THE EFFECT OF MODERATE EXERCISE ON THE THERMOREGULATORY THRESHOLD FOR SWEATING

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INTRODUCTION

We previously demonstrated a prolonged (65 min or longer) post-exercise elevated plateau of esophageal temperature (T_{es}) (0.5-0.6 "C above pre-exercise values) in humans following moderate exercise at different ambient temperatures (1). In addition, the plateau value was equal to the threshold T_{es} at which active skin vasodilation was initiated during exercise (Th_{dil}). The post-exercise elevation was not of a metabolic origin as oxygen consumption returned to baseline **values** within 5-10 min of exercise termination. Skin blood flow and temperatures (T_{sk}) at all sites, except over the exercised muscle, also decreased back to control **values** within 10-15 min post-exercise despite the sustained increase in T_{es}. The reduction of T_{sk} and **skin** blood flow throughout the prolonged elevated plateau in T_{es} is consistent with a sustained exercise-induced increase of the active vasodilation threshold (2) which persists during recovery.

The post-exercise elevations in T_{es} and Th_{dil} could be a function of either: a) some residual exercise-related factors which have thermal effects: (I.e., metabolic factors, plasma osmolarity, central modulators and pyrogenic factors); or b) the significant elevation of whole body heat content itself. In a previous effort to address the latter mechanism we immersed subjects in **warm** water (**42** "C) **until** T_{es} increased to levels similar to those induced by 15 min of moderate exercise **(3).** Following exit from the warm water, T_{es} rapidly returned to control values within 10 min of recovery. Therefore the post-exercise increase in T_{es} does not **seem** to be solely a consequence of increased whole body heat content. **A** subsequent observation, that successive exercise/recovery cycles **performed** at progressively increasing pre-exercise T_{es} resulted in further and parallel increases of Th_{dil} during exercise and the post-exercise plateau in T_{es} (4), further supports an exercise-related effect on the warm thermoregulatory response of active cutaneous vasodilation.

It is unclear if this exercise-related effect is limited to the warm thermoregulatory response of active cutaneous vasodilation or if an effect on the sweating response also occurs. The core temperature threshold for sweating (Th_{sw}) has been reported to increase (2), decrease (5,6), or remain unchanged **(7)** from baseline during exercise, with no change reported in recovery in a protocol which includes a **state** of hyperhydration *(5).* Since hyperhydration may itself decrease Th_{sw} (8), the present study evaluates the hypothesis that Th_{sw} decreases during moderate exercise but that some residual exercise-related factor(s) actually increases the subsequent post-exercise Th_{sw}.

METHODS

Four males and 3 females participated in the study. They were physically active but not regularly engaging in competitive athletics or following a specific physical exercise routine.

Esophageal temperature was monitored as an index of core temperature. Skin temperature was monitored at 9 sites and the area-weighted mean was calculated by assigning the following regional percentages: head 6%, upper arms 9%, forearms 9%, fingers 2%, back 22%, chest 11%, abdomen 11%, anterior thigh 17%, posterior calf 13%. Heart rate was monitored continuously. Oxygen consumption was determined by an open circuit method, sweat rate was measured using a ventilated capsule (–5.0 x 3.5 cm) placed on the forehead, and fingertip blood flow was measured by a modified pulse oximeter.

All experimental trials were conducted in the morning. Baseline data were collected over 30 min at an ambient temperature (T_a) of 24 °C. The subjects were then immersed to the clavicles in 42 °C water (W1) until 3-5 min following initiation of sweating. Subjects then rested (–20-35 min) in air (T_a = 24 °C) until T_{es}, T_{sk} and finger tip blood flow returned to baseline. Subjects exercised on a cycle ergometer (11 METS) for fifteen min (Ex) and then rested for 30 min. This time period was sufficient to ensure that T_{sk} and finger tip blood flow returned to baseline in all subjects (1,3,4). Subjects were immersed a second time in 42 °C water (W2) until 3-5 min following initiation of sweating.

