THERMAL RESPONSES OF NUDE AND CLOTHED SUBJECTS EXPOSED TO INCREASING LEVELS OF SKIN WETTEDNESS AT CONSTANT REQUIRED EVAPORATION

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INTRODUCTION

During exercise in the heat, the primary means for heat transfer to the environment is by evaporation. The maximum evaporative rate which is restricted in humid conditions, also appears to be limited as a function of the clothing layers : this limitation led to the permeation efficiency factor, F_{pcl} (1). For human beings exposed to warm humid environments, there is a threshold of ambient vapor pressure at which thermoequilibrium cannot be maintained and beyond this threshold, body temperature shows a continuous upward inflection as a result of heat stress. At the point at which thermoequilibrium is impossible corresponds a level of critical skin wettedness (w_{crit}). The w_{crit} threshold is obtained for lower ambient vapor pressure in clothed subject compared to nude ones, and this allows indirect determination of F_{pcl} (2).

The present study allows a reexamination of our methodology for w_{crit} and F_{pcl} physiological determination previously based on onset of upward of body drift temperature, when clothed subjects were compared to nude ones. In this work, we examined the different variables reflecting the occurrence of thermal imbalance in nude or clothed subjects while exercising in humid heat.

METHODS

Experimental tests were conducted on 2 groups of four healthy unacclimatized male subjects (Ss).

The subjects were dressed either in briefs and sport-shoes (nude) or in a 0.55 clo clothing ensemble consisting of briefs, long-sleeved shirt, trousers (all 100 % coton) and shoes (3).

After an initial 30 min rest-exposure at the thermoneutrality, the subjects started to exercise for 90 minutes at a constant work load (W = 50 Watts at 60 rotations per minute) while T_a and T_r were increase stepwise to 35°C and V_a to 0.6 $m.s^{-1}$. At the same time, T_{dp} was raised to the level required by the experimental test ($2.3 < P_a < 4.5$ kPa for nude Ss and $1.6 <$ kPa < 3.6 for clothed Ss).

After $\overline{T}_{sk}$ had reached the 35°C level, air and wall temperatures were set at $\overline{T}_{sk}$ value with the purpose of reducing R and C to a value close to 0. The imposed ambient conditions (differing only because of Pa) where chosen arbitrarily in a semi-random schedule, alternating the nude and clothed weekly exposures.

Rectal temperature (T_{re}) and 10 local skin temperatures were recorded, as well as local chest sweat rate, using a dew point measuring technique. For clothed subjects, miniature dew point sensors allowed local skin wettedness assessments (4) Average skin wettedness was calculated from local determinations. Sweat accumulation in the clothes was also determined at the end of each experimental session on clothed Ss.

RESULTS

Local sweat rate

The chest sweat rate under a local thermal clamp of 36°C increased beyond a certain threshold in both clothed or nude subject. However the slope of the increment was more marked in clothed man ($p < 0.05$) since the slope ratio was 1.5 (clothed/nude). The humidity thresholds for an increase in local sweating was 2.6 and 3.6 kPa for clothed and nude subjects, respectively. This yields a 0.70 ratio in vapour pressure differences between the skin and the air at the treshold for sweat rate acceleration.

Drift in core temperature

The drift in temperature was determined as the slope of the Tre increase with time during the last 30 min of the test. The slope of the Tre drift was steeper in nude subjects. The rise in core temperature occurred sooner in clothed man ($P_a > 2.3$ kPa) compared to nude man ($P_a > 3.7$ kPa).

Taking into account the small but significant ($p < 0.05$) difference in $\overline{T}_{sk}$ observed at the threshold point ($\overline{T}$sk, nude = 36.2°C and $\overline{T}$sk, clothed = 35.7°C, the ratio of the differences in water vapour pressure between skin and air at the critical point was 0.66.

Skin wettedness in clothed subjects

Below 2.5 kPa, mean skin wettedness was found to be near 53% without any significant effect of the ambient level of water vapour pressure within the humidity range used here.

When humidity was raised above 2.5 kPa, skin wettedness started to increase and rose to 82% at 3.1 kPa. For technical reasons, condensation problems disturbed the measurements at the highest level of humidity (3.6 kPa).

Sweat accumulation in the clothes

The weight gain of the clothes removed quickly from the subject after the 90 min work-period, showed that above a humidity level of 2.2kPa, the sweat accumulation occurred in the garments and increased then with P_a increases.

CONCLUSION

Comparison of data obtained on core temperature or sweat rate, skin wettedness or sweat accumulation in the clothes gives similar results and confirm that the critical skin wettedness threshold is reached as soon as some over-sweating occurs due to decrease in sweat efficiency. The present results show that the critical skin wettedness lies near 50 %. Both ratios of differences in water vapour pressure between skin and air obtained at the onset of T_{re} drift or of local sweating acceleration confirm a F_{pcl} value close to 0.70 for the considered garments (2). These experiments carried out in steady state conditions thus validate (5) our previous approach of permeation efficiency factor determination under thermal transients.

REFERENCES

1. Nishi, Y. and Gagge, A.P., Moisture permeation of clothing : a factor governing thermal equilibrium and comfort.
   ASHRAE Trans. 76,I: 137-145, 1970.

2. Candas, V., Sagot, J.C., and Vogt, J.J., Critical skin wetness and the estimation of the permeation efficiency factor for clothing.
   in: Trends in Ergonmics/Human Factors IV, ed. by S.S. Asfour, Elsevier, Amsterdam, pp. 293-301, 1987.

3. Olesen, B., Sliwinska, E., Madsen, T.L. and Fanger, P.O., Effect of body posture and activity on the insulation of clothing. Measurements by movable thermal manikin.
   ASHRAE Trans. 88,2: 791-805, 1982.

4. Berglund, L.G. and Cunningham, D.L., Skin wettedness and discomfort estimates from dew-point measurements under clothing,
   in : Aspects médicaux et biophysiques des vêtements de protection. Ed. by Centre de Recherche du Service de Santé des Armées (Lyon, France) pp. 238-246, 1984.

5. Kenney, W.L., The physiologic determination of vapor permeation efficiency of clothing.
   Int. J. Ind. Ergon. 3: 115-120, 1988.