THERMAL CONVERGENCE AS AN INDEX OF WORK TOLERANCE TIME IN THE HEAT

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INTRODUCTION

It is desirable and often essential to be able to calculate or to estimate the safe work tolerance time in those exposed to heat stress in the work-place. Various methods of doing this have been proposed, including the absolute values of deep body temperature, skin temperature, body heat storage, sweat loss and the rates of change of these variables. Pandolf and Goldman (1) proposed that the time to convergence of rectal and mean skin temperatures (thermal convergence) was a useful predictor for those wearing protective clothing that offers a high resistance to the transfer of moisture vapour.

However, Nunneley *et al* (2) and Bennett *et al* (3) found it an unreliable predictor in the circumstances they examined, but neither study used subjects acclimated to heat, as they were in the original work of Pandolf and Goldman. Therefore, the aim of our study was to examine whether thermal convergence changed after heat acclimation. We choose environmental conditions that minimised convective and radiative heat transfer but which allowed evaporative heat loss. We used a moderate rate of work (350 Watts), higher than Pandolf and Goldman, and clothing with a moisture vapour transfer characteristic similar to that of the Nunneley *et al.* We postulated that in these conditions the rate of change of skin temperature would be lower in heat acclimated subjects because of the improved evaporative cooling of the additional sweat produced. Thermal convergence time should thus increase after heat acclimation.

