1 g (Tanita, Tokyo, Japan). Percent fluid retention was calculated from weighted inventories of fluid intake (inclusive of food water content) and urinary volumes in the recovery period. Insensible water loss was assumed to be similar between experimental trials.

Immediately before each ergometer trial, athletes were asked to rate their performance expectations and motivation using a five-point Likert scale (1 = very poor, 5 = excellent). Thereafter, athletes initiated a standardized warm-up before each maximal 2000-m ergometer time trial, as described elsewhere (26). Arterialized capillary blood was sampled at rest and immediately after each submaximal workload and the 2000-m time trial; blood was analyzed without delay for pH plus glucose, bicarbonate (HCO_3^-), lactate (La^-), and sodium concentrations (ABL 725, Radiometer, Copenhagen, Denmark). The analyzer was calibrated daily in accordance with the manufacturer's specifications.

Average power (W), heart rate, and ratings of perceived exertion (RPE) were recorded on completion of each of the workloads. Heart rate during each ergometer test was monitored using short-range telemetry (Vantage, Polar Electro OY, Kempele, Finland), and RPE was ascertained using the 15-point Borg scale (1).

Statistical analysis. Performance, biochemical, and other parameters during the final three ergometer trials were compared using repeated-measures ANOVA with the following factors: recovery formula (COM, FLU, CHO) and trial number (TR2–TR4). The same procedure was used to obtain 95% confidence intervals (CI) for effects considered to be of main interest. Some of the blood parameters needed to be log transformed to satisfy the assumption of constant variance. For performance, weight loss in the 24 h before each ergometer trial was included as a covariate to assess the impact of short-term weight loss on performance. Similarly, serum OSM, cortisol, glucose, lactate, and plasma volume at the time of weigh-in were included as covariates to assess their impact on the corresponding postrecovery formula-ingestion concentrations.

Standardized residuals were calculated for each observation. A value greater than 3.0 was considered to be extreme or an outlier, and such observations were removed from analysis one at a time. The general linear modeling analysis was conducted using Minitab software (Minitab Inc., State College, PA). Significance was accepted at $P < 0.05$. Data are reported as means ± SD unless otherwise specified.

RESULTS

Characteristics of all 12 athletes who completed the investigation are presented in Table 1.

Body mass. Body-mass loss in the 24 h before TR2 was greater than that experienced before TR3 and TR4 (TR2, −5.2 ± 0.4; TR3, −2.9 ± 0.9; TR4, −2.7 ± 1.3%; $P < 0.001$). However, body-mass loss was not different between interventions ($P = 0.833$).

Ergometer performance. Weight loss in the 24 h before ergometer trials was initially included in the analysis as a covariate. However, it did not influence results ($P = 0.589$) and was removed from all subsequent analyses. No main effects of trial number ($P = 0.093$) or recovery formula ($P = 0.388$) were evident for the 2000-m ergometer time trials, nor was there an interaction between main effects ($P = 0.437$). However, when one outlier was omitted (standardized residual, −3.14), main effects of trial number ($P = 0.042$) and recovery formula ($P = 0.009$) were evident, but there was no interaction between main effects ($P = 0.699$). There was some evidence to suggest that performances improved throughout the regatta; TR4 was faster than TR2 (mean, −3.13; 95% CI, −5.98 to −0.28 s; $P = 0.031$) but not TR3 (−1.02; 95% CI, −4.00 to 1.96 s; $P = 0.657$). Performance was slower for CHO compared with both COM (4.13; 95% CI, 1.37 to 6.88 s; $P = 0.003$) and FLU (2.88; 95% CI, 0.13 to 5.63 s; $P = 0.039$). However, FLU was not significantly different from COM (1.24; 95% CI, −1.41 to 3.90 s; $P = 0.474$). Results of the three body mass–restricted 2000-m time trials, exclusive of the outlier, are summarized in Figure 3. On the whole, athletes performed best for COM and worst for CHO (Table 2).

Hydration status and plasma volume. Using a urinary OSM ≥ 0.900 mOsm·kg^{-1} to confirm hypohydration (15), results indicated that, with the exception of one subject before TR3, all volunteers presented at the laboratory in a hypohydrated state before each of the body mass–restricted trials (TR2 0.919–1.262, TR3 0.884–1.264, TR4 0.912–1.172 mOsm·kg^{-1}). On waking, urinary OSM did not vary between body mass–restricted trials ($P = 0.199$). The serum OSM response before ingestion of recovery formulas was similar (COM 0.302 ± 0.003, FLU, 0.303 ± 0.003, CHO 0.302 ± 0.004 mOsm·kg^{-1}; $P = 0.664$). However, serum OSM at the end of the recovery period was higher for CHO compared with both COM and FLU (COM 0.297 ± 0.003, FLU 0.293 ± 0.003, CHO 0.303 ± 0.005 mOsm·kg^{-1}; $P < 0.001$), whereas COM was higher than FLU ($P < 0.001$). There was some evidence to suggest that trial number ($P = 0.054$) and serum OSM at weigh-in ($P = 0.053$) influenced the serum OSM response. There was no evidence of an interaction between trial number and recovery formula ($P = 0.598$).

