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PAPER 22: EVIDENCE OF SHIVERING FATIGUE: VERIFICATION OF A PREDICTION MODEL

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INTRODUCTION

Search and Rescue authorities in Canada use a prediction model of survival time for cold exposure developed at DCIEM [1, 2]. This model predicts body cooling rates based on anthropometric, environmental, and clothing protection inputs. In circumstances where the cold stress overwhelms the individual's capacity to generate sufficient metabolic heat to offset heat loss, survival time essentially depends on how quickly the body cools to the point of lethal hypothermia (assumed to be a core temperature of 28°C). Often, the cold stress is less severe and the body attains a stable core temperature, usually at a value less than normal. In this circumstance, survival time depends on how long shivering metabolism can be maintained to offset the steady state rate of heat loss.

The survival model uses a prediction of shivering endurance developed by Wissler [3], yet this prediction has not been verified. The present study was undertaken to determine the onset of decline in steady state shivering during continuous exposure to cold and to test the shivering endurance prediction. The first phase of the study determined maximum shivering intensities and the second phase addressed shivering endurance.

MATERIALS AND METHODS

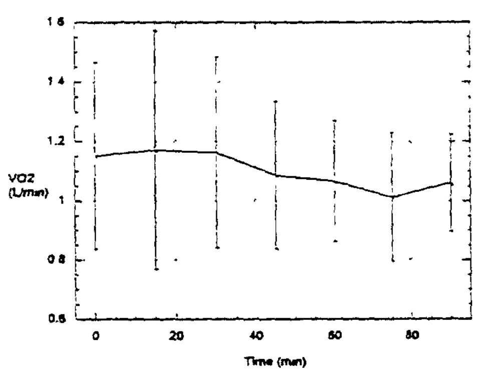
Twelve fit male (n = 9) and female (n = 3) subjects (mean ± SD: age = 24.8 ± 6.3 yr; mass = 71.7 ± 13.2 kg; height = 1.75 ± 0.10 m; body fat = 22.7 ± 7.4%, and $\dot{V}O_{2max}$ = 52.8 ± 6.1 mL·min^{-1}·kg^{-1}) participated in the experiment after providing an informed consent. In the first phase, subjects began neck-level immersion in 8°C water for up to 70 min to decrease their core temperature. Thereafter, while still immersed, the water temperature was gradually increased to 20°C to invoke a maximal shivering response. Core temperature (T_{es}) was measured with an esophageal thermocouple. Skin temperatures were measured at 12 sites and weighted [4] to obtain a mean value ($\overline{T}_{sk}$). Oxygen consumption was measured continuously from expired minute ventilation and gas concentrations. The maximal $\dot{V}O_2$ reported ($\dot{V}O_{2shiv\,max}$) was the highest value measured during the entire immersion.

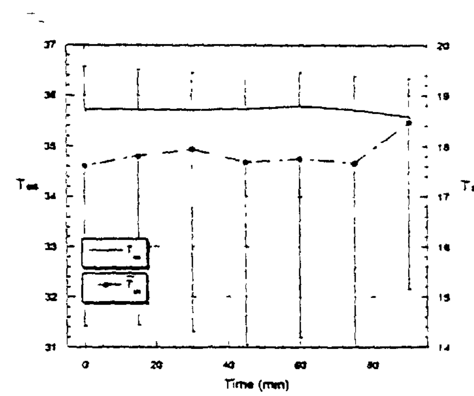
In the second phase, subjects were immersed in water at 8°C for the first 15 min and then at a warmer temperature (but less than 20°C) to invoke a submaximal shivering response. Subjects remained immersed until 6 h elapsed, by request, or by discretion of the investigator.

According to Wissler [3], the end of shivering endurance (t_{end}) is predicted when SUM, defined by $\sum L \cdot \exp^{4L} \cdot \Delta t$, equals 18, where L is the relative shivering intensity given by $(\dot{V}O_2 - \dot{V}O_{2rest})/(\dot{V}O_{2shiv\,max} - VO_{2rest})$ and Δt is the time step (in h) based on the interval of the measured oxygen consumption rate. Shivering thermogenesis is considered to be driven by decreases in the core and skin temperatures [5]. Thus, any change in the metabolic rate due to shivering must be adjusted to compensate for changes in body temperature before any trend analysis on shivering intensity is attempted. The normalization chosen for this purpose was to divide the measured shivering metabolism by a predicted value based on core and mean skin temperatures [6] The resultant variable was designated as NSHIV, which under ideal circumstances should equal unity. Data (1 min values) were grouped according to the last 30 min before t_{end} (pre30), the 30 min period following t_{end} (post30), and the last 60 min of immersion (last60). These data were then linearly regressed and slopes were tested for significance ($p < 0.05$). All mean data are reported with ± SD.

RESULTS

The subjects' oxygen consumption rates during rest and at maximal shivering were 0.330 ± 0.055 and 1.533 ± 0.238 $L{\cdot}min^{-1}$, respectively. The latter represents a 465% increase in metabolism over resting values. The accompanying figures show the subjects' oxygen consumption rate, and esophageal and mean skin temperatures during the last 90 min of immersion.





Figures of subjects' mean ± SD rate of oxygen consumption, and esophageal and mean skin temperatures during the last 90 min of immersion.

The predicted end of shivering endurance during the second phase immersion was 113 ± 47 min in contrast to the total immersion time of 215 ± 79 min. The immersion was terminated in 6 cases due to the discretion of the investigator, in 4 cases due to subject request, and in 2 cases because the maximum immersion period of 6 h was achieved. During the immersion, the value of SUM was 38.4 ± 16.8, representing an excess in the predicted endurance time by 113%. The average rate of oxygen consumption was 1.043 ± 0.209 $L{\cdot}min^{-1}$ or 68% of $\dot{V}O_{2shiv\,max}$. The slopes of NSHIV were +25.8, -37.8, and −25.3%$\cdot h^{-1}$ for pre30, post30, and last60, respectively, and all were significant.

CONCLUSIONS

The nearly 5-fold increase in shivering metabolism over resting values is in close agreement with the results reported by Iampietro et al. [7], and were deemed valid for the analysis of shivering endurance. That shivering continued well beyond the predicted end of endurance suggests an underprediction in the Wissler endurance function [3]. However, shivering intensity began to decrease significantly after t_{end}, indicating that perhaps this variable expresses not the abrupt end of shivering, but the start of shivering fatigue. Indeed, Wissler [3] acknowledged that t_{end} may more accurately reflect the end of steady state shivering. Accordingly, this study supports the Wissler shivering endurance function, although the underlining mechanism of shivering fatigue has not been verified.

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