

# **Prior Heat Stress: Effect on Subsequent 15-minute Time Trial Performance in the Heat**

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## **INTRODUCTION**

Workers and athletes must often perform in the heat after prior exposure to heat stress with some period of recovery. In addition, exercise scientists commonly employ prior exercise-heat stress to achieve dehydration and expose volunteers to the same stress while maintaining fluid intake for the control (euhydration). It is generally assumed that prior exercise-heat stress does not itself impact performance. However, it is uncertain (8) whether euhydrated performance following heat stress and recovery actually reflects a true baseline for comparison with dehydration.

Emerging data support the possibility that prior heat stress, despite recovery, might negatively impact subsequent tasks performed in the heat. During exercise-heat stress, Nybo and colleagues (10) demonstrated that cerebral blood flow velocity is reduced while Wilson and colleagues (12) also demonstrated that whole-body heating increases cerebral vascular resistance to an orthostatic challenge. When Carter et al. (1) examined both measures before and after exercise-heat stress, they observed that decreases in cerebral blood flow velocity and increases in cerebral vascular resistance persisted into recovery despite a return to normothermia. It is therefore possible that prior heat stress can have a residual, but pernicious impact on human physiology which could affect exercise performance (9; 11). At present, we are unaware of any investigation that has studied the impact of prior heat stress on aerobic time trial performance in the heat. Given this gap in the literature further investigation is warranted.

The purpose of the present study was to determine the effects of prior heat stress, despite recovery of body temperature, on aerobic time trial performance in the heat. We hypothesized that prior heat stress would degrade performance. The findings of this investigation have important implications not only for research methodology but for, labourers, athletes and military personnel who may work, train or compete in the heat with intermittent opportunities for rest and rehydration. Care was taken to carefully control for hydration status, time of day, and prior heat exposure (e.g., by using non-acclimatized subjects, using two groups, and comparing performance to temperate conditions).

## **METHODS**

**Subjects.** Two volunteer groups of nine men (total n=18), who were not heat acclimated, volunteered to participate in this investigation. Volunteers in both groups were tested in a euhydrated state, with one group being exposed to 50°C for three hours prior to testing (EUH<sub>PH</sub>) while the control group (EUH) was not exposed. Physical characteristics were (mean± SD): EUH, age, 23.2 ± 6.2 yr; mass, 77.1 ± 9.6 kg; BSA, 1.9 ± 0.1 m<sup>2</sup>; BMI, 24.5 ± 2.2 kg·m<sup>-2</sup>; and VO<sub>2peak</sub>, 45 ± 5 ml·kg<sup>-1</sup>·min<sup>-1</sup>; EUH<sub>PH</sub>, age, 23.2 ± 4.5 yr; mass, 88.3 ± 6.7 kg; BSA, 2.1 ± 0.1 m<sup>2</sup>; BMI 27.1 ± 2.1 kg·m<sup>-2</sup>; and VO<sub>2peak</sub>, 44 ± 7 ml·kg<sup>-1</sup>·min<sup>-1</sup>. Appropriate institutional review boards approved this study. Investigators adhered to policies for protection of human subjects as

prescribed in Army Regulations 70-25 and US Army Medical research and Materiel Command Regulation 70-25. The research was conducted in adherence with the provisions of 45 Code of Federal Regulations Part 46.

**Preliminary Procedures and Familiarization.** Two weeks of preliminary testing preceded the experimental trials. Peak power (Watts) and  $\text{VO}_{2\text{peak}}$  were measured using an incremental protocol on an electronically braked cycle ergometer (Lode Excalibur Sport, Lode, Groningen, The Netherlands) and a computer-based metabolic system with continuous gas exchange measurements (Parvo Medics, Inc., Sandy, UT). The cycle ergometer was used in the hyperbolic mode (pedal rate independent) for  $\text{VO}_{2\text{peak}}$  testing while volunteers maintained a constant cadence of  $60 \pm 5$  rpm to exhaustion. Briefly, volunteers began exercise at 40 W and the workload increased by 20 W every minute until the subject reached volitional exhaustion. During preliminary testing volunteers performed four familiarization sessions on the cycle ergometer in order to reduce training and learning effects (3). Each familiarization session took place in a  $22^\circ\text{C}$ , 20-30%rh environment and consisted of 30-min of steady-state cycling ( $50\% \text{VO}_{2\text{peak}}$ ), followed by a short rest break, then a 15-minute maximal performance time trial.