TABLE 1. Physiological and anthropometric characteristics of volunteers.

Variable	Mean ± SD (N = 12)
Age (yr)	19.6 ± 1.6
Height (cm)	182.1 ± 4.2
Body mass (kg)	74.0 ± 1.8
$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	64.4 ± 3.0

Values are means ± SD.
$\dot{V}O_{2peak}$, peak O_2 uptake.

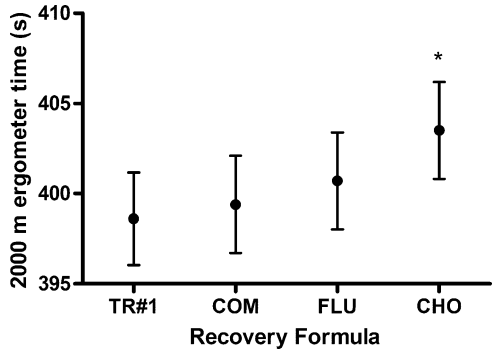

FIGURE 3—The impact of nutrient intake after weigh-in on 2000-m ergometer time-trial performance among oarsmen making weight. Results from trial 1 (TR1, familiarization with unrestricted body mass) were not included in any statistical analysis because the order of this trial was not randomized. Values are means ± within-subject SD for 12 volunteers. * Significantly different from other recovery formulas ($P < 0.05$).

Plasma-volume restoration during the recovery period between weigh-in and racing was not influenced by nutrient intake (COM 2.81 ± 3.84, FLU 3.82 ± 6.10, CHO 2.35 ± 3.26%; $P = 0.274$) or trial ($P = 0.082$). However, there was some evidence to suggest that urinary excretion during recovery was influenced by recovery-formula ingestion (COM 82.6 ± 37.6, FLU 110.4 ± 28.5, CHO 80.0 ± 27.5 mL; $P = 0.074$). Accordingly, retention of ingested fluid during recovery between weigh-in and racing was influenced by recovery formula (COM 95.9 ± 1.9, FLU 94.5 ± 1.4, CHO 84.1 ± 5.5%; $P < 0.001$) but not trial number ($P = 0.456$). Fluid retention was lower for CHO compared with both COM (−11.7, 95% CI, −15.5 to −8.0%; $P < 0.001$) and FLU (−10.3; 95% CI, −14.1 to −6.6%; $P < 0.001$). However, there was no significant difference between COM and FLU (−1.4; 95% CI, −5.2 to 2.3%; $P = 0.606$).

Hormonal response. Cortisol concentration at the end of the recovery period before ergometer trials did not vary according to trial number (TR2 374.8 ± 91.6, TR3 411.4 ± 80.0, TR4 414.0 ± 107.0 nmol·L^{-1}; $P = 0.154$) or recovery formula (COM 407.5 ± 96.5, FLU 373.8 ± 88.3, CHO 418.9 ± 94.7 nmol·L^{-1}; $P = 0.129$), nor was there an interaction between these main effects ($P = 0.869$).

Fluid regulatory hormone data are presented in Table 3. One outlier was omitted from the analysis of ALD (standardized residual, +3.17). Plasma ALD concentration at the end of the recovery period did not vary according to trial number ($P = 0.465$). However, main effects of the covariate, ALD concentration at weigh-in ($P = 0.001$), and recovery formula ($P < 0.001$) were evident, with ALD concentration being higher after FLU than both COM (97.6; 95% CI, 33.5–161.8 nmol·L^{-1}; $P = 0.003$) and CHO (120.1; 95% CI, 54.5–185.6 nmol·L^{-1}; $P = 0.001$). No interaction was evident between trial number and recovery formula ($P = 0.565$). The coefficient of the covariate was estimated to be 0.289 (SE = 0.072).

TABLE 2. Count of individual performances according to recovery formulas.

Recovery Formula	Ranking of Individual Performances		
	Fastest	Second Fastest	Slowest
COM	8	1	3
FLU	2	7	3
CHO	2*	4	6

COM, combination of fluids and carbohydrates; FLU, fluids; CHO, carbohydrates.
* Includes the outlier who was removed from analysis.

