The effects of pre-warming on the metabolic and thermoregulatory responses to prolonged submaximal exercise in moderate ambient temperatures

Accepted: 21 December 2001 / Published online: 2 March 2002 © Springer-Verlag 2002

Abstract To determine the effects of pre-warming on the human metabolic and thermoregulatory responses to prolonged steady-rate exercise in moderate ambient temperatures and relative humidities [means (SD) 21.7 (2.1)° C and 36.7 (5.4)%], six healthy men each ran at a steady-rate (70% maximal oxygen uptake) on a treadmill until exhausted after being actively pre-warmed (AH), passively pre-warmed (PH), and rested (Cont). Exercise time to exhaustion was significantly reduced following both AH and PH compared to Cont [AH 47.8 (14.0) min, PH 39.6 (16.0) min, Cont 62.0 (8.8) min; P < 0.05]. During exercise there were no significant differences in oxygen uptake, total sweat loss, mean skin temperature (Tsk) and the thermal gradient (T<sub>re</sub>–Tsk, where T<sub>re</sub> is rectal temperature) following the three conditions. Serum prolactin, plasma catecholamine and plasma free fatty acid concentrations were also similar between all three trials. In contrast, T<sub>re</sub>, mean body temperature, heart rate and ratings of perceived exertion were significantly greater during the initial 25 min of exercise following both AH and PH, compared with Cont (P < 0.05). At exhaustion, there were no significant differences in the metabolic and thermoregulatory responses to exercise between the trials. The current findings demonstrate that AH and PH promote a reduction in prolonged submaximal endurance performance under moderate environmental temperatures compared with pre-exercise rest. Such observations appear likely to have been mediated through mechanisms associated with the earlier development of high internal body temperature which resulted in changes in the capacity for heat storage.

Keywords Exhaustion · Heat storage · High internal body temperature

Introduction

The ability to perform prolonged sub-maximal exercise under conditions of high ambient heat stress (30–40 °C) is reduced compared with exercise performed under moderate environmental conditions (20–25 °C) (Galloway and Maughan 1997; Parkin et al. 1999). Such declines in exercise performance in the heat are frequently accompanied by a number of metabolic (Febbraio et al. 1994), thermoregulatory (Gonzalez-Alonso et al. 1999; Nielsen et al. 1993; Parkin et al. 1999) and cardiovascular changes (Gonzalez-Alonso et al. 1997, 1998). These alterations, associated primarily with the increased thermal load associated with exercise under these conditions, may promote the observed fatigue (Febbraio 1999).

In contrast with exercise in high ambient temperatures there are few studies which have determined the effects of moderate ambient heat stress (20–21 °C) on prolonged exercise capacity (Galloway and Maughan 1997; Parkin et al. 1999). Under such environmental conditions mechanisms similar to those associated with high ambient heat stress, have also been associated with a decline in endurance capacity when compared with exercise performed under cooler conditions (3–11 °C) (Galloway and Maughan 1997; Kozlowski
et al. 1985; MacDougall et al. 1974). Thus, environmental temperature-mediated changes would also appear likely to be key determinants of fatigue during exercise in moderate temperatures. Support for such observations is provided by studies that have demonstrated improvements in exercise performance as a consequence of strategies that reduce the level of thermoregulatory strain compared to control conditions (Lee and Haymes 1995; Maughan et al. 1996; McConnell et al. 1997; Olszewski and Bruck 1988).

It can be predicted from such observations that any manipulation to raise core body temperature and/or reduce hydration levels would promote a number of physiological alterations that should reduce endurance capacity in moderate environmental temperatures. Pre-warming procedures that promote an increase in the level of body temperature prior to the onset of exercise (both with and without concomitant changes in the level of hydration) have been shown to reduce prolonged exercise performance in the heat (40–46 °C; Craig and Froehlich 1968; Gonzalez-Alonso et al. 1999). However, to date, no study has been undertaken to determine the effects of pre-warming strategies on endurance capacity in moderate ambient temperatures.

The process of pre-warming can be promoted actively through heat produced directly as a by-product of skeletal muscle contractions, or passively, by heating of the body using external sources (e.g. immersion in warm water; Shellock and Prentice 1985). As there are profound differences in the cardiovascular and thermoregulatory responses to active and passive heating procedures (Nielsen 1987), it may be anticipated that the physiological responses to subsequent prolonged exercise would also differ. No study to date has compared the effects of active and passive pre-warming on sub-maximal endurance performance.

The aim of the current investigation was to determine the effects of active and passive pre-exercise warming on the capacity to perform prolonged submaximal exercise in normal laboratory temperatures (20 °C) and to evaluate the metabolic and thermoregulatory responses to prolonged exercise, following such body-temperature manipulations. It was hypothesised that active and passive pre-warming would reduce submaximal exercise capacity by increasing the metabolic and thermoregulatory strain associated with exercise. Furthermore, it was proposed that differences in exercise performance would also arise as a result of the differing physiological responses associated with differing pre-warming procedures.