For five consecutive days during the second week of familiarization, volunteers consumed 2 L of sports drink after 6 PM. On each subsequent morning, volunteers provided a first morning urine sample and had a blood sample ( $< 5\text{ml}$ ) taken to measure plasma osmolality. In addition, nude body mass was measured before breakfast and after voiding. The five day measures of body mass, plasma osmolality and urine specific gravity were averaged to establish a reliable baseline to determine euhydration. On the day of testing, volunteers with a combination of any two urine specific gravity  $< 1.02$ , nude body mass within 1% of the five day average, or plasma osmolality  $< 290 \text{mOsmol}\cdot\text{kg}^{-1} \text{H}_2\text{O}$  were considered euhydrated (11).

**Experimental Design and Testing - Previous Heat Exposure.** On the morning of each trial, nude body mass, urine specific gravity and plasma osmolality were measured for comparison against the preceding week's 5-day average. Volunteers consumed a standardized breakfast of 540 kcals (16 g fat, 94 g carbohydrate, 8 g protein) and 250 mls of water. In  $\text{EUH}_{\text{PH}}$ , volunteers were instrumented for measurements of heart rate and core temperature before entering the environmental chamber set at  $50^\circ\text{C}$ ,  $\sim 20\%$  relative humidity,  $1.6 \text{m}\cdot\text{s}^{-1}$  air speed. In the EUH group, volunteers rested in a comfortable environment ( $\sim 22^\circ\text{C}$ ). Rectal temperatures were obtained from a telemetric temperature sensor (VitalSense Jonah™ Ingestible Capsule, Minimitter inc., Bend, OR) inserted 8-10 cm beyond the anal sphincter.

The  $\text{EUH}_{\text{PH}}$  group proceeded to walk on a treadmill at 3 mph at 3.5% grade for 30 minutes, followed by 30 minutes of seated rest. This work/rest cycle continued for the duration of the 3 hour dehydration protocol. Throughout the heat exposure, if core temperature reached  $39.5^\circ\text{C}$  walking was discontinued and volunteers sat in the chamber for the remaining duration of the exercise cycle. Sweat loss volume was determined from changes in body mass measured every 30-min. A 90 minute break followed heat exposure where volunteers showered and relaxed. The purpose of this break was to allow core temperature to return to pre-heat exposure levels (2). Following the break, nude body mass was again measured and this value was compared to the pre-heat exposure value. If body mass did not equal pre-heat exposure values, additional fluid was provided.

**Experimental Performance Testing.** Just prior to testing, group EUH was instrumented for measures of heart rate and core temperature as described for  $\text{EUH}_{\text{PH}}$  and these measures were continuously monitored and recorded during exercise. Upon entering the test environment set to  $40^\circ\text{C}$ , 20%rh, both EUH and  $\text{EUH}_{\text{PH}}$  volunteers began the experiment by cycling for 30 minute at

50%  $\text{VO}_{2\text{peak}}$ . A 10 minute break followed, after which a self-paced 15 minute cycling performance time trial was completed. The 30-minute exercise pre-load followed by a shorter time trial in this study was selected because: 1) it has ecological validity for comparison to the similar exercise duration and energy system requirements of the Army 2-mile run, and 2) it is a reliable performance test modality (5). During the steady-state ride, a pedal rate of  $60 \pm 5$  rpm was used because in novice cyclists, endurance has been shown to be maximized at lower pedal cadences (7). The Lode Linear Factor was individualized to elicit a 50%  $\text{VO}_{2\text{peak}}$  workload for each volunteer at this cadence. During the 15 minute time trial volunteers were blinded to all test parameters except time. Exercise heart rates and core temperatures were measured by automated means to limit distractions.

Performance was assessed as the total amount of work completed (kilojoules) in 15 minutes. Although cycling is a body mass independent exercise modality, performance relative to body mass ( $\text{kJ}\cdot\text{kg}^{-1}$ ) was also examined due to the larger body mass of group  $\text{EUH}_{\text{PH}}$ . The percent change in performance relative to the best practice trial at  $22^\circ\text{C}$  was also calculated for comparison between EUH and  $\text{EUH}_{\text{PH}}$  as another way of evaluating the effects of heat stress and residual heat stress on performance.

