

ORIGINAL ARTICLE

## Effects of ingesting a sports drink during exercise and recovery on subsequent endurance capacity

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### Abstract

Most rehydration studies prohibit fluid ingestion during the preceding bout of dehydrating exercise. However, an athlete using a widely researched carbohydrate-electrolyte sports drink as a nutritional strategy is likely to consume the fluid both *during and after* exercise, warranting a study design with administration of test fluids during a preceding exercise bout *and* recovery. This is further enhanced with the incorporation of wind speed to mimic outdoor conditions. Improved performance, usually extrapolated from improved recovery, was directly quantified in this investigation with an endurance capacity test. Twelve males (mean  $\pm$  s: age  $24.3 \pm 1.6$  years; body fat  $14.6 \pm 4.0\%$ ;  $\dot{V}O_{2\text{peak}}$   $53.9 \pm 8.8$  ml  $\cdot$  kg $^{-1}$   $\cdot$  min $^{-1}$ ) performed three trials in which they ingested water, placebo or a carbohydrate-electrolyte sports drink during exercise and ensuing recovery to evaluate their efficacy in replacing fluids and carbohydrates, and the effects on subsequent endurance capacity. Double-blind administration of the placebo and sports drink minimized any researcher and participant bias. A total volume equivalent to 150% of sweat loss was ingested during 75 min cycling at 65% peak aerobic capacity ( $\dot{V}O_{2\text{peak}}$ ) in the heat (temperature  $32.1 \pm 0.3^\circ\text{C}$ ; relative humidity  $66 \pm 1\%$ , wind speed  $2.5 \pm 0.1$  m  $\cdot$  s $^{-1}$ ) and within 1 h of recovery (temperature =  $23^\circ\text{C}$ , relative humidity = 60%). An exercise capacity test at 65%  $\dot{V}O_{2\text{peak}}$  was conducted after a further 4 h of recovery. A paired *t*-test with Bonferroni correction was used to analyse variation between two trials ( $P < 0.017$ ). Percent fluid retention was higher with the sports drink than the placebo (water  $36 \pm 10\%$ , placebo  $33 \pm 9\%$ , sports drink  $41 \pm 6\%$ ;  $P = 0.004$ ). Following rehydration, mean serum sodium concentration was higher with the sports drink (water  $136 \pm 1$  mmol  $\cdot$  l $^{-1}$ , placebo  $137 \pm 1$  mmol  $\cdot$  l $^{-1}$ , sports drink  $138 \pm 1$  mmol  $\cdot$  l $^{-1}$ ;  $P < 0.001$ ). Percent change in plasma volume at 5 h of recovery, relative to 0 min of exercise, was greater with the sports drink than with water (water  $3 \pm 2\%$ , placebo  $3 \pm 3\%$ , sports drink  $6 \pm 3\%$ ;  $P = 0.014$ ). Blood glucose concentration was higher with the sports drink at 0 min (water  $5.0 \pm 0.3$  mmol  $\cdot$  l $^{-1}$ , placebo  $5.0 \pm 0.3$  mmol  $\cdot$  l $^{-1}$ , sports drink  $6.2 \pm 1.4$  mmol  $\cdot$  l $^{-1}$ ;  $P < 0.017$ ) and 1 h (water  $4.8 \pm 0.3$  mmol  $\cdot$  l $^{-1}$ , placebo  $4.9 \pm 0.3$  mmol  $\cdot$  l $^{-1}$ , sports drink  $7.3 \pm 0.7$  mmol  $\cdot$  l $^{-1}$ ;  $P < 0.001$ ) of recovery. Endurance capacity was greater with the sports drink ( $1.14 \pm 0.22$  h) than with water ( $0.85 \pm 0.27$  h;  $P < 0.001$ ) or placebo ( $0.92 \pm 0.25$  h;  $P = 0.013$ ). Ingestion of the sports drink *during and after* moderate-intensity exercise replaces fluids and energy lost more effectively than water and a placebo, leading to an improvement in subsequent endurance capacity.

**Keywords:** *Endurance cycling, rehydration, heat, isotonic sports drink*

### Introduction

Commercial carbohydrate-electrolyte sports drinks are formulated to include carbohydrate as an energy source to supplement liver and muscle glycogen stores (Coyle, 2004; Jeukendrup, 2004), fluids to counteract the debilitating effects of dehydration and hyperthermia (Montain, Sawka, Latzka, & Valeri, 1998), and electrolytes, mainly sodium, to replace losses via sweating and to promote intestinal glucose and water

uptake (Maughan, 1998; Shirreffs, Armstrong, & Chevront, 2004). The effects of ingesting carbohydrate-electrolyte fluids during exercise (for review, see Coombes & Hamilton, 2000) and recovery (for review, see Maughan, 1998) have been extensively investigated and shown to be generally effective compared with water or other placebo solutions. However, investigations of carbohydrate-electrolyte fluid ingestion both during exercise and the ensuing

recovery period are rare. Adopting a study protocol with the ingestion of test fluids during a preceding exercise bout and recovery mimics a realistic nutritional strategy employed by endurance athletes who use commercial sports drinks during training and competition.

Motivation to consume a carbohydrate-electrolyte beverage after exercise stems from its ability to enhance recovery and encourage optimal performance in a subsequent bout of exercise. The assumption that greater fluid retention and substrate replenishment will result in improved exercise performance is prevalent in most previous studies of post-exercise rehydration, with minimal direct measurements of subsequent performance (Fallowfield, Williams, & Singh, 1995; Merson, Maughan, & Shirreffs, 2008). Direct measurement of endurance capacity after short-term recovery will help quantify the extended exercise duration with ingestion of a sports drink.

In this study, we investigated the physiological responses to ingesting a commercial sports drink during exercise and recovery, and its efficacy in subsequent endurance capacity in a warm and humid environment with airflow. The assumption here is that an individual who recovers faster will be able to train harder in the second bout of exercise, hence allowing for greater physiological adaptations to enhance performance during competition. It was hypothesized that ingestion of the commercially available sports drink would be more effective in replacing the fluids and energy lost during exercise, leading to an extended exercise time to exhaustion compared with ingesting water or a placebo.