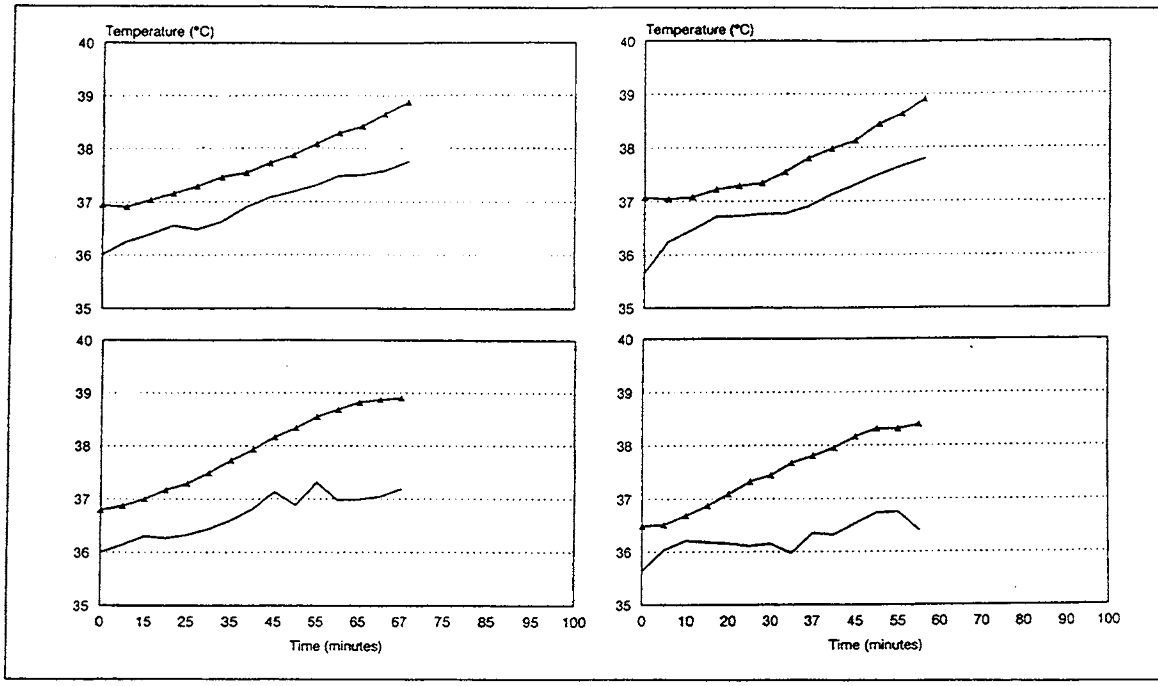
METHODS

Rectal (T_{re}) and mean skin (T_{sk}) temperatures (4) were measured at 5-minute intervals in 9 male subjects, dressed in Royal Navy chemical protective clothing, during an 'exercise-in-heat' before and after 10 successive days of heat acclimation. **Clothing:** multi-layered garments covering the torso, head, arms and legs; rubber gloves and boots; respirator. Total weight = 9.4 (0.4) kg; ratio of Woodcock Moisture Permeability Index (i_m) to total clothing insulation (I_T) = 0.17 at an airspeed of 1.1 m/s. **Exercise-in-heat test:** treadmill walk at 4.8 km/h, 0% incline, for a maximum of 100 minutes (measured oxygen consumption was about 1 litre/minute); ambient air dry-bulb temperature = 35 °C; relative humidity = 50%; globe temperature = dry-bulb temperature; airspeed = 1.1 m/s; wet-bulb globe temperature (WBGT) index = 29 °C. **Acclimation:** Wearing light clothing treadmill walk (4.8 km/h, 0% incline) in a hot environment (WBGT index 38-40 °C) until T_{re} reached 38.8 °C when subjects sat; T_{re} was maintained at this level for about 1 hour, by continued rest or by intermittent walking, as required. The ratio water evaporated : total water loss (E/P %) was calculated from nude and clothed weights taken before and after each heat exposure. Endurance times (time to self withdrawal or ethics withdrawal limits reached) were also recorded. Pandolf and Goldman (1) defined **thermal convergence** from calculation, by the least-squares linear regression method, from " ... the first seven values ..." of T_{sk}. Nunneley *et al* (2) defined thermal convergence as being when T_{sk} rose " ... to within 0.1 °C ..." of T_{re}. We have calculated linear regression equations for the pooled T_{re} and T_{sk} data collected over the whole of the exposure times, and then used the calculated differences between the slopes as an index of convergence. Although a linear model may not be entirely appropriate, we consider it to be adequate for this preliminary analysis. Data are given as mean (1SD). Statistical significance was accepted at $P<0.05$. The experiment was approved by the local Ethics Committee.

RESULTS

Physical characteristics of the subjects: age = 23.2 (3.1) y; height = 1.73 (0.12) m; weight = 70.9 (5.7) kg; body fat = 12.5 (3.9) %. The rate of change of T_{sk} was essentially biphasic, the rate of rise over the first 10 to 20 minutes was greater than during the remainder of the exposure (see Figure). In none of the 18 exposures did we observe thermal convergence using the definition of Nunneley *et al.* The difference between the slopes of the T_{re}

and T_{sk} lines was 0.016 (0.07) in non-acclimated subjects and 0.054 (0.05) for acclimated ones *ie* on average the rate of convergence of the lines was 4 times greater in acclimated subjects. We did not calculate thermal convergence according to the method of Pandolf and Goldman because of our uncertainty over their method. We do not consider this an important omission at present. Mean work tolerance time was shorter for non-acclimated subjects (46 (16) minutes) than for acclimated ones (59 (20)) minutes. Mean E/P was 31.8 (14.3) % for non-acclimated subjects; 20.0 (7.7) % for acclimated subjects.



Graphs of rectal temperature (lines with triangles) and mean skin temperature (smooth lines) in the two subjects having the greatest 'divergence' in the rates of change of these variables; upper panels non-acclimated, lower panels heat acclimated.

CONCLUSIONS

In this study we have been unable to show thermal convergence as defined by Nunneley *et al* (2). We are reluctant to calculate linear regression equations according to the method of Pandolf and Goldman because we have insufficient description to be certain that we adopt an identical method. Nevertheless, it is apparent from the individual data presented here that thermal convergence did not occur in our exposures, and so would not have been useful as a predictor of safe work tolerance times. We have shown that after heat acclimation the curves of rectal and mean skin temperature tended to diverge rather than converge. This emphasises the importance of taking this variable into account when seeking to use predictors of safe work tolerance time. We therefore conclude that thermal convergence has limited scope as a predictor of safe work time in conditions other than those used in the original study of Pandolf and Goldman, or possibly in any conditions in which skin temperature rises very quickly in the early part of the exposure.

REFERENCES

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