**Statistical Analysis.** The primary outcome variable of interest in this experiment was time trial performance. Group performances were compared using an independent samples t-test, as were other variables of interest at single time points. A mixed model two-factor ANOVA with repeated measures on the second factor was used to make all group x time comparisons. F-values were adjusted for sphericity where appropriate and main or interaction effects were investigated by Newman-Keuls post-hoc test. An analysis selecting conventional  $\alpha$  (0.05) and  $\beta$  (0.20) parameters showed that 8 subjects in each group would provide sufficient power to detect a 10% difference in time trial performance between groups. This estimate was made using the mean total work ( $\sim 175$  kJ) and coefficient of variation ( $\text{CV} = 5\%$ ) calculated from trials of negligible difference during two weeks of time trial practice. The desire to detect a two-fold change from the %CV was chosen based on the likelihood of experimental perturbations producing unique performance infidelity (4). Graphical data are presented with unidirectional error bars for clarity of presentation. All data are presented as means  $\pm$  SD.

## RESULTS

In both the EUH and  $\text{EUH}_{\text{PH}}$  trials, volunteers were euhydrated prior to the start of testing, body mass was within 1% of the 5-day average, urine specific gravity was below 1.020 and plasma osmolality was  $<290$   $\text{mOsm}\cdot\text{kg}^{-1}$ . In the  $\text{EUH}_{\text{PH}}$  trial body mass did not significantly change from pre-heat exposure to pre-experimental testing, as sweat losses were matched with fluid intake ( $3.5 \pm .05$  L; Table 1).

Table 1. Experiment 1 Selected pre-heat exposure and pre-experimental testing variables.

	<b>EUH</b>	<b><math>\text{EUH}_{\text{PH}}</math></b>
Pre-heat exposure initial body weight (kg)	$77.3 \pm 9.3$	$89.0 \pm 7.3^*$
Pre-experimental testing body weight (kg)	$77.8 \pm 8.9$	$89.1 \pm 7.3^*$
Pre-experimental testing urine specific gravity	$1.016 \pm 0.006$	$1.016 \pm 0.004$
Pre-experimental testing plasma osmolality ( $\text{mOsm}\cdot\text{kg}^{-1}$ )	$289.0 \pm 4.0$	$288.0 \pm 4.0$

\* denotes significant difference ( $p < 0.05$ ) from EUH.

Total accumulated work was not different ( $p > 0.05$ ) between the EUH ( $150.5 \pm 28.3$  kJ) and  $\text{EUH}_{\text{PH}}$  ( $160.3 \pm 24.0$  kJ) trials. Expressed relative to body mass to control for group differences

in absolute  $\text{VO}_{2\text{peak}}$ , differences were even smaller at  $1.96 \text{ kJ}\cdot\text{kg}^{-1}$  (EUH) and  $1.82 \text{ kJ}\cdot\text{kg}^{-1}$  (EUH<sub>PH</sub>). The percent change in time trial performance relative to the best 15-minute practice time trial in  $\sim 22^\circ\text{C}$ , 20% rh during familiarization was also not different ( $p > 0.05$ ) between the EUH ( $18.7 \pm 9.2\%$ ; 95% CI 12.7-24.7) and the EUH<sub>PH</sub> ( $15.0 \pm 7.8\%$ ; 95% CI 9.9-20.1) trials. As there was no difference between the percent change in time trial performance between the EUH and EUH<sub>PH</sub> trials, they were collapsed and compared relative to the best 15-min performance time trial in  $\sim 22^\circ\text{C}$ . This percent change in performance between the combined EUH and EUH<sub>PH</sub> trials in  $40^\circ\text{C}$  trials vs. those in the  $22^\circ\text{C}$  trials was  $16.9 \pm 8.5\%$ . Figure 1 depicts the percentage decrease in time trial performances in  $40^\circ\text{C}$  compared to best training values observed in  $22^\circ\text{C}$ . The shaded region represents within-subjects CV (5%) during training.

Figure 1.

