THE EFFECT OF MODERATE EXERCISE ON THE THERMOREGULATORY THRESHOLDS FOR VASOCONSTRICTION AND SHIVERING

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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) following moderate exercise (1). **In** addition, the plateau value was equal to the threshold T, 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,. The reduction of T_{sk} and skin blood flow, throughout the prolonged elevated plateau in T,, is consistent with a sustained exercise-induced increase of the active vasodilation threshold (2) which persists during recovery.

The post-exercise elevation in T, and Th_{dil} are not a result of the exercise-induced elevation of whole body heat content. When subjects were immersed in 42 "C water until T, increased, to levels similar to those induced by 15 min of moderate exercise, T, rapidly returned to control values within 10 min of recovery **(3).**

We have recently studied the effects of moderate exercise on another warm thermoregulatory response **(i.e.,** sweating). Although the sweating threshold decreased during exercise, it actually increased post-exercise **(4).** Although our combined data indicate that residual exercise-related factors cause a post-exercise increase in both the vasodilation and sweating thresholds (i.e., warm responses), it is not known if there are parallel effects on cold thermoregulatory responses.

This knowledge may have practical implications for the interpretation of thermoregulation studies in which exercise is used to manipulate core temperature (5,6). The present study evaluates the hypothesis that the vasoconstriction and shivering thresholds are increased post-exercise.

METHODS

Five males and 2 females (71.4 ± 2.3 Kg, 177.3 ± 4.4 cm) participated in the study.

Esophageal temperature was monitored as an index of core temperature. Skin temperature was monitored at 15 sites and the area-weighted mean was calculated by assigning the following regional percentages: head 6%, upper arm 9%, forearm 6%, hand 2.5%, finger 2%, chest 9.5%, abdomen 9.5%, upper back 9.5%, lower back 9.5%, anterior thigh 9.5%, posterior thigh 9.5%, anterior calf 7.5%, posterior calf 6.0%, foot 4%.

Heart rate was monitored continuously. Oxygen consumption was determined by an open circuit method 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 37.6 °C water where they rested until cutaneous vasodilation occurred (6.5-25 min). Water-temperature was then decreased by 6.0 $°C \cdot hr^{-1}$ (C1) until vasoconstriction (17-42 min) and vigorous shivering (42-91 min) occurred. Water temperature was then gradually returned to 37.6 °C (7-25 min). Subjects then exited the water, were towel dried, and sat in air (T_a = 24 °C) until T_{es}, T_{sk} and finger tip blood flow returned to baseline (6-22 min). Subjects then exercised on a cycle ergometer (10.5 METS) for fifteen min (EX). They then rested for 30 min during which an elevated plateau in T_{es} was established. Subjects were immersed a second time in 37.6 °C water where they again rested until cutaneous vasodilation occurred (1-30 min). Water temperature was then cooled gradually (6.0 $°C \cdot hr^{-1}$) (C2) until vasoconstriction (11-47 min) and vigorous shivering (30-96 min) occurred.

The vasoconstriction threshold (Th_{vc}) was defined as a decrease in fingertip blood flow from a sustained elevated value. The shivering threshold (Th_{sh}) was defined as a sustained 40% increase in oxygen consumption above the baseline level (7). In order to compare thresholds between conditions in which both T_{sk} and T_{es} were changing, the following equation (7) 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 C1 and C2 conditions (i.e. 33.0 °C) and β = fractional contribution of T_{sk} to the vasoconstriction and shivering responses (β = 0.2) (8).

RESULTS

First cooling period (Cl)

Baseline T, and T_{sk} were 37.05 L- 0.32 ''C and 31.15 L- 0.41 ''C respectively. T, during warm-water immersion (37.6 ''C) remained stable (37.06 ± 0.41 ''C) while T_{sk} increased to 35.86 If: 0.41 °C. T, and T_{sk} decreased at a rate of 0.23 ± 0.06 °C· hr^{-1} and 4.52 ± 0.22 °C· hr^{-1} respectively during the cooling phase (C1). On average, vasoconstriction and shivering onset occurred successively at 29 and 68 min following initiation of cooling. T_{es} was 37.01 L- 0.30 °C and 36.86 ± 0.24°C at vasoconstriction and shivering thresholds respectively (Table 1). Calculated T_{core} at the threshold for vasoconstriction and shivering were 37.20 ± 0.37 °C and 36.32 ± 0.48 °C respectively. During the subsequent rewarming of the bath to 37.6°C (7-25 rnin), T, decreased subsequently to 36.67°C while T_{sk} increased from 29.56 ± 0.30 ''C to 34.77 L- 0.30 ''C. Within an average of 15 rnin of exiting the water bath, T_{es} and T_{sk} returned to near baseline (36.93 and 30.55 °C respectively) values.

Exercise (Ex)

T_{es} rose to an end-exercise value of 38.12 ± 0.40 ''C. Following exercise termination T, decreased to 37.58 ''C within 20 rnin with only a slight further decrease to 37.52 °C after 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 within 10-15 rnin of the 30 rnin recovery period.

Second cooling period (C2)

Upon immersion in 37.6 ''C water, T_{es} transiently increased by 0.1 °C (–15 min) followed by a steady decrease to 36.88 ± 0.30 ''C at the end of cooling (–90 min) (C2). Vasoconstriction and shivering onset occurred successively, 30 and 66 min following initiation of cooling, at T, of 37.13 ± 0.23 ''C and 37.04 ± 0.20 °C. The calculated T_{core} at vasoconstriction (37.34 L- 0.37 ''C) and shivering (36.50 ± 0.37°C) thresholds in C2 were greater than during C1 ($p<0.05$).

Table 1. Temperatures at vasoconstriction and shivering thresholds.

	Baseline	Vasoconstriction Thresholds		Shivering Thresholds	
		Pre-Ex	Post-Ex	Pre-Ex	Post-Ex
Mean T_{sk} (''C)	**31.15M.4**	33.94fo.5	33.88M.6	30.86±1.2	30.86±1.6
Actual T_{es} (''C)	37.05±0.3	37.01M.3	37.13±0.2*	36.86±0.2	37.04±0.2*
$T_{core(calculated)}$ (°C)	36.59±0.1	37.20M.4	37.34±0.4*	36.32M.5	36.50±0.4*

(mean± SD, $T_{core(calculated)}$ at T_{sk}=33.0 °C, * >first cooling (C1), $p<0.05$)

CONCLUSION

Compared to pie-exercise values **(C1)**, there was a **0.14** °C and **0.18** °C increase in vasoconstriction and shivering thresholds respectively. The mean time of onset for vasoconstriction and shivering, pre- and post-exercise respectively were similar **(29** and 30 min for vasoconstriction, **68** and **66** min for shivering). There was no effect of exercise on the rate of cooling in T_{es} or T_{sk} during C2. The cooling rate for T_{es} was **0.23 °C· hr^{-1}** for both conditions. The cooling rate for T_{sk} was **4.52 °C· hr^{-1}** and **4.69 °C· hr^{-1}** for C1 and C2 respectively. These **data** demonstrate that a moderate exercise bout increases the subsequent post-exercise threshold for both cold thermoregulatory responses without a measurable change in core-to-skin and skin-to-environment thermal conductivity. We conclude that some residual exercise-related factor(s) increase the post-exercise vasoconstriction and shivering thresholds.

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