VALIDATION OF THE DURATION LIMITED EXPOSURE INDEX

D. Gavhed and I.Holmér

National Institute for Working Life, Department of Ergonoinics,
S-171 84 Solna, Sweden

INTRODUCTION

In cold environments, appropriate assessment of working time limits is important to avoid unacceptable body cooling during work. The cold stress index, IREQ (insulation required index) (1,2), is based on pliysiological and physical models and predicts the required insulation for heat balance during work in tlie cold. The data in tlie models were collected from the relatively few published studies on tliermopliysiological 'responses during work in cool or cold temperatures and included a restricted number of conditions. **A** supplementary method, DLE (duration limited exposure), determines time limits for occupational work in cold conditions when tlie clothing insulation is not sufficient to maintain tliermoneutrality (2). Tlie reduction of the body heat content is allowed to be at most 40 $Wh \cdot m^{-2}$.

The objective of the study was to validate tlie DLE index at three subzero ambient temperatures and to examine tlie associated subjective and physiological effects.

MATERIALS AND METHODS

Ten young male subjects participated in this study. The subjects were dressed in **a** multi-layer cold-weather clothing ensemble with a basic insulation value of 2.23 clo (0.346 m^2 "C W^{-1}), measured on a static thermal mannequin (3).

Tlie experiments were performed in a climatic chamber at three ambient temperatures (T_a): -6, -14 and -22 "C. The experimental conditions (combination of climate, thermal insulation and activity level) were calculated with IREQ/DLEneu (4) to allow work for approx. 2 h at -6