The sweating threshold (Th_{sw}) was defined as the onset of a sustained and continuous increase in sweat rate above 50 $g \cdot m^{-2} \cdot h^{-1}$ (5). In order to compare thresholds between conditions in which both T_{sk} and T_{es} were changing, the following equation (9) was used to calculate core temperature thresholds at a single designated skin temperature:

$$T_{core(calculated)} = T_{es} + (\beta/1-\beta)(T_{sk}-T_{skin(designated)});$$

$T_{skin(designated)}$ was set as the mean T_{sk} of W1 and W2 conditions (i.e. 36.5 °C) and β = fractional contribution of T_{sk} to the sweating response (β = 0.1) (10).

Sweating thresholds for the three conditions were compared using repeated-measures ANOVA and Scheffé's F-test.

RESULTS

First water immersion (W1)

Baseline T_{es} and T_{sk} were 36.96 ± 0.1 °C and 32.25 ± 0.3 °C respectively. Upon immersion in 42 °C water there was a transient decrease of 0.15 °C followed by a steady increase to 37.28 "C at the end of immersion (average immersion time was 17.2 rnin). On average, sweating onset occurred 9.8 rnin after immersion at T, of 37.04 4 0.1 °C (Table 1). Calculated T, at the threshold was 37.07 ± 0.1 "C. During recovery T_{es} decreased to 37.11°C within 20 rnin and remained constant for the last 10 rnin of recovery. Recovery T_{es} was not significantly different from baseline. T_{sk} and finger blood flow returned to baseline values within 15-20 min of recovery.

Exercise (Ex)

Upon initiation of exercise T_{es} increased at a rate of 0.16 °C·min^{-1} during the first 7.5 min afterwhich T, either remained stable or rose only slightly reaching an end-exercise temperature of 38.01 ± 0.2 "C. Sweating onset occurred at 37.30 ± 0.1 °C. The calculated T_{core} at the threshold (36.69 ± 0.2°C) was lower than during W1 ($p<0.05$). Following exercise termination T_{es} decreased from 38.01 °C to 37.44 °C within 15 rnin with only a slight further decrease to 37.39 "C at 30 min. This plateau **was** significantly higher than the pre-exercise value ($p<0.05$). T_{sk} and finger tip blood flow returned to baseline values by the 25 th rnin of the 30 min recovery.

Second water immersion (W2)

Upon immersion in 42 "C water, T_{es} transiently decreased by 0.07 °C followed by a steady increase to 37.43 ± 0.1 "C at the end of immersion (llmin). Sweating onset occurred 7.2 rnin after immersion at T_{es} of 37.34 ± 0.1 °C. The calculated T_{core} at the threshold (37.33 ± 0.1 "C) was greater than both W1 ($p<0.05$) and Ex ($p<0.01$).

Table 1. Temperatures at sweating thresholds.

	Baseline	Pre-exercise Immersion	Exercise	Post-exercise Immersion
Mean T_{sk} ("C)	32.25±0.3	36.76± 0.2	30.93± 0.3*	36.38±0.2†
Actual T_{es} ("C)	36.96±0.1	37.04± 0.1	37.30± 0.1*	37.34±0.1*
$T_{core(calculated)}$ ("C)	36.4950.1	37.07± 0.1	36.692 0.2*	**37.33±0.1*†**

(mean ± **SD, $T_{core(calculated)}$ at T_{sk}=36.5 °C, *> Immersion A. †> Exercise, $p<0.05$)**

CONCLUSION

Compared to pre-exercise conditions, there was a 0.38 °C decrease in Th, during exercise **and a** subsequent 0.26 "C increase during recovery. The reduced Th, during exercise is in agreement with previous studies (5.6). Although Lopez et al, (5) found a decreased Th_{sw} during exercise, their post-exercise Th, was not elevated above pre-exercise values. During their study however, subjects were infused with 3-5 *l* of fluid over 2.5 hr. Since hyperhydration itself has **been** shown to lower Th, (8), our different post-exercise results are not surprising. We conclude that some residual exercise-related factor(s) increase the post-exercise sweating threshold.

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