### Methods

#### Subjects

Six healthy men [mean (SD) age 25 (6) years, height 1.77 (0.1) m, body mass (m) 76.6 (6.5) kg, body fat 9.3 (3.6)%, estimated muscle mass 45.0 (3.1) kg; maximal oxygen uptake ( VO₂max) 4.90 (0.4) l min⁻¹] were studied. All subjects were well-trained soccer players and were not heat acclimatised. All subjects were informed of the experiment procedures and associated risks, and gave their written informed consent to participate. The study was approved by the University Ethics Committee. These experiment procedures complied with standards adopted by the 18th World Medical Assembly, Helsinki, Finland, June 1964 for biomedical research involving the use of human subjects.

Before taking part in the trials, all subjects were assessed as to their VO₂max and body composition. The VO₂max was assessed using a continuous incremental running protocol to exhaustion on a motorised treadmill (Power Jog GX 200, Sport Engineering Ltd, England). Body composition was determined by measuring skinfold thicknesses using Harpenden skinfold callipers (HSK BI, Batty International, England). Estimations of percentage body fat (Jackson and Pollock 1978; Siri 1956) and muscle mass (Martin et al. 1990) were made using the appropriate equations.

#### Procedures

Each subject ran at a steady-rate on a treadmill at an intensity corresponding to approximately 70% VO₂max until he was exhausted, following either active (AH) or passive heating (PH) protocols to raise body temperature. A third trial with no prior manipulation of body temperature was also included as a control (Cont). All trials were undertaken with no fan assisted air movement in moderately stressful laboratory conditions [21.7 (2.1) °C dry bulb temperature and 35.7 (5.4)% relative humidity].

On the morning of the trials, the subjects arrived at the laboratory after an overnight fast, having refrained from exercise, alcohol, tobacco and caffeine during the previous 24 h. The subjects also recorded their nutritional and fluid intakes prior to the first trial. This was photocopied and returned to subjects so that the diet could be repeated before the remaining trials. This ensured standardisation of nutritional and hydration status prior to all experiments. The trials were conducted 1 week apart in a randomised order and at the same time of day to avoid the effects of circadian variations in internal body temperature (Reilly and Brooks 1986). The subjects were not allowed to consume fluid at any time during AH, PH, or Cont trials.

On arrival at the laboratory, anthropometric variables were obtained. These included height (metres) and nude m, (kilograms) (GEC Avery, BSI Testing, England). Body composition was determined by measuring skinfold thicknesses (GEC Avery, BSI Testing, England). A venous cannula (Venflon 2, BOC Ohmeda, Sweden) was inserted in an ante-cubital vein by a qualified phlebotomist. The cannula was kept patent by infusion of saline (2 ml) immediately following insertion, and after each blood sample. A rectal probe was also inserted to a depth of 10 cm beyond the anal sphincter. The probe was then attached to a Squirrel data logger (1250, Grant Instruments, England) to record rectal temperature ( Tₐ). A heart rate monitor was positioned across the chest (Polar, Finland). Skin thermistors were attached to the upper chest, lower forearm, upper thigh, and medial side of the calf, to allow the calculation of weighted mean skin temperature ( Tₘₛ), using the equation of (Ramanathan 1964). As the PH protocol required partial immersion of the body, the thigh and calf skin thermistors were not placed until afterwards. Consequently, Tₘₛ measurements during the course of PH were recorded only from the chest and forearm. The thigh and calf thermistors were applied after PH to allow the calculation of Tₐ during exercise. The Tₑ and Tₘₛ measurements were used to calculate mean body temperature ( Tₑ; Burton 1935) and the thermal gradient (Tₑ–Tₐ) during each experiment. The rate of heat storage (HS; watts per metre squared) was calculated as previously described by Lee and Haymes (1995): HS = 0.97 mₒ (ΔTₑ/Δt)/ΔAₑ, where 0.97 is the specific heat capacity of body tissue (watts per kilogram), mₒ is body mass, ΔTₑ/Δt is the change (Δ) in Tₑ from the beginning to the end of exercise divided by the duration of exercise (Δt), and ΔAₑ is body surface area (metre squared) calculated according to Dubois and Dubois (1916).

Following this initial preparation, all subjects rested in a seated position for 30 min wearing shorts, socks and training shoes, to ensure standardisation of physiological parameters prior to all trials. Baseline values for Tₑ, heart rate (HR), oxygen uptake (VO₂), Tₘₛ, Tₐ and all blood borne substrates were recorded following the 30 min standardisation period.