A UK VIEW OF THE TEXAS MODEL

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INTRODUCTION

Whole body thermal models are potentially valuable tools in the prediction of thermal strain in stressful conditions. However it is important that their general behaviour is well understood if they are to be used to extrapolate to conditions which are too hazardous to be reproduced in the laboratory. Essential components of both real and model systems are negative feedback loops - e.g. sweating and shivering - which tend to maintain body temperature within a prescribed range. As a result, the use of absolute levels of predicted variables such as rectal temperature as the sole comparison between experimental and model behaviour can be misleading. A more precise description of model response is provided by a comparison of the change in observed and predicted variables as a consequence of changes in the subject parameters or the environment.

The Texas model (1) is among the most highly developed thermal models, and has been employed by a number of nations for the prediction of survival time in cold water (2). In this paper, the model predictions are compared with the results from an experiment involving 15 subjects undergoing nude immersion in cold water, while both resting and exercising on a submerged cycle ergometer.

METHOD

The data on which these validations were based were obtained from a series of immersions in well stirred water at temperatures between 12°C and 35.5°C, each subject undertaking two immersions at each water temperature, one resting and one exercising intermittently at a randomly ordered series of levels between 10% and 50% of the subject's $\dot{V}O_2$ max. Exercise lasted 10 minutes and was followed by between 10 and 15 minutes rest. Metabolic rate for each rest and exercise period was determined by indirect calorimetry to yield one value per period. Rectal temperature, and skin temperature and surface heat flux at 9 sites, were recorded every 2 minutes. Immersions continued for 2 hours or until rectal temperature fell to 35°C or until the subject asked to be removed from the water. Total heat flux was calculated by correcting for the thermal resistance of the transducer (3) and weighting the corrected values according to body surface area (4).

The model was set up to simulate as closely as possible the exact conditions of the experiments for the 12 subjects for whom the data were most complete at each water temperature. The subject's mass, height, and mean weighted skin fold thickness was supplied to the model, as were the precise times of rest and exercise for the exercising immersions. Values of heat flux, metabolic rate and rectal temperature were recorded every 5 minutes during resting immersions, and every 2 minutes during exercising immersions.

The observed and predicted values of rectal temperature, heat flux and metabolic rate were compared initially using analysis of variance. For the resting immersions, the first 20 minutes of each run was discarded, as the rapid changes in heat flux during this period were not described in sufficient detail by observations taken every two minutes. Twelve subjects had relatively complete results for runs at 18°C and 24°C, while only 6 completed runs at 12°C. Two sets of analyses were therefore undertaken. The effect of mean weighted skinfold thickness (MWST) was examined by allocating the 12 subjects into three groups, and the 6 subjects to 2 groups. Five factors were identified in the analysis of variance : T (5 minute interval), W (Water temperature), F (Body Composition), S (Subject) and M (Observed vs Model). T, W, F, and M were treated as fixed effects, while S was treated as a random effect nested under F and crossed with the remaining factors. A similar analysis was undertaken for the 6 subjects at three water temperatures. For the exercising immersions a similar analysis was carried out on the data from the experiments at each water temperature separately, using 4 levels of exercise and the first post-exercise rest period.

RESULTS

For the resting immersions, there is a tendency for the model to underestimate metabolic rate ($p<0.01$), and this varies with water temperature ($p<0.05$). Similarly, there is a tendency for the model to underestimate total heat flux ($p<0.01$), although this effect varies with water temperature ($p<0.001$), subject MWST ($p<0.05$) and both together ($p<0.05$). Overall the model predicts too small a fall in rectal temperature ($p<0.01$) and there was evidence that the time course of the decline is not reconstructed correctly.

For the exercising immersions, comparison was confined to rectal temperature and heat flux. For all three temperatures, the difference between observed and predicted values varies with time and temperature ($p<0.001$) with the model predicting too high a heat flux at high exercise rates, and too small a flux at rest. Similarly, the difference between observed and predicted rectal temperatures varies with exercise level ($p<0.001$) with the model forecasting too large a drop at high exercise levels, and too small a drop at rest.

For some of the resting immersions the model predicts an oscillation in metabolic rate with a period of approximately 10 minutes. This oscillation only occurs when the predicted rate of fall of core temperature approximates 0.01°C per minute - the criterion for extra shivering (1). This causes an increase in shivering which produces an increased heat loss which then increases the rate of fall of core temperature. A further increase in metabolic rate occurs until the increased heat production reduces the rate of fall of core temperature below the critical value. Metabolic rate then declines and the cycle repeats.

The metabolic response to cold predicted by the model is less than that observed in these experiments. In general, the dominant contribution to metabolic rate is the term derived from the deviation of skin and rectal temperature from set point values (1). The value of this contribution was compared with the observed metabolic rate, using the observed skin and rectal temperatures. The pattern of predicted response follows that of the full model, indicating that the inconsistency between observed and predicted values is determined mainly by the deviations in this term rather than those in body temperatures.

CONCLUSIONS

In general the Texas model predicts the behaviour of rectal temperature at 18°C and 24°C in the resting immersions realistically over the first hour of nude immersion at rest. The behaviour at 12°C is not predicted as reliably, particularly for the thinner subjects, and this poorer prediction is associated with an underestimate of heat flux. The effect of increased metabolic rate on heat flux is not predicted well by the model, and this appears to be reflected in the presence of the oscillation in metabolic rate for some subjects. Overall, the analysis suggests that the key weakness in the model at high core skin gradients is in the representation of the redistribution of blood flow and, therefore, heat transport, although the effect is only marked under relatively extreme conditions.

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