## Methods

### *Participants*

Twelve physically active males (mean  $\pm$  s; age  $24.3 \pm 1.6$  years, body mass  $65.2 \pm 6.6$  kg, height  $1.73 \pm 0.05$  m, body mass index  $21.8 \pm 2.5$ , body fat  $14.6 \pm 4.0\%$ ,  $\dot{V}O_{2\text{peak}}$   $53.9 \pm 8.8$  ml  $\cdot$  kg $^{-1}$   $\cdot$  min $^{-1}$ , peak power output  $265 \pm 38$  W) were recruited for the study. All participants were non-smokers and accustomed to exercising at least five times a week. Informed consent was provided in writing after reading a document describing the nature, benefits, and risks of the study. The study was approved by the Institutional Review Board.

### *Preliminary measurements*

On the participant's first visit, body mass was measured to the nearest 0.001 kg using a precision weighing scale (Mettler-Toledo (Albstadt) GmbH, Germany). Height was measured to the nearest 0.5 cm using a stadiometer (Seca, Germany). Body mass index was calculated as (body mass in kg)/

(height in m) $^2$  and body surface area was estimated using the equation of DuBois and DuBois (1916). Skinfold thickness measurements were taken at four sites (biceps, triceps, subscapular, and suprailiac) in triplicate by a trained anthropometrist (Level 1) accredited by the International Society for the Advancement of Kinanthropometry (ISAK); the mean value was used to calculate total skinfolds. Body density was calculated according to Durnin and Womersley (1974) and percent fat estimated using the equation of Siri (1956).

Peak aerobic capacity ( $\dot{V}O_{2\text{peak}}$ ) was determined via a continuous incremental test on a cycle ergometer (Ergomedic 894 Ea, Monark, Sweden). The test began at 105 W, with increments of 35 W every 3 min until volitional exhaustion. A cadence of 70 or 80 rev  $\cdot$  min $^{-1}$  was selected by each participant and was maintained throughout the test. Expired air samples were monitored via a facemask and metabolic cart (MetaLyzer 3B R2, Cortex, Germany). Heart rate was monitored by short-range telemetry (S810i, Polar Electro Oy, Finland) and ratings of perceived exertion (RPE; Borg 1973) were collected at the end of each stage and at volitional exhaustion. Peak power output was calculated from the equation of Kuipers and colleagues (Kuipers, Verstappen, Keizer, Guerten, & Van Kraneburg, 1985). Based on the  $\dot{V}O_2$ -power output relationship, the power output of 65%  $\dot{V}O_{2\text{peak}}$  was calculated for use during the subsequent exercise trials.

### *Familiarization*

On a second visit to the laboratory, each participant completed a full familiarization trial. The ride to exhaustion permitted two 2-min breaks when the participant could not maintain the required cadence and exhaustion was defined by a decrease in cadence of more than 5 rev  $\cdot$  min $^{-1}$  for the third time (Betts, Williams, Duffy, & Gunner, 2007; Wong & Williams, 2000). During the familiarization trial, an apple-flavoured cocktail (total calories: 0.09 kcal  $\cdot$  100 ml $^{-1}$ ) was administered.

### *Control of pre-trial status*

Participants were asked to standardize their dietary intake 48 h before the start of each experimental trial. They were also requested to avoid strenuous physical activity and refrain from alcohol 24 h prior to each trial. A diet and physical activity record sheet was kept to facilitate their compliance with the requirements. Participants were asked to arrive at the laboratory after an overnight fast. They were instructed to ingest 500 ml of water 90 min before arriving at the laboratory and to refrain from drinking thereafter.

*Telemetric body core temperature sensor*

Gastrointestinal temperature was used as an index of body core temperature. Participants ingested a temperature sensor (Vitalsense, Mini Mitter Company, Inc., Bend, OR) between 7 and 11 h before arriving at the laboratory.

*Experimental design*

Participants performed three experimental trials in which they ingested water, a placebo or a commercially available carbohydrate-electrolyte sports drink (Table I). All fluids were served at  $23.0 \pm 0.3^\circ\text{C}$ . Trials were randomized, separated by at least 7 days, and commenced at the same time for each volunteer. Treatments were administered in a crossover manner, with double-blind provision of sports drink and placebo.

On arrival at the laboratory, a urine sample was collected from the volunteer. A cannula was inserted into a superficial vein on the dorsal surface of the forearm before the volunteer's nude body mass was recorded. Each trial consisted of three phases: (1) 75 min of cycling at  $65\% \dot{V}O_{2\text{peak}}$ , (2) 5 h of recovery, and (3) an endurance capacity test at  $65\% \dot{V}O_{2\text{peak}}$ . The experimental protocol is illustrated in Figure 1.

*Phase 1: 75 min of cycling at  $65\% \dot{V}O_{2\text{peak}}$* 

Participants entered an environmental chamber (VEKZ10, Vötsch Industrietechnik, Germany) in which the ambient temperature was set at  $32^\circ\text{C}$  with relative humidity of 65% and wind velocity of  $2.5 \text{ m} \cdot \text{s}^{-1}$ . The environmental conditions were recorded by a climatic logger (Squirrel, 1000 Series, Grant Instruments, Cambridge, UK). After 5 min of seated rest, the volunteer's hand was immersed in warm water ( $42\text{--}44^\circ\text{C}$ ) for 10 min to promote arterialization of venous blood (Forster, Dempsey, Thomson, Vidruk, & DoPico, 1972). Blood samples

Table I. Energy content and composition of test drinks

Drink contents	Water	Placebo	Sports drink
Energy value ( $\text{kcal} \cdot \text{l}^{-1}$ )	0	6	270
Fat ( $\text{g} \cdot \text{l}^{-1}$ )	0	0	0
Protein ( $\text{g} \cdot \text{l}^{-1}$ )	0	0	0
Carbohydrate ( $\text{g} \cdot \text{l}^{-1}$ )	0	0	68
Sucrose	0	0	48
Glucose	0	0	20
Osmolality ( $\text{mOsmol} \cdot \text{kg}^{-1}$ )	$2 \pm 1$	$25 \pm 6$	$338 \pm 10$
$\text{Na}^+$ ( $\text{mmol} \cdot \text{l}^{-1}$ )	$2 \pm 0$	$3 \pm 0$	$26 \pm 1$
$\text{K}^+$ ( $\text{mmol} \cdot \text{l}^{-1}$ )	0	0	$2.9 \pm 0.1$

