J. L. J. Bilzon · A. J. Allsopp · C. Williams

Short-term recovery from prolonged constant pace running in a warm environment: the effectiveness of a carbohydrate-electrolyte solution

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Abstract Recovery from prolonged exercise involves both rehydration and replenishment of endogenous carbohydrate stores. This study examined the influence of drinking a carbohydrate-electrolyte solution on short-term recovery and subsequent exercise capacity in a warm environment. Thirteen healthy male volunteers completed two trials, at least 7 days apart. On each occasion subjects performed an initial treadmill run at 60% of maximal oxygen uptake ($VO_{2 \text{max}}$), for 90 min or until volitional fatigue (T1), in a warm environment (35 °C, 40% relative humidity, RH). Volitional ingestion of water was permitted during each of the exercise trials. During a subsequent 4-h recovery period (REC) subjects consumed either a 6.9% carbohydrate-electrolyte solution (CES) or a sweetened placebo (P), in a volume equivalent to 140% of body mass loss. Following REC, subjects ran to exhaustion at the same %$VO_{2 \text{max}}$ in order to assess their endurance capacity (T2). Mean (SEM) run times during T1 did not differ between the CES [74.8 (4.6) min] and P [72.5 (5.2) min] trials. Body mass was reduced ($P < 0.01$) by 1.9 (0.2)% (CES) and 1.7 (0.2)% (P), and plasma volume ($P < 0.01$) by 6.0 (0.9)% (CES) and 5.4 (1.0)% (P) during the T1 trials. During REC 2006 (176) ml and 1830 (165) ml of fluid was ingested, providing 138 (12) g and 0 g of carbohydrate in the CES and P trials, respectively. Prior to T2, plasma volume and net fluid balance were similarly restored [CES +58 (26) g; P −4 (68) g] in both trials. During T2 the exercise duration was longer ($P < 0.01$) in the CES compared to the P trial [CES 60.9 (5.5) min; P 44.9 (3.0) min]. Thus, provided that an adequate hydration status is maintained, inclusion of carbohydrate within an oral rehydration solution will delay the onset of fatigue during a subsequent bout of prolonged submaximal running in a warm environment.

Key words Carbohydrate · Dehydration · Metabolism · Recovery · Thermoregulation

Introduction

Substantial losses of water and electrolytes occur through sweating during prolonged exercise, especially when the ambient temperature is high (Adolph 1947; Lentner 1981). The ensuing dehydration decreases blood volume (Harrison 1985), and impairs thermoregulatory function (Pandolf et al. 1994) as well as exercise capacity (Sawka 1992). Indeed, previous investigations suggest that volitional fatigue during prolonged exercise in a warm environment is directly related to dehydration, thermoregulatory incapacity and hyperthermia (Nielsen et al. 1993; Sawka 1992). Recently, exercising in a warm environment (Febbraio et al. 1994) and progressive dehydration (Hargreaves et al. 1996) have been shown to increase the rate of muscle glycogen degradation. Muscle glycogen depletion may account, at least in part, for physiological fatigue when exercising in a warm environment. Inclusion of carbohydrate within a rehydration beverage may therefore be essential when repeated bouts of exercise are performed in a warm environment, on the same or successive days.

Previous research has clearly demonstrated that ingesting carbohydrate-electrolyte solutions (CES) during short-term (4 h) and long-term (22.5 h) recovery periods enhances subsequent endurance capacity when exercise is performed in a cool (20 °C) environment (Fallowfield and Williams 1993; Fallowfield et al. 1995).
The availability of such a solution is determined by gastric emptying, intestinal absorption and subsequent fluid retention (Mitchell and Voss 1991). These processes are influenced by several factors, including the solute content of a fluid (Costill and Saltin 1974) and the volume ingested (Noakes et al. 1991). Although, the addition of carbohydrate (CHO) increases the solute content and therefore the osmotic load of a solution, it does not, at least in low concentrations (5–10%), appear to significantly compromise gastric emptying (Maughan and Leiper 1990; Rehner et al. 1989). As such, exogenous CHO can be absorbed quickly, without compromising the rehydration process (Maughan and Leiper 1990).

Adequate CHO intake following exercise is essential for recovery and rapid repletion of endogenous reserves (Bergstrom et al. 1967). This is particularly true in the 2 h after exercise, when the rate of muscle glycogen re-synthesis is somewhat greater than normal (Ivy et al. 1988). Ingestion of CES between bouts of physical activity in a warm environment may therefore alleviate the symptoms of fatigue (Carter and Gisolfi 1989) and assist in the maintenance of performance during subsequent exercise. The influence of ingesting CES during recovery from exercise on subsequent exercise capacity in a warm environment has not been investigated. The aim of the present study was to assess whether ingesting CES during recovery from exercise in the heat (35 °C, 40% relative humidity, RH) influences endurance capacity 4 h later.