TABLE 3. Corrected fluid regulatory hormone concentrations at the end of the recovery period after adjusting for hormone concentrations before ingestion of the recovery formula.

Recovery Formula	Aldosterone (nmol·L^{-1})	Renin (nmol·L^{-1})	Arginine–Vasopressin Ln (nmol·L^{-1})
COM	325.5*	573.9†	2.357
FLU	423.2	382.1	2.314
CHO	303.1	478.5	2.497

Values are means for all subjects, excluding outliers.
* Significantly different from other recovery formulas ($P < 0.05$); † significantly different from FLU ($P = 0.003$).

One outlier was omitted from the analysis of REN (standardized residual, −3.19). Plasma REN concentration at the end of recovery did not vary according to trial number ($P = 0.686$). However, main effects of the covariate, REN at weigh-in ($P < 0.001$), and recovery formula ($P = 0.005$) were observed, with REN concentration higher after COM than FLU (191.7; 95% CI, 66.9–316.5 nmol·L^{-1}; $P = 0.003$) but not CHO (95.2; 95% CI, −31.0 to 221.4 nmol·L^{-1}; $P = 0.156$). An interaction between trial number and recovery diet was observed ($P = 0.032$). The coefficient of the covariate was estimated to be 0.585 (SE = 0.223).

A main effect of covariate at weigh-in was observed for ADH ($P < 0.001$). Although no main effect of trial number was evident for ADH ($P = 0.162$), the effect of recovery formula was close to being significant ($P = 0.070$). There was no indication of an interaction between main effects ($P = 0.565$). The coefficient of the covariate was estimated to be 0.427 (SE = 0.093).

Blood sodium. Blood sodium concentration at the end of the recovery period was influenced by both trial number (TR2 142.4 ± 3.2, TR3 141.4 ± 2.5, TR4 140.6 ± 2.3 mmol·L^{-1}; $P = 0.003$) and recovery-formula ingestion (COM 141.3 ± 1.4, FLU 138.6 ± 1.1, CHO 144.2 ± 1.9 mmol·L^{-1}; $P < 0.001$), with CHO higher than both COM (2.9; 95% CI, 1.9–3.9 mmol·L^{-1}; $P = 0.193$) and FLU (5.3; 95% CI, 4.3–6.4 mmol·L^{-1}; $P < 0.001$), and COM higher than FLU (2.5; 95% CI, 1.4–3.5 mmol·L^{-1}; $P < 0.001$).

Blood metabolites. Blood glucose concentrations before the start of ergometer trials were lower for FLU (4.97 ± 0.30 mmol·L^{-1}) compared with COM (5.67 ± 0.73 mmol·L^{-1}, $P = 0.010$), with the same trend evident for CHO (5.50 ± 0.55 mmol·L^{-1}, $P = 0.071$). Similarly, blood lactate concentrations were lower for FLU compared with the other recovery formulas (COM 1.78 ± 0.41, FLU 0.84 ± 0.20, CHO 1.52 ± 0.30 mmol·L^{-1}; $P < 0.001$). After statistically accounting for these differences before ergometer trials, blood glucose concentration immediately after ergometer trials were higher for FLU (7.62 ± 0.90 mmol·L^{-1}) compared with both COM (5.63 ± 0.85 mmol·L^{-1}, $P < 0.001$) and CHO (6.33 ± 1.05 mmol·L^{-1},

$P = 0.025$). The blood glucose response was not influenced by trial number ($P = 0.735$). Hypoglycemia (blood glucose < 3.5 mmol·L^{-1}) was not evident either before or after ergometer trials for any athlete.

No main effects or interactions between recovery formula and trial number were evident for blood lactate concentration or other indices of acid–base status immediately after ergometer trials ($P > 0.05$). Urinary ketones were absent throughout the simulated regatta. Performance expectation, motivation, perception of effort, and heart rate response during ergometer trials were not influenced by recovery formula or trial ($P > 0.05$).

Dietary intake and training load. Nutrient intake, including both food and fluid, did not differ in the 24 h before each of the final three trials ($P > 0.05$). Training load was greater before TR2 than both TR3 (44.9; 95% CI, 18.7–71.1 min; $P = 0.001$) and TR4 (63.7; 95% CI, 37.5–89.8 min; $P < 0.001$), but there was no statistically significant difference between the TR3 and TR4 (-18.8; 95% CI, -7.4 to 44.9 min; $P = 0.193$). Training load before the interventions was similar ($P = 0.250$). All nutritional recovery formulas were well tolerated, and there were no reports of intestinal discomfort or nausea.