Note: Energy content and macronutrients concentrations were obtained from the manufacturer and are presented as mean values. Osmolality and concentration of electrolytes are presented as means  $\pm$  standard deviations.

were withdrawn from the cannula after at least 15 min in a seated position. This procedure was repeated for all blood samples obtained during recovery. Samples (7 ml each) were taken at 15 min of seated rest, 30, 60, and 75 min of the 75-min cycling bout, 0, 1, 3, and 5 h during recovery, and immediately after exhaustion in the endurance capacity test. Portions of fluid equivalent to  $1.5 \text{ ml} \cdot \text{kg body mass}^{-1}$  were provided immediately before the start and at 15-min intervals during the 75-min cycle at  $65\% \dot{V}O_{2\text{peak}}$ . A fluid questionnaire was completed after the ingestion of each fluid bolus during exercise and recovery. Using 10-cm visual analogue scales (0 = "not at all", 10 = "very"), the questionnaires assessed subjective responses to sweetness, saltiness and palatability, and associated feelings of thirst and mouth taste. Participants consumed each aliquot within 1 min during exercise and 10 min during recovery.

After 20 min of seated rest, participants commenced cycling at  $65\% \dot{V}O_{2\text{peak}}$ . Rating of perceived exertion, thermal sensation, and environmental data were recorded at 15-min intervals during exercise, and always immediately preceding the blood draws, if any. A thermal sensation rating of 0 = "neutral", 1 = "slightly warm", and 2 = "warm" was used. Core temperature and heart rate were obtained every 5 min.

*Phase 2: 5 h of recovery*

On completion of the 75-min cycle, participants exited the chamber and provided a full urine sample. This phase was conducted at an ambient temperature of  $23^\circ\text{C}$  and 60% relative humidity. Nude body mass was measured within 15 min, following the removal of unevaporated sweat with a towel. A blood sample corresponded to 0 h of recovery, and equal portions of test fluid were provided at 15, 30, 45, and 60 min. The time taken to ingest each aliquot was standardized for each participant to minimize differences in fluid retention due to the rate of rehydration (Shafiee et al., 2005). Total amount of test fluid ingested during the trial was equivalent to 150% of sweat volume, inclusive of that ingested during the 75 min of cycling. Sweat loss was estimated from the difference in body mass, corrected for fluid intake and urine production, and not corrected for respiratory water loss and metabolic water production. Any urine produced during recovery was accumulated as the volume at the end of each hour. Percent fluid retention was calculated from fluid ingested and urine output:

% Fluid retention

$$= [(\text{Total fluid ingested} - \text{Urine output}) / \text{Total fluid ingested}] \times 100\%$$

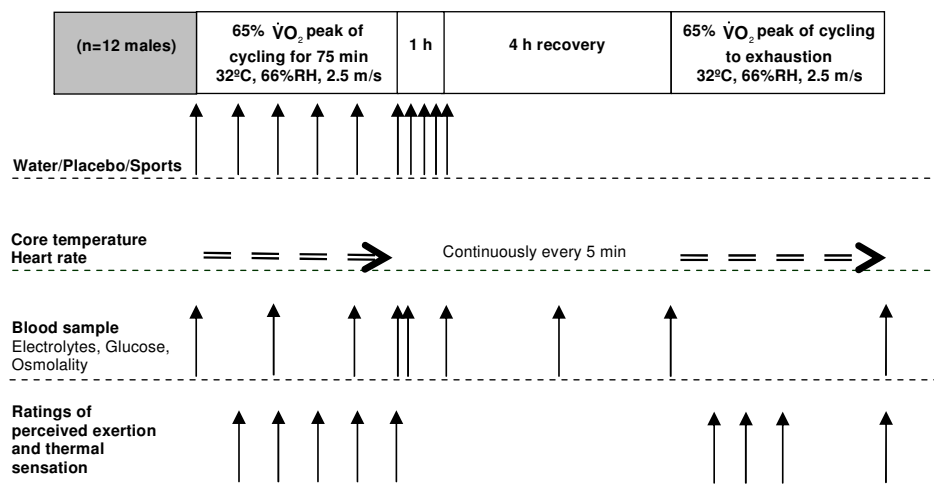


Figure 1. Schematic representation of the experimental protocol.

After the blood sampling at 5 h of recovery, the volunteers' nude body mass was recorded.

### Phase 3: Endurance capacity test at 65% $\dot{V}O_{2peak}$

In the endurance capacity test, participants cycled at 65%  $\dot{V}O_{2peak}$  until volitional exhaustion under the same environmental conditions as the initial 75-min ride. Verbal encouragement was provided during exercise. Core temperature and heart rate were recorded every 5 min. Ratings of perceived exertion and thermal sensation were recorded at 5, 15, and 30 min and at exhaustion. Time to exhaustion was recorded but withheld from the participant until completion of all three trials. Within 15 min of the end of the ride, a complete urine sample was obtained and nude body mass measured.

### Blood, urine, and drink analyses

Approximately 4 ml of blood was dispensed into a plain blood tube containing clot activator (BD Vacutainer 4.0 ml Plus Red top, BD Diagnostics, USA) and 3 ml was dispensed into an anticoagulant  $K_2EDTA$  blood tube (BD Vacutainer 3.0 ml Plus  $K_2EDTA$ , BD Diagnostics). Venepuncture was used to obtain blood samples when collection was unsuccessful via the cannula.

Blood glucose concentration was determined immediately via a portable handheld analyser (Accu-Chek<sup>®</sup> Advantage, Roche, Germany) using whole blood samples. Blood samples in the  $K_2EDTA$  blood tube were used to obtain duplicate measurements of haemoglobin concentration (using an automated counter; Coulter AcT diff 2, Beckman Coulter, USA) and triplicate measurements of spun haematocrit (Adams Micro-hematocrit Centrifuge, Clay Adams, USA). The relative changes in plasma, blood, and red cell volumes during exercise were

calculated from the haemoglobin concentrations and haematocrit values, with reference to the resting sample, using the equation of Dill and Costill (1974). The plain blood tube was left to stand for at least 1 h before it was centrifuged at 4°C and 2500  $rev \cdot min^{-1}$  for 10 min (BR4i, Jouan, France) to allow for extraction of serum. Serum was used to determine sodium and potassium concentrations using ion-selective electrodes (AVL 9181 Electrolyte Analyzer, AVL Scientific Corporation, USA), and osmolality using freezing point depression (Osmomat 030-D, Gonotec, Germany). Haematocrit, haemoglobin, sodium, and potassium concentrations were determined within 4 h of sampling, and serum osmolality within 2 weeks of storage at 4°C. Based on 20 samples, the coefficients of variation for blood glucose, haemoglobin, haematocrit, serum sodium and potassium, and osmolality were 2.4, 0.3, 0.1, 0.2, 0.3, and 0.2%, respectively.

