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 \( (T_u) \) at which active skin vasodilation was initiated during exercise \( (T_{thd}) \). 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 \( (T_a) \) 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 \( T_u \). The reduction of \( T_{sk} \) and skin blood flow throughout the prolonged elevated plateau in \( T_u \) is consistent with a sustained exercise-induced increase of the active vasodilation threshold (2) which persists during recovery.

The post-exercise elevations in \( T_u \) and \( T_{thd} \) could be a function of either: a) some residual exercise-related factors which have thermal effects: (Le., 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 \( T_u \) increased to levels similar to those induced by 15 min of moderate exercise (3). Following exit from the warm water, \( T_u \) rapidly returned to control values within 10 min of recovery. Therefore the post-exercise increase in \( T_u \) 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 \( T_u \) resulted in further and parallel increases of \( T_{thd} \) during exercise and the post-exercise plateau in \( T_u \) (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 \( (T_{thw}) \) 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 \( \text{Th}_\text{x} \) \((8)\), the present study evaluates the hypothesis that \( \text{Th}_\text{x} \) decreases during moderate exercise but that some residual exercise-related factor(s) actually increases the subsequent post-exercise \( \text{Th}_\text{x} \).

**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 males 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 \((T_i = 24 °C)\) until \(T_s\), \(T_k\) and finger tip blood flow returned to baseline. Subjects exercised on a cycle ergometer (11 METS) for 15 min \((\text{Ex})\) and then rested for 30 min. This time period was sufficient to ensure that \(T^*\) 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 \((T_{sw})\) was defined as the onset of a sustained and continuous increase in sweat rate above 50 g m\(^{-2}\)h\(^{-1}\) \((5)\). In order to compare thresholds between conditions in which both \(T_s\) and \(T\) were changing, the following equation \((9)\) was used to calculate core temperature thresholds at a single designated skin temperature:

\[
T_{\text{core (calculated)}} = T_s + (\beta/1-\beta)(T_{sk (designated)} - T_{sk (designated)});
\]

\(T_{sk (designated)}\) 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 \(T_s\) and \(T_k\) 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, of 37.04 ± 0.1 °C (Table 1). Calculated T, at the threshold was 37.07 ± 0.1 °C. During recovery T, decreased to 37.11 °C within 20 min and remained constant for the last 10 min of recovery. Recovery T, was not significantly different from baseline. T, and finger blood flow returned to baseline values within 15-20 min of recovery.

Exercise (Ex)

Upon initiation of exercise T, increased at a rate of 0.16 °C/min during the first 7.5 min after which 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, at the threshold (36.69 ± 0.2 °C) was lower than during W1 (p<0.05). Following exercise termination T, 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, 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, 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, of 37.34 ± 0.1 °C. The calculated T, 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, (°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, (°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, (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>

(mean ± SD, T, (calculated) at T,=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 $Th_{th}$ 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.

REFERENCES


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