DISCUSSION

The primary finding of this investigation is that nutrient intake in the recovery period between weigh-in and racing influences 2000-m rowing ergometer time-trial performance among lightweight oarsmen who undertake short-term weight loss before racing. Although the difference between nutritional recovery formulas was small, the combination of fluid, carbohydrate, and sodium in accordance with current guidelines resulted in the best performance for the majority of athletes. Fluid replacement seemed to be the most critical nutritional component for this group of athletes, who presented at weigh-in in a hypohydrated state. Results of the present investigation are consistent with our previous findings and confirm that any impact of short-term weight loss on rowing performance is not exaggerated when these practices are repeated for several days (23).

Although consistent with our previous findings (23,26), the present data contrast markedly with the work of Burge and associates (2), who observed substantial performance decrements (average 22 s during a simulated 2000-m ergometer time trial) after short-term weight loss (5.2% over 24 h) when only water was provided before performance tests. Because the amount of weight loss and techniques used to promote weight loss were similar between our investigations and that of Burge et al. (2), we have previously attributed the performance differences to nutrient intake after weigh-in (23,26). The present data provide only partial support for this hypothesis and suggest that other factors likely explain the vast majority of the differences in findings between our work and that of Burge et al. (2).

Whereas the combination of nutrients had a mean effect on performance that was only slightly better than that resulting from fluid alone, the majority of athletes performed best after the coingestion of fluid, carbohydrate, and sodium. Unfortunately, the source of this difference between interventions cannot be isolated from the present data because both sodium and carbohydrate intake differed between trials.

The inclusion of a body mass–restricted placebo trial with minimal amounts of fluid, carbohydrate, and sodium ingested after weigh-in may have enhanced the scientific integrity of the present investigation. However, a suitable placebo could not be identified. Furthermore, although self-reported nutritional recovery practices of lightweight rowers may not be in accordance with current guidelines (24), these athletes still perceive recovery strategies after weigh-in to be an important component of their overall race preparations. We were concerned with the psychological implications (specifically, race motivation) if no or minimal nutritional intervention was offered after weigh-in. Consequently, it was deemed inappropriate to include a nonfluid, noncarbohydrate, nonsodium trial.

Although self-directed/*ad libitum* nutritional recovery practices of lightweight rowers may not meet current sports nutrition guidelines (24), few athletes consume only water in recovery from short-term weight loss. Perhaps volunteers in the investigation of Burge and associates (2) perceived they would perform poorly when only water was provided in recovery. Indeed, mood has been shown to be an effective predictor of performance in combat sports (28). In the present investigation, where an artificially flavored placebo was used in place of water, motivation and performance expectation did not vary between interventions, suggesting that athletes perceived they would do equally well irrespective of the recovery strategy implemented. Alternatively, the competitive environment created by having six athletes race simultaneously and the offer of performance incentives in the present investigation may explain our data.

Rates of gastric emptying at rest and during exercise may decrease by as much as 20–25%, and the risk of gastrointestinal symptoms increases while in a hypohydrated state (16,29). Despite this, gastric emptying rates within the range of 900–1000 mL·h^{-1} have been observed when aggressive rehydration strategies are employed in the first 2 h after exercise-induced dehydration (14). Using these rates of emptying to prescribe fluid intake in the present investigation, no incidents of gastrointestinal distress were reported, suggesting that aggressive nutritional recovery strategies were well tolerated before high-intensity exercise. The performance response observed for the high-carbohydrate (low-fluid) trial compared with the ingestion of fluid alone or combination of fluid, sodium, and carbohydrate suggests that the larger fluid volume was a critical component of the recovery formula. A mechanism for this performance response is not readily apparent because the larger fluid intake did not enhance plasma-volume restoration, at least during the first 90 min of recovery. However, it is possible that by the time athletes began their time trials, plasma-volume restoration

was superior with the higher fluid intake in recovery after weigh-in. Fluid-retention data support this hypothesis.

Whereas the maximum volume of fluid ingested after weigh-in in the present investigation was similar to that provided by Burge and associates (2) to their athletes, dietary sodium intake was substantially higher; sodium provided by Burge et al. (2) was negligible. A sodium intake within the range of 50–60 $mmol \cdot L^{-1}$ is recommended for optimal rehydration (13), substantially greater than the self-selected intake of athletes (24). The elevated sodium intake maintained serum osmolality and sodium concentration, as has been observed previously (17). Despite this, fluid retention and restoration of plasma volume were similar between trials in which volunteers ingested either fluid alone or the combination of fluid, sodium, and carbohydrate. This perceived inability of sodium to assist with recovery from short-term weight loss was surprising, but it may merely reflect the short recovery period available to lightweight rowers. Generally, a minimum of 2 h is required after drinking a bolus of fluid to allow sufficient time for any significant renal excretion of water to occur (22). Only the first 90 min of recovery after weigh-in were monitored in the present investigation to ensure that athletes had adequate time to warm up before each time trial. Venous blood sampling was not undertaken after each ergometer trial because we were primarily interested in the impact of different nutritional strategies between weigh-in and racing than the response to exercise itself.