The volume of urine output was measured and samples analysed for osmolality. A sample of drink from each trial was analysed for sodium and potassium concentrations, and osmolality.

### Statistical analyses

All statistical computations were performed using the Statistical Package for Social Sciences version 15.0. A one-factor analysis of variance (ANOVA) was performed to evaluate differences between trials in the measured variables at a single time point, sweat loss and exercise capacity between trials. A paired Student's *t*-test, with a Bonferroni adjustment, isolated differences among treatment means ( $P < 0.017$ ). Repeated-measures ANOVA was used to evaluate the changes in the remaining measured variables over time (the number of time points computed was in accordance with the reported sampling intervals described earlier). Exercise

capacity data were analysed up to 20 min and at fatigue to include all 12 participants unless otherwise stated. Figures report means  $\pm$  standard errors of the mean ( $s_{\bar{x}}$ ) and all other data are presented as means  $\pm$  standard deviations ( $s$ ).

## Results

One participant experienced difficulty in ingesting a volume equivalent to 150% of fluid lost as sweat and was provided with 120% instead. During the endurance capacity ride, data are included up to 20 min because it was the maximum time over which all participants exercised before requesting the first 2-min break.

### Environmental conditions

There were no differences in environmental conditions during the 75 min of cycling at 65%  $\dot{V}O_{2\text{peak}}$  (temperature: water  $32.1 \pm 0.3^\circ\text{C}$ , placebo  $32.1 \pm 0.3^\circ\text{C}$ , sports drink  $32.0 \pm 0.2^\circ\text{C}$ ,  $P=1.00$ ; relative humidity: water  $66 \pm 1\%$ , placebo  $66 \pm 0\%$ , sports drink  $66 \pm 1\%$ ,  $P=0.77$ ; wind velocity: water  $2.5 \pm 0.1 \text{ m} \cdot \text{s}^{-1}$ , placebo  $2.5 \pm 0.1 \text{ m} \cdot \text{s}^{-1}$ , sports drink  $2.5 \pm 0.2 \text{ m} \cdot \text{s}^{-1}$ ,  $P=0.40$ ) and the ride to exhaustion (temperature: water  $32.1 \pm 0.3^\circ\text{C}$ , placebo  $32.0 \pm 0.3^\circ\text{C}$ , sports drink  $32.0 \pm 0.2^\circ\text{C}$ ,  $P=0.83$ ; relative humidity: water  $66 \pm 1\%$ , placebo  $66 \pm 0\%$ , sports drink  $66 \pm 1\%$ ,  $P=0.53$ ; wind velocity: water  $2.5 \pm 0.1 \text{ m} \cdot \text{s}^{-1}$ , placebo  $2.5 \pm 0.1 \text{ m} \cdot \text{s}^{-1}$ , sports drink  $2.5 \pm 0.1 \text{ m} \cdot \text{s}^{-1}$ ,  $P=0.56$ ).

### Pre-trial physiological status

Diet records reflected no differences for 48–24 h (calories: water  $2374 \pm 716 \text{ kcal}$ , placebo  $2217 \pm 816 \text{ kcal}$ , sports drink  $2186 \pm 714 \text{ kcal}$ ,  $P=0.81$ ; carbohydrate: water  $312 \pm 103 \text{ g}$ , placebo  $280 \pm 117 \text{ g}$ , sports drink  $291 \pm 102 \text{ g}$ ,  $P=0.76$ ; protein: water  $100 \pm 28 \text{ g}$ , placebo  $96 \pm 30 \text{ g}$ , sports drink  $93 \pm 30 \text{ g}$ ,  $P=0.87$ ; fat: water  $82 \pm 32 \text{ g}$ , placebo  $81 \pm 33 \text{ g}$ , sports drink  $74 \pm 29 \text{ g}$ ,  $P=0.79$ ) and 24–0 h prior

to each trial (calories: water  $2453 \pm 788 \text{ kcal}$ , placebo  $2428 \pm 825 \text{ kcal}$ , sports drink  $2442 \pm 885 \text{ kcal}$ ,  $P=1.00$ ; carbohydrate: water  $329 \pm 111 \text{ g}$ , placebo  $314 \pm 120 \text{ g}$ , sports drink  $323 \pm 129 \text{ g}$ ,  $P=0.96$ ; protein: water  $92 \pm 40 \text{ g}$ , placebo  $95 \pm 39 \text{ g}$ , sports drink  $93 \pm 41 \text{ g}$ ,  $P=0.98$ ; fat: water  $86 \pm 35 \text{ g}$ , placebo  $87 \pm 35 \text{ g}$ , sports drink  $86 \pm 38 \text{ g}$ ,  $P=0.99$ ). Volunteers did not participate in strenuous physical activity for 24 h prior to each trial. There were no differences in the physiological parameters measured before all experimental trials (Table II). Similar hydration status before each trial was indicated by the consistency of body mass, haemoglobin concentration, haematocrit, and urine osmolality. All participants were considered euhydrated before each trial, as demonstrated by pre-exercise urine osmolality.

### Core (gastrointestinal) temperature

Mean core temperatures were similar across trials during the 75-min exercise bout (water  $37.9 \pm 0.3^\circ\text{C}$ , placebo  $37.8 \pm 0.3^\circ\text{C}$ , sports drink  $37.9 \pm 0.3^\circ\text{C}$ ,  $P=0.80$ ) and the ride to exhaustion (water  $37.8 \pm 0.2^\circ\text{C}$ , placebo  $37.8 \pm 0.3^\circ\text{C}$ , sports drink  $37.8 \pm 0.3^\circ\text{C}$ ,  $P=0.97$ ). Core temperatures were similar between trials at exhaustion (water  $38.6 \pm 0.5^\circ\text{C}$ , placebo  $38.7 \pm 0.4^\circ\text{C}$ , sports drink  $38.7 \pm 0.4^\circ\text{C}$ ,  $P=0.65$ ), with a range of  $38.0$ – $39.7^\circ\text{C}$ .

