

# 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  $T_{sk}$  at which active skin vasodilation was initiated during exercise ( $Th_{sk}$ ). 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  $Th_{sk}$  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  $Th_{sk}$  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  $gm^{-2}h^{-1}$  (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  $\beta$  = fractional contribution of  $T_{sk}$  to the sweating response ( $\beta = 0.1$ ) (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  $36.96 \pm 0.1$  °C and  $32.25 \pm 0.3$  °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 min). On average, sweating onset occurred 9.8 min after immersion at  $T_{es}$  of  $37.04 \pm 0.1$  °C (Table 1). Calculated  $T_{core}$  at the threshold was  $37.07 \pm 0.1$  °C. During recovery  $T_{es}$  decreased to 37.11°C within 20 min and remained constant for the last 10 min 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<sup>-1</sup> during the first 7.5 min after which  $T_{es}$  either remained stable or rose only slightly reaching an end-exercise temperature of  $38.01 \pm 0.2$  °C. Sweating onset occurred at  $37.30 \pm 0.1$  °C. The calculated  $T_{core}$  at the threshold ( $36.69 \pm 0.2$ °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 min 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 min 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  $37.43 \pm 0.1$  °C at the end of immersion (11min). Sweating onset occurred 7.2 min after immersion at  $T_{es}$  of  $37.34 \pm 0.1$  °C. The calculated  $T_{core}$  at the threshold ( $37.33 \pm 0.1$  °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)	36.49±0.1	37.07± 0.1	36.69± 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  $T_{hw}$  during exercise and a subsequent 0.26 °C increase during recovery. The reduced  $T_{hw}$  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  $Th_{sw}$  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  $Th_{sw}$  (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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Support: NSERC, MHRC and Augustine Med. Inc.