

ROLE OF EXTERNAL WORK IN THE CUTANEOUS VASODILATOR RESPONSE TO EXERCISE IN HEAT-STRESSED HUMANS

J. Smolander, J.M. Johnson, W.A. Kosiba, M.K. Park

Department of Physiology, Finnish Institute of Occupational Health, Laajaniityntie 1, FIN-01620 Vantaa, Finland

Department of Physiology, The University of Texas Health Science Center at San Antonio, San Antonio, TX 78284, USA

INTRODUCTION

During dynamic exercise skin blood flow increases in linear relation to the rise in core temperature (T_c), modified by skin temperature. The skin blood flow/ T_c relationship is also affected by "exercise-related reflexes". For example, skin blood flow at a given level of T_c is lower during exercise than in heat-stressed resting subjects (1). Also, above a certain exercise intensity the T_c -threshold for skin vasodilation is increased (2,3), whereas the gain of the response is unaffected.

During exercise in a hot environment skin blood flow often reaches a plateau or an upper limit despite of a rise in T_c (4,5). This upper limit is not representative of maximal vasodilation of skin, as the level is well below that typically seen with hyperthermia at rest. Further, local warming of the skin will further vasodilate skin from the apparent upper limit (4). The upper limit is probably related to blood pressure regulation (6), and to a reduced active vasodilator activity instead of an increased vasoconstrictor activity (7).

The aim of our study was to examine the role of work load on skin blood flow vasodilator response to exercise, especially on the upper limit, in heat-stressed humans.

MATERIALS and METHODS

Four young, healthy men volunteered for the study. The experiments included 17-30 min exercise tests on a cycle ergometer: one with a "high" work load (100-175 W), and one with a "low" work load (50-75 W). Skin temperature was clamped at 37-38 °C with a water-perfused suit (2). The suit covered the entire body with the exception of the head, arms, and feet. The exercise tests were followed by a 5 min period of very light exercise (25 W), and a rest period during which the suit was gradually cooled. Room temperature was 22-24 °C. The study procedures followed the Helsinki declaration.

During the tests, esophageal temperature (T_{es}), heart rate, and mean arterial pressure were continuously measured. As an index of skin blood flow, forearm blood flow (FBF) was measured three times per minute by venous occlusion plethysmography. Forearm vascular conductance (FVC) was calculated by dividing FBF by mean arterial pressure.

Student's t-test for paired observations was used in the statistical analysis.

RESULTS

At the end of exercise at "low" work load, heart rate and T_{es} averaged 115 ± 4 beats/min and 37.59 ± 0.05 °C, respectively. At the "high" work load, the corresponding figures were 155 ± 6 beats/min ($p < 0.01$) and 38.33 ± 0.29 °C ($p < 0.05$).

Throughout the exercise at "high" work load FBF and FVC were significantly lower at a given T_{es} as compared to the "low" work load. At the end of exercise FBF was 17.7 ± 5.1 ml/100ml/min at the "low" work load and 15.0 ± 3.9 ml/100ml/min at the "high" work load. One subject's FVC/ T_{es} -relationship is shown in Fig. 1, and the average results of FVC are shown in Fig. 2. At the "high" work load, an upper limit of FVC was observed in three subjects, and an attenuated rise in one. At the "low" work load, an upper limit of FVC was seen in two subjects, whereas no deviation from a linear response occurred in the other two.

After transition to the 25 W work load and to rest, T_{es} did not change significantly as compared to the end of exercise (Table 1). However, at the "low" work load a significant increase occurred in FVC after transition to the 25 W work load, whereas at the "high" work load the rise did not occur until after transition to the rest period.

CONCLUSIONS

1. A "high" work load, as compared to the "low" work load, reduced the skin vasodilator response to the rising core temperature including the upper limit.
2. Transition to 25 W work load and to rest increased the skin blood flow while T_{es} was unaltered. This increase in skin blood flow occurred later after the "high" work load as compared to the "low" work load.
3. The effect of work load on the control of cutaneous circulation during exercise under heat stress is probably related to the maintenance of arterial pressure and muscle perfusion.

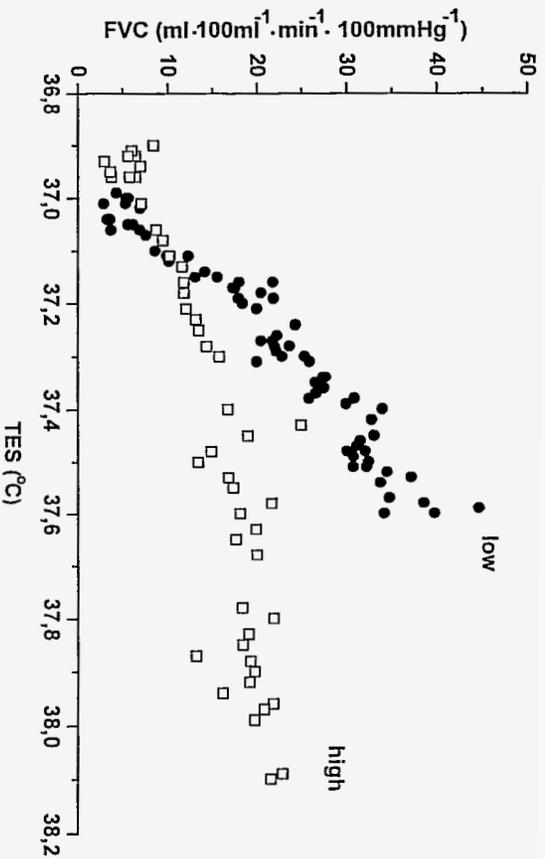


Figure 1. One subject's response of forearm vascular conductance to the rising esophageal temperature (T_{es}) during exercise at a "low" and a "high" work load. Skin temperature was clamped at around 38 °C with a water-perfused suit.