### Heart rate

Mean heart rates were similar across trials during the 75-min exercise bout (water  $160 \pm 8 \text{ beats} \cdot \text{min}^{-1}$ , placebo  $158 \pm 7 \text{ beats} \cdot \text{min}^{-1}$ , sports drink  $159 \pm 9 \text{ beats} \cdot \text{min}^{-1}$ ,  $P=0.81$ ). During the ride to exhaustion, mean heart rates were lower with the ingestion of the sports drink than with water ( $P=0.011$ ; Figure 2), but similar with water and placebo ( $P=0.43$ ), and placebo and the sports drink ( $P=0.16$ ). Heart rates were similar between trials at exhaustion ( $P=0.66$ ).

Table II. Pre-trial physiological parameters

Parameters	Water	Placebo	Sports drink	<i>P</i>
Body mass (kg)	$65.02 \pm 6.77$	$65.14 \pm 6.49$	$65.14 \pm 6.76$	0.99
Haemoglobin ( $\text{g} \cdot \text{dl}^{-1}$ )	$14.3 \pm 0.7$	$14.4 \pm 0.7$	$14.3 \pm 0.6$	0.97
Haematocrit (%)	$44.7 \pm 1.7$	$44.6 \pm 1.6$	$44.7 \pm 1.6$	0.98
Serum sodium ( $\text{mmol} \cdot \text{l}^{-1}$ )	$138 \pm 1$	$138 \pm 1$	$138 \pm 1$	0.82
Blood glucose ( $\text{mmol} \cdot \text{l}^{-1}$ )	$5.3 \pm 0.2$	$5.4 \pm 0.3$	$5.3 \pm 0.3$	0.56
Serum potassium ( $\text{mmol} \cdot \text{l}^{-1}$ )	$4.2 \pm 0.1$	$4.3 \pm 0.1$	$4.3 \pm 0.1$	0.67
Core temperature ( $^\circ\text{C}$ )	$37.0 \pm 0.3$	$37.0 \pm 0.2$	$36.9 \pm 0.2$	0.73
Heart rate ( $\text{beats} \cdot \text{min}^{-1}$ )	$73 \pm 7$	$70 \pm 7$	$74 \pm 8$	0.40
Urine osmolality ( $\text{mOsmol} \cdot \text{kg}^{-1}$ )	$292 \pm 168$	$344 \pm 162$	$282 \pm 142$	0.60

Note: There were no differences between trials as denoted by the *P*-values. Values are presented as means  $\pm$  standard deviations.

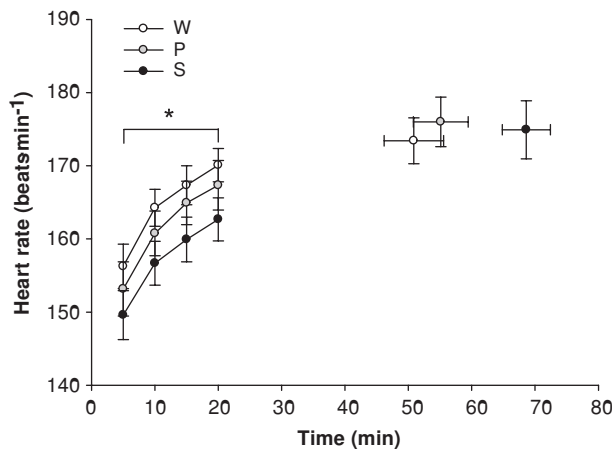


Figure 2. Heart rate during the ride to exhaustion. Mean values  $\pm$  standard errors are shown. \*Sports drink significantly different from water ( $P < 0.017$ ).

### Fluid balance

Sweat loss (water  $1672 \pm 494$  ml, placebo  $1627 \pm 372$  ml, sports drink  $1584 \pm 325$  ml,  $P = 0.87$ ) and total fluid intake (water  $2444 \pm 642$  ml, placebo  $2388 \pm 510$  ml, sports drink  $2325 \pm 434$  ml,  $P = 0.86$ ) during the 75-min exercise bout were similar across trials. Cumulative urine output during recovery was lower with the sports drink than placebo (placebo  $1599 \pm 377$  ml, sports drink  $1361 \pm 293$  ml,  $P = 0.002$ ), but the comparison with water failed to reach statistical significance (water  $1545 \pm 385$  ml,  $P = 0.028$ ). Similarly, fluid retention was higher with the sports drink than placebo ( $P = 0.004$ ; Figure 3).

### Ratings of perceived exertion and thermal sensation

Ratings of perceived exertion (RPE) rose from  $12 \pm 1$  to  $17 \pm 1$  ( $P < 0.001$ ) with no differences observed across trials in mean RPE of  $14 \pm 1$  ( $P = 0.57$ ) during the 75-min exercise bout. During the ride to exhaustion, RPE was lower after ingesting the sports drink ( $15 \pm 2$ ) than placebo ( $16 \pm 2$ ,  $P = 0.010$ ;  $n = 11$ ) at 30 min. One participant did not complete at least 30 min in the water trial and therefore is not represented at this time point. Mean ratings of thermal sensation were similar across trials during the 75-min exercise bout (water  $1 \pm 0$ , placebo  $2 \pm 0$ , sports drink  $1 \pm 0$ ,  $P = 0.90$ ) and the ride to exhaustion (water  $1 \pm 0$ , placebo  $1 \pm 1$ , sports drink  $1 \pm 0$ ,  $P = 0.71$ ;  $n = 11$ ).