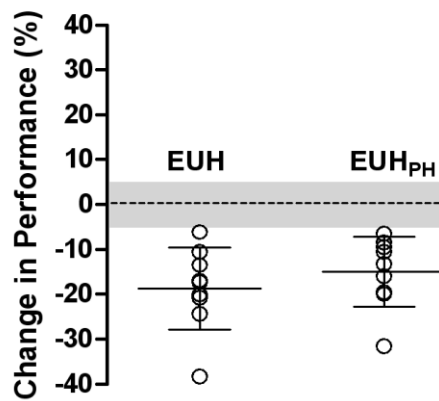
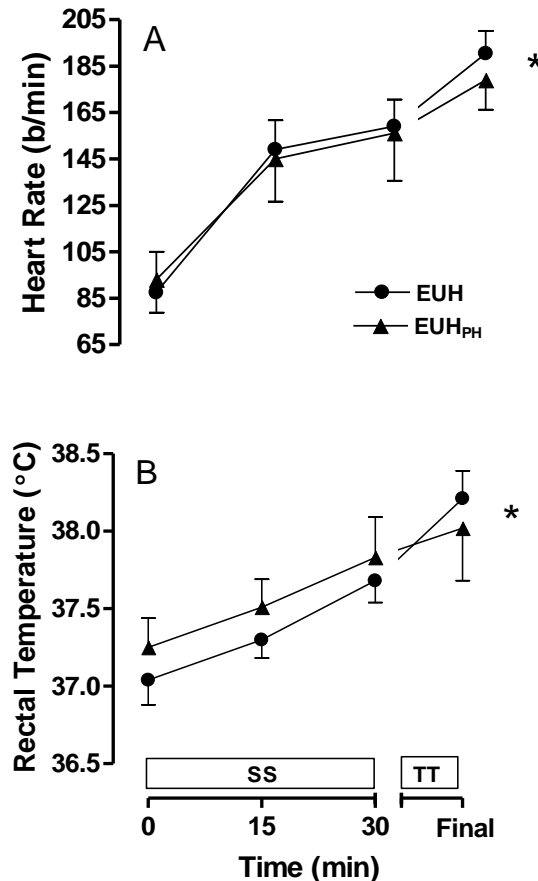


Figure 2 A and B.



During heat exposure core temperature for the EUH<sub>PH</sub> group increased from pre- ( $37.0 \pm 0.3^\circ\text{C}$ ) to post ( $38.25 \pm 0.5^\circ\text{C}$ ) heat exposure, but returned to baseline ( $37.2 \pm 0.2^\circ\text{C}$ ,  $p > 0.05$ ) before the start of experimental testing. Heart rates and core temperatures were not different ( $p > 0.05$ ) during the steady-state or performance time trial rides between the EUH and EUH<sub>PH</sub> trials. However, there was a significant main effect for time ( $p < 0.05$ ) where both heart rate and core temperature increased during exercise (0, 15, 30 min and end of performance time trial; Figure 2 A and B). Ratings of perceived exertion were also similar during steady-state and not different ( $p < 0.05$ ) between the EUH ( $18.2 \pm 1.3$ ) and EUH<sub>PH</sub> ( $19.0 \pm 1.5$ ) trials at the end of the aerobic time trial. Figure 2 depicts heart rate (A) and rectal temperature (B) responses to exercise with (EUH<sub>PH</sub>) and without (EUH) prior heat exposure. (A) Main effect of time where \* = progressive differences across all time points (Final > 30 > 15 > 0 min). (B) Main effect of time where \* = progressive differences across all time points (Final > 30 > 15 > 0 min). All notations are significantly different at  $P < 0.05$ . SS = steady-state exercise; TT = time trial.

## CONCLUSIONS

These findings may also afford important insight for workplace settings where individuals may work in the heat, rest, and then resume work in the heat. In addition the findings of the present study are important as many research protocols employ these very same methods when studying the effects of body water deficits on human physiology. However, any application of these findings must take into consideration adequate recovery of body core temperature and hydration state. In the present study, volunteers were given a 90 minute break out of the heat, where they showered and any fluids lost were replaced in order to maintain euhydration. During this time period, heart rate and core temperatures nearly recovered to pre-heat stress levels. It is likely that if dehydration of  $>2\%$  was not corrected or if body core temperature was not allowed to recover, greater performance decrements would occur (6) during subsequent aerobic exercise.

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