Despite a lack of perceived benefit, the inclusion of sodium in the recovery formula could be justified on several grounds. Not only does dietary sodium assist in maintaining serum OSM and sodium concentrations (17), which, in turn, maintains the drive to drink (18), it also stimulates glucose absorption in the small intestine via the active cotransport of sodium and glucose (11). Alternatively, it could be argued that sodium ingestion after weigh-in would merely increase fluid retention and, thus, body-mass gain in the hours after racing, without enhancing performance beyond the ingestion of fluid alone. Ultimately, this would likely require increased weight loss before subsequent races of the regatta, the performance implications of which remain to be addressed. However, previous work by our group suggests that more aggressive recovery strategies after racing assist in maximizing subsequent performance despite the need for greater body-mass loss (23). The impact of variation in sodium ingestion (independent of fluid volume) before subsequent performance efforts when the recovery period is short (i.e., 2 h or less) warrants investigation.

The ergogenic potential of preexercise carbohydrate intake on endurance performance has been well researched (8). However, the performance implications of carbohydrate ingestion in the few hours before brief, high-intensity exercise has received less attention, especially among athletes in weight-category sports who routinely undertake short-term energy restriction before competition. After an 8% loss of body mass in 4 d, Houston and associates (9) reported no benefit of nutrient intake (unspecified) during a 3-h recovery period in restoring indices of both aerobic and anaerobic performance. In contrast, refeeding wrestlers a high-carbohydrate (75%) beverage after 3 d of energy restriction ($75\ kJ \cdot kg^{-1}$) that resulted in a 3.3% body-mass loss restored anaerobic performance after 5 h (30). An energy-matched, moderate (47%) carbohydrate intake did not restore performance in the test designed to replicate the demands of wrestling competition, suggesting that a high carbohydrate intake after weigh-in may be important in maintaining performance. Maximal rates of muscle glycogen restoration are achieved with a carbohydrate intake of approximately $1.2\ g \cdot kg^{-1} \cdot h^{-1}$ (10), similar to that provided in the present investigation.

We have previously shown that total energy and carbohydrate intakes can be reduced by more than 50% as lightweight rowers attempt to make weight before competition (23,26). Such short-term weight-loss strategies can reduce muscle glycogen stores by 30–50% (2,27). Although it may seem unlikely that substrate availability limits performance during a 5- to 7-min event (6), it has been recognized that performance of high-intensity exercise of short duration (2–7 min) can be impaired if carbohydrate reserves are sufficiently compromised (12). Indeed, the present data suggest that carbohydrate and/or sodium ingestion may have assisted in maximizing performance when coingested with fluid compared with an equivalent amount of fluid alone. We can only speculate on a possible mechanism for performance enhancement with the addition of carbohydrate to the higher fluid intake. Previous research has shown performance enhancement from carbohydrate ingestion during high-intensity exercise of 60-min duration (5), although exogenous carbohydrate is unlikely to contribute greatly to total carbohydrate oxidation over such a time frame, leaving some researchers to propose an impact on central fatigue mechanisms and motivation (3,5). This has not gained support from others for shorter-duration time trials (19).

Although the combination of fluid, sodium, and carbohydrate provided in the present investigation was well tolerated and seemed to generally result in the best performances, optimal nutritional recovery strategies are likely influenced by the method(s) of body-mass management before weigh-in. The preferred techniques for short-term body-mass manipulation among volunteers in this investigation and lightweight rowers in general include short-term energy and fluid restriction in conjunction with an increase in training load (24). Therefore the recovery formula used in the present investigation that included a combination of fluid, carbohydrate, and sodium in accordance with current guidelines would likely be suitable for the majority of lightweight oarsmen after weigh-in.

In summary, the present investigation has shown that a focus on the provision of adequate fluid, carbohydrate, and sodium in the recovery period after weigh-in is most effective in optimizing performance among lightweight oarsmen who undertake moderate short-term weight loss in

the 24 h before weigh-in. Aggressive fluid ingestion seems to be most important among athletes who present in a hypohydrated state. Thus, consideration should be given to aggressive nutritional recovery strategies after weigh-in among lightweight male rowers who undertake short-term weight loss to achieve specified body-mass limits.

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