### Subjective ratings of the drinks

Mean rating of sweetness was highest when ingesting the sports drink, intermediate with placebo, and lowest with water (water  $1.1 \pm 1.5$ , placebo  $4.0 \pm 2.1$ , sports drink  $5.8 \pm 2.4$ ,  $P < 0.017$ ). Similar ratings of saltiness were observed with placebo and the sports

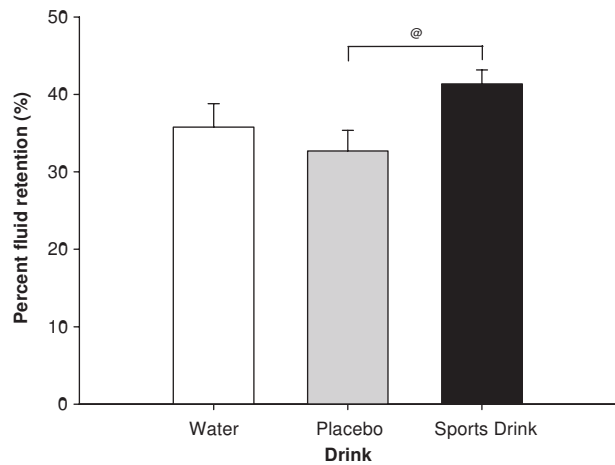


Figure 3. Percent fluid retention. Mean values  $\pm$  standard errors are shown. @Sports drink significantly different from placebo ( $P < 0.017$ ).

drink, which were rated more salty than water (water  $0.9 \pm 1.4$ , placebo  $4.5 \pm 2.4$ , sports drink  $3.9 \pm 2.2$ ,  $P < 0.017$ ). Ratings of pleasantness were higher when ingesting the sports drink than water (water  $4.2 \pm 1.6$ , placebo  $5.0 \pm 1.6$ , sports drink  $6.3 \pm 1.8$ ,  $P < 0.017$ ).

### Plasma volume

With all three interventions, plasma volumes fell by  $\sim 10\%$  in the first 30 min and declined by a further 1% at the end of the 75-min cycle (Figure 4;  $n = 11$ ). Expansion in percent change in plasma volume at 5 h of recovery was above baseline with all drinks, being greater with ingestion of the sports drink than water, and similar between the sports drink and placebo.

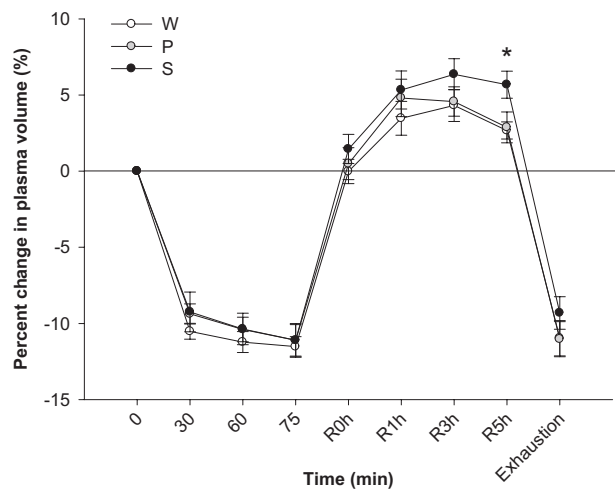


Figure 4. Percent change in plasma volume during the experimental trial ( $n = 11$ ). Mean values  $\pm$  standard errors are shown. \*Sports drink significantly different from water ( $P < 0.017$ ).

### Blood glucose

Mean blood glucose concentration during the 75-min exercise bout was similar across trials ( $P=0.32$ ; Figure 5a). Blood glucose concentrations at 0 h ( $P<0.017$ ) and 1 h ( $P<0.001$ ) of recovery were higher with the sports drink than with water and

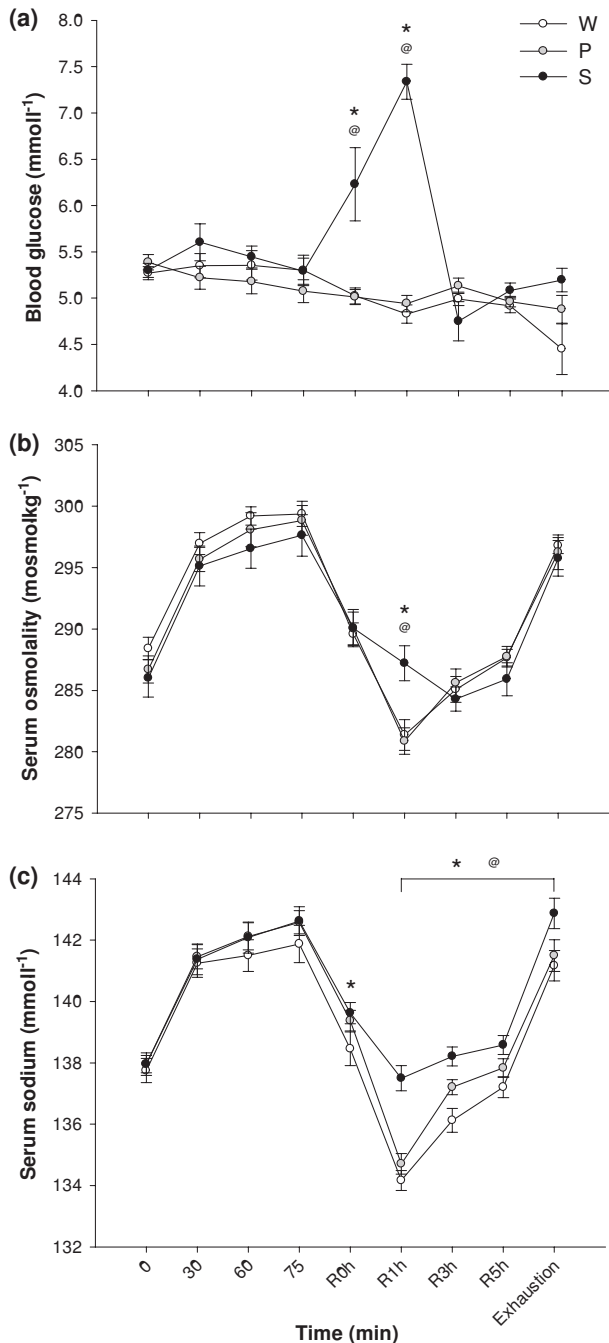


Figure 5. (a) Blood glucose, (b) serum osmolality, and (c) serum sodium concentration during the experimental trial. Mean values  $\pm$  standard errors are shown. \*Sports drink significantly different from water ( $P<0.017$ ). @Sports drink significantly different from placebo ( $P<0.017$ ). Square bracket indicates significance for mean concentration following rehydration, and at exhaustion.

placebo. Mean blood glucose concentration between trials was similar at 3 h and 5 h of recovery ( $P=0.67$ ), and at exhaustion ( $P=0.04$ ).