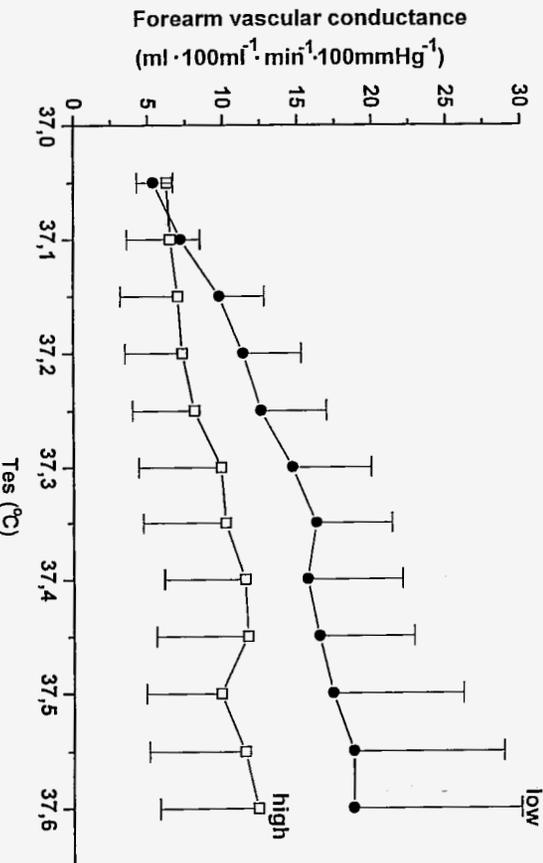


Figure 2. The average forearm vascular conductance response to the rising esophageal temperature (T_{es}) during exercise at a "low" and a "high" work load. Skin temperature was clamped at around 38 °C with a water perfused suit. Mean \pm SEM.

Table 1. Three minute averages of esophageal temperature (T_{es}) and forearm vascular conductance (FVC in $\text{ml} \cdot 100 \text{ ml}^{-1} \cdot \text{min}^{-1} 100 \text{ mmHg}^{-1}$)

Variable	End of the load	After transition to 25 W	Rest after exercise
T_{es} ($^{\circ}\text{C}$)	37.59 ± 0.05	<u>" " ad</u> 37.61 ± 0.07	37.57 ± 0.06
FVC	21.9 ± 6.1	$23.2 \pm 6.3^*$	21.2 ± 5.2
T_{es} ($^{\circ}\text{C}$)	38.33 ± 0.29	<u>"high" ad</u> 38.44 ± 0.30	38.28 ± 0.29
FVC	15.1 ± 4.0	16.4 ± 3.7	$18.8 \pm 4.2^*$

* $p < 0.05$

REFERENCES

1. Johnson, J.M., Rowell, L.B. and Brengelmann, G.L. 1974, Modification of the skin blood flow - body temperature relationship by upright exercise. *Journal of Applied Physiology*, 37, 880-886.
2. Taylor, W.F., Johnson, J.M., Kosiba, W.A. and Kwan, C.M. 1988, Graded cutaneous vascular responses to dynamic leg exercise. *Journal of Applied Physiology*, 64, 1803-1809.
3. Smolander, J., Saalo, J. and Korhonen, O. 1991, Effect of work load on cutaneous vascular response to exercise. *Journal of Applied Physiology*, 71, 1614-1619.
4. Brengelmann, G.L., Johnson, J.M., Hermansen, L. and Rowell, L.B. 1977, Altered control of skin blood flow during exercise at high internal temperatures. *Journal of Applied Physiology*, 43, 790-794.
5. Smolander, J., Kolari, P., Korhonen, O. and Ilmarinen, R. 1987, Skin blood flow during incremental exercise in a thermoneutral and a hot dry environment. *European Journal of Applied Physiology*, 56, 273-280.
6. Nose, H., Takamata, A., Mack, G.W., Oda, Y., Kawabata, T., Hashimoto, S., Hirose, M., Chihara, E. and Morimoto, T. 1994, Right atrial pressure and forearm blood flow during prolonged exercise in a hot environment. *Pflugers Archives European Journal of Physiology*, 426, 177-182.
7. Kellogg, Jr., D.L., Johnson, J.M., Kenney, W.L., Pergola, P.E. and Kosiba, W.A. 1993, Mechanisms of control of skin blood flow during prolonged exercise in humans. *American Journal of Physiology*, 265, H562-H568.