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 ($T_e$) (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 $T_a$ at which active skin vasodilation was initiated during exercise ($Th_{dl}$). 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 ($T_J$) 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 $T_e$. The reduction of $T_a$ and skin blood flow throughout the prolonged elevated plateau in $T_e$ is consistent with a sustained exercise-induced increase of the active vasodilation threshold (2) which persists during recovery.

The post-exercise elevations in $T_e$ and $Th_{dl}$ 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 $T_e$ increased to levels similar to those induced by 15 min of moderate exercise (3). Following exit from the warm water, $T_e$ rapidly returned to control values within 10 min of recovery. Therefore the post-exercise increase in $T_e$ 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 $T_e$ resulted in further and parallel increases of $Th_{dl}$ during exercise and the post-exercise plateau in $T_e$ (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 ($Th_w$) 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 $\text{Th}_{ew}$ (8), the present study evaluates the hypothesis that $\text{Th}_{ew}$ decreases during moderate exercise but that some residual exercise-related factor(s) actually increases the subsequent post-exercise $\text{Th}_{ew}$.

**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 $T_{ew}$, $T_{sk}$ 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 ($\text{Th}_{ew}$) 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 $T_{ew}$ were changing, the following equation (9) was used to calculate core temperature thresholds at a single designated skin temperature:

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

$T_{sk\text{(designated)}}$ 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 $T_{ew}$ 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 min). On average, sweating onset occurred 9.8 min after immersion at $T_s$ of 37.04 ± 0.1 °C (Table 1). Calculated $T_{core}$ at the threshold was 37.07 ± 0.1 °C. During recovery $T_s$ decreased to 37.11 °C within 20 min and remained constant for the last 10 min of recovery. Recovery $T_s$ was not significantly different from baseline. $T_s$ and finger blood flow returned to baseline values within 15-20 min of recovery.

**Exercise (Ex)**

Upon initiation of exercise $T_s$ increased at a rate of 0.16 °C·min$^{-1}$ during the first 7.5 min after which $T_s$ 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 $T_s$ 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). $T_s$ and finger tip blood flow returned to baseline values by the 25th min of the 30 min recovery.

**Second water immersion (W2)**

Upon immersion in 42 °C water, $T_s$ transiently decreased by 0.07 °C followed by a steady increase to 37.43 ± 0.1 °C at the end of immersion (11 min). Sweating onset occurred 7.2 min after immersion at $T_s$ 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.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Pre-exercise Immersion</th>
<th>Exercise</th>
<th>Post-exercise Immersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean $T_s$ (°C)</td>
<td>32.25±0.3</td>
<td>36.76±0.2</td>
<td>30.93±0.3*</td>
<td>36.38±0.2†</td>
</tr>
<tr>
<td>Actual $T_s$ (°C)</td>
<td>36.96±0.1</td>
<td>37.04±0.1</td>
<td>37.30±0.1*</td>
<td>37.34±0.1*</td>
</tr>
<tr>
<td>$T_{core\text{calculated}}$ (°C)</td>
<td>36.49±0.1</td>
<td>37.07±0.1</td>
<td>36.69±0.2*</td>
<td>37.33±0.1*†</td>
</tr>
</tbody>
</table>

(means ± SD, $T_{core\text{calculated}}$ at $T_s$=36.5 °C, * > Immersion A, †> Exercise, p<0.05)

**CONCLUSION**

Compared to pre-exercise conditions, there was a 0.38 °C decrease in $T_{th}$ during exercise and a subsequent 0.26 °C increase during recovery. The reduced $T_{th}$ during exercise is in agreement with previous studies (5,6). Although Lopez
et al. (5) found a decreased $T_{thw}$ during exercise, their post-exercise $T_{thw}$ 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 $T_{thw}$ (8), our different post-exercise results are not surprising. We conclude that some residual exercise-related factor(s) increase the post-exercise sweating threshold.

REFERENCES


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