### Serum osmolality and electrolytes

Mean serum osmolality was similar across trials during the 75-min exercise bout ( $P=0.51$ ; Figure 5b) and at 0 h of recovery ( $P=0.94$ ). Serum osmolality at 1 h of recovery was higher with the sports drink than water ( $P=0.004$ ) and placebo ( $P=0.016$ ). Mean serum osmolality was similar between trials at 3 h and 5 h of recovery ( $P=0.45$ ), and at exhaustion ( $P=0.80$ ). Mean serum sodium concentration was similar across trials during the 75-min exercise bout ( $P=0.66$ ; Figure 5c).

Serum sodium concentration was greater with the sports drink than water at 0 h of recovery ( $P=0.004$ ). Following rehydration ( $P<0.001$ ) and at exhaustion ( $P<0.017$ ), mean serum sodium concentration was higher with the sports drink than with water and placebo. Mean serum potassium concentration was similar across trials during the 75-min exercise bout (water  $5.3 \pm 0.1$  mmol $\cdot$ l $^{-1}$ , placebo  $5.2 \pm 0.2$  mmol $\cdot$ l $^{-1}$ , sports drink  $5.2 \pm 0.3$  mmol $\cdot$ l $^{-1}$ ,  $P=0.34$ ) and at 0 h of recovery (water  $4.4 \pm 0.2$  mmol $\cdot$ l $^{-1}$ , placebo  $4.4 \pm 0.2$  mmol $\cdot$ l $^{-1}$ , sports drink  $4.2 \pm 0.2$  mmol $\cdot$ l $^{-1}$ ,  $P=0.12$ ).

Serum potassium concentration at 1 h of recovery was lower with the sports drink ( $4.0 \pm 0.2$  mmol $\cdot$ l $^{-1}$ ) than water ( $4.4 \pm 0.2$  mmol $\cdot$ l $^{-1}$ ,  $P<0.001$ ) and placebo ( $4.3 \pm 0.3$  mmol $\cdot$ l $^{-1}$ ,  $P=0.007$ ). Mean serum potassium concentration was similar in all three treatments at 3 h and 5 h of recovery (water  $4.0 \pm 0.1$  mmol $\cdot$ l $^{-1}$ , placebo  $4.0 \pm 0.1$  mmol $\cdot$ l $^{-1}$ , sports drink  $4.0 \pm 0.2$  mmol $\cdot$ l $^{-1}$ ,  $P=0.77$ ), and at exhaustion (water  $4.8 \pm 0.1$  mmol $\cdot$ l $^{-1}$ , placebo  $4.7 \pm 0.3$  mmol $\cdot$ l $^{-1}$ , sports drink  $4.9 \pm 0.3$  mmol $\cdot$ l $^{-1}$ ,  $P=0.27$ ).

### Time to exhaustion

Endurance capacity was greater with ingestion of the sports drink than water ( $P<0.001$ ; Figure 6) and placebo ( $P=0.013$ ). Cycling time to exhaustion was similar between the water and placebo trials ( $P=0.38$ ). When ingesting the sports drink, the participants cycled for  $43 \pm 34\%$  ( $17.7 \pm 12.1$  min) longer than in the water trial, and  $30 \pm 34\%$  ( $13.5 \pm 15.7$  min) longer than in the placebo trial.

### Discussion

The formulation of the sports drink used in this study is similar to several commercially available sports drinks that contain 4–8% carbohydrate and 10–30 mmol $\cdot$ l $^{-1}$  of sodium (Coombes & Hamilton,



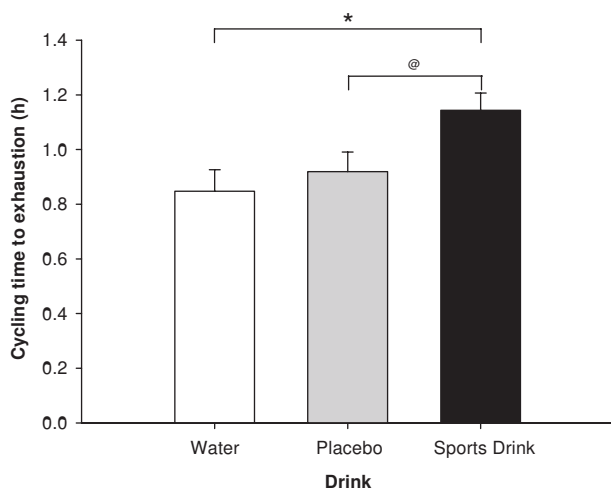


Figure 6. Cycling time to exhaustion. Mean values  $\pm$  standard errors are shown. \*Sports drink significantly longer than water ( $P < 0.017$ ). @Sports drink significantly longer than placebo ( $P < 0.017$ ).

2000). The primary aim of this study was to examine the efficacy of ingesting this commercially available sports drink in replacing fluids and energy during moderate-intensity cycling exercise and subsequent recovery. To our knowledge, this is the first report of isotonic sports drink ingestion during exercise and ensuing recovery, with direct measurement of subsequent performance with an endurance capacity test.

Unlike previous rehydration studies in which fluids were restricted during the preceding dehydration phase, test solutions were administered in this study. The feeding volume ingested during exercise, although small, is a practical volume, since athletes do not fully replenish fluid losses while exercising (Pugh, Corbett, & Johnson, 1967). The selected study design sought to mimic the use of sports drink during training and competition, as athletes ingesting fluids after exercise in their recovery regime are also likely to ingest fluids during exercise. Drinking during the 75-min exercise bout may have had an effect on measured parameters during recovery, and thus it is worth noting that baseline values before the rehydration phase for the three drinks may not have been equal.

The main factors influencing the hydration process are volume and composition of fluid ingested (Shirreffs et al., 2004). In our study, isovolumetric treatments isolated the efficacy of each test solution to solely its constituents. An ingested volume that approximates 150% of sweat loss will achieve full restoration of body fluids after a preceding bout of exercise due to obligatory urine losses that continue after exercise (Mitchell, Grandjean, Pizza, Starling, & Holtz, 1994; Shirreffs, Taylor, Leiper, Maughan, 1996).