**Methods**

**Subjects**

Thirteen healthy male volunteers acted as subjects for this study, which was carried out with the approval of the Ministry of Defence (Navy) Personnel Research Ethics Committee. Written consent to participate was provided by all subjects after the nature of the study had been explained to them. All were involved in various training programmes, of which submaximal running was a central feature, and had taken part in previous laboratory trials involving treadmill running to exhaustion. Mean (SEM) physical characteristics of the subjects were: age, 32.3 (1.4) years; height, 178.2 (1.4) cm; body mass, 79.4 (2.8) kg; body fat, 16.5 (1.0)%.

**Preliminary measurements**

Following a full medical examination and the estimation of percentage body fat from four skinfold measurements (Durnin and Womersley 1974), subjects were familiarized with treadmill running and with the experimental procedures. Each subject then completed two preliminary tests before the two main trials. The first test consisted of 16 min of continuous running on a level treadmill to determine the oxygen cost (VO2) of running over a range of submaximal speeds. The second of these tests was to determine each subject’s maximal oxygen uptake (VO2max) during uphill treadmill running (Taylor et al. 1955) in a warm environment (see “Procedures”): mean (SEM) VO2max was 60.3 (3.3) ml · kg⁻¹ · min⁻¹. Subjects maintained a constant training level throughout the experimental period and refrained from strenuous activity for 48 h prior to an experimental day.

**Procedures**

The CES and sweetened placebo (P) treatments were administered in a double-blind, cross-over design. In the CES trial subjects consumed a commercially available sports drink (containing: 6.9% carbohydrate; 24 mmol · l⁻¹ Na⁺; 2.6 mmol · l⁻¹ K⁺; 1 mmol · l⁻¹ Cl⁻; 300 mosmol · kg⁻¹) over a 4-h recovery period. During the placebo (P) trial subjects consumed flavoured sweetened water. All exercise trials were conducted in an environmental chamber controlled at a mean (SEM) temperature 35.1 (0.1) °C, humidity 40.3 (0.2)% RH and an air velocity of 0.5 m · s⁻¹.

On reporting to the laboratory, subjects were seated in a room maintained at 22 °C, where they consumed a standard breakfast (685 kcal; 70% CHO; 20% fat; 10% protein) and water (550 (22) ml). After 90 min subjects entered the environmental chamber and were asked to empty their bladder. Nude body mass was then measured to the nearest 5 g (Sauter SD100) before dressing in shorts, socks and running shoes. Two aural thermistors (insulated with cotton wool) and three electrocardiogram (ECG) chest electrodes were attached to the subjects for the determination of tympanic membrane temperature (Taur) and heart rate (HR), respectively. Immediately after sitting in a relaxed position for 15 min, an initial 10-ml venous blood sample was drawn from an antecubital vein, without venostasis. Subsequent venous blood samples were obtained in the same manner. Duplicate 20-μl capillary blood samples were simultaneously drawn from the finger.

After recording baseline Taur and HR, subjects stood on the treadmill and the velocity was then increased to elicit 60% VO2max (T1). During T1 subjects were asked to continue running until volitional fatigue, whichever was reached first. Ingestion of water was permitted at a rate of 2 ml · kg⁻¹ body mass every 15 min. Expired air samples were collected over 60-s periods at 15-min intervals during T1 using the Douglas bag technique. Percentage oxygen (FeO2) content was measured by a paramagnetic O2 analyser, percentage carbon dioxide (FeCO2) was measured by an infrared CO2 analyser (Taylor Servomex, Series 1400) and minute ventilation was measured by a dry gas meter (Harvard, Kent, UK). From gas analyses, VE, VO2 and VCO2 were determined and the respiratory exchange ratio (RER) calculated. Rates of total CHO and fat oxidation were calculated from O2 uptake and CO2 production, using previously described methods (Frayn 1983). Ratings of perceived exertion (RPE) and thermal discomfort (TD) were similarly recorded at 15-min intervals. Duplicate capillary blood samples were drawn at 30 and 45 min of each trial and HR were recorded at 60-s intervals throughout the exercise period. Post exercise venous and capillary samples were obtained at the end of T1. Following the assessment of nude body mass subjects left the environmental chamber to begin their controlled 4-h recovery period (REC) in a room maintained at 22 °C.

During REC subjects ingested three equal feedings of CES or P (equivalent to 100% weight loss) at 0, 1 and 2 h. After 3 h subjects were asked to void their bladder, nude body mass was recorded, and a bolus dose equivalent to the remaining fluid deficit was ingested. Ingested volumes were therefore equivalent to 140% of body mass loss, providing 138 (12) g or 6 g of CHO during the CES and P trials, respectively. No food and only the prescribed fluids were consumed during the 4-h period. Duplicate capillary blood samples were similarly drawn at 60-min intervals throughout the recovery period. Urine was collected throughout the recovery period and subjects were asked to finally void their bladder upon entering the environmental chamber for a second time. Following the assessment of nude body mass subjects were dressed and instrumented as before. After venous and capillary blood samples were drawn, subjects stood in position on the treadmill and the speed was gradually increased to elicit a metabolic demand equivalent to 60% VO2max. Subjects were required to run until volitional exhaustion to assess their endurance capacity (T2). The frequency of data collection during T2 was identical to that during T1. At the end of the trial venous and capillary blood samples were drawn and body mass recorded.