Sodium is included in most sports drinks, mainly because it is the primary cation lost in sweat (Shirreffs et al., 2004). Its concentration is related to net fluid retention (Maughan & Leiper, 1995; Shirreffs et al., 1996; Wemple, Morocco, & Mack, 1997), with an  $\sim 20 \text{ mmol} \cdot \text{l}^{-1}$  difference suggested to have an effect on whole-body hydration status (Maughan, Owen, Shirreffs, & Leiper, 1994). During recovery, the inclusion of sodium offers several advantages over water: first, it sustains the osmotic drive to drink (Nose, Mack, Shi, & Nadel, 1988), thereby promoting better voluntary fluid intake (Passe, 2001); second, it maintains greater plasma and extracellular fluid volumes (Below & Coyle, 1995); and third, it lowers urine output. Gonzalez-Alonso and colleagues (Gonzalez-Alonso, Heaps, & Coyle, 1992) reported fluid retention to be 5% higher with a sports drink than water (water  $64 \pm 5\%$ , sports drink  $69 \pm 5\%$ ), similar to the differences observed in our study (placebo  $33 \pm 9\%$ , sports drink  $41 \pm 6\%$ ,  $P = 0.004$ ). Other than differences in test conditions between the present study and that of Gonzalez-Alonso et al. (1992), the lower retention volume is likely to be due to the difference in time catered for fluid replenishment during the recovery phase. Gonzalez-Alonso et al. (1992) provided  $\sim 2$  litres of test fluids over 2 h compared with  $\sim 1.8$  litres of fluids in 1 h in the present study, with the latter likely to induce greater diuresis. The cumulative urine output was about 250 ml lower with the sports drink than placebo, with an insignificant decrease (about 200 ml;  $P = 0.028$ ) observed in comparison with the water trial. Consistent with Shirreffs and Maughan (1998), we observed a marginal difference in hydration status with a  $24 \text{ mmol} \cdot \text{l}^{-1}$  sodium difference between water and the sports drink. Nose et al. (1988) reported an acute fall in serum osmolality with the ingestion of water and placebo, which stimulated diuresis. In our study, serum osmolality at 1 h of recovery was  $6 \text{ mOsmol} \cdot \text{kg}^{-1}$  higher with the sports drink than water and placebo, thereby promoting fluid retention. Our results imply that the sodium content present in the sports drink administered is sufficient to enhance fluid retention after exercise, although we are unsure whether these small differences *per se* had any effect on subsequent endurance performance.

Below and Coyle (1995) demonstrated better maintenance of plasma volume when participants ingested 550 mg ( $18 \text{ mmol} \cdot \text{l}^{-1}$ ) of sodium during 50 min of cycling. This was demonstrated in our study at the end of recovery, where the restoration of plasma volume was greater with the sports drink than water. The greater 3% expansion did not reach statistical significance ( $P = 0.019$ ) compared with placebo. Within the environmental conditions imposed, all three drinks restored plasma volume



above baseline at the end of recovery. For restoration of plasma volume, this study suggests that ingesting 150% of sweat volume may not be mandatory if fluids are consumed during the preceding exercise bout.

Carbohydrate supplementation delays the onset of fatigue during steady-state moderate-intensity exercise by preventing hypoglycaemia (Horowitz, Mora-Rodriguez, Byerley, & Coyle, 1999), rather than sparing or reducing the rate of muscle glycogen utilization (Coyle et al., 1986). In our study, blood glucose concentrations were higher at 0 and 1 h of recovery with the sports drink than water or placebo. This is likely to promote glycogen synthesis during recovery. As an intensity of 65%  $\dot{V}O_{2\text{peak}}$  relies predominantly on carbohydrate to sustain exercise, glucose availability is likely to be one of the limiting factors for trial termination with the ingestion of water and placebo.

A high body core temperature, instead of substrate availability, has been identified as a limitation to exercise performance in the heat (Nybo & Nielsen, 2001). In this study, the incorporation of wind speed to mimic outdoor conditions is likely to have contributed to the improved endurance capacity with the sports drink, as it reduces heat storage and body temperature (Saunders, Dugas, Tucker, Lambert, & Noakes, 2005). Mean core temperature observed with all three fluids was below 39°C and mean ratings of thermal sensation were “2 = warm” at exhaustion, indicating that heat stress was unlikely to be the main reason for exercise cessation. The induced convective element allowed the test drinks to be evaluated under realistic conditions and increased the likelihood of fatigue due to substrate unavailability.

Ingestion of sports drinks increases sustainability of a given workload, with an average 36% greater endurance capacity than with water and placebo in our study. Bilzon and colleagues (Bilzon, Allsopp, & Williams, 2000) reported 16 min longer running with a sports drink than placebo, similar to the 15.6 min (average between water and placebo) observed with ingestion of the sports drink in our study. The lower mean heart rate with the sports drink than water, and lower ratings of perceived exertion with the sports drink than placebo, during the endurance capacity test are in line with the observed enhanced capacity with the sports drink. Intake of a sports drink may prepare the athlete for a subsequent exercise bout by reducing the initial cardiovascular strain experienced, and rating of perceived exertion measured early during exercise has been shown to be a sensitive predictor of exhaustion time (Eston, Faulkner, St. Clair, Noakes, & Parfitt, 2007; Garcin & Billat, 2001; Horstman, Morgan, Cymerman, & Stokes, 1979).

## Conclusion

Based on the composition of the commercially available sports drink used here, studies should provide an indication of its efficacy. However, few studies have evaluated the efficacy of isotonic sports drinks when ingested during exercise and recovery, and their effects on subsequent endurance capacity. Based on the present findings, we conclude that ingestion of carbohydrate-electrolyte solutions replaces fluids and carbohydrates more effectively than water and placebo after exercise. For athletes participating in repeated exercise bouts within a single day, ingesting sports drink during exercise and recovery will improve subsequent endurance capacity compared with water and placebo. The results of this study will be of interest to athletes seeking to recover optimally after exercise to improve performance in a subsequent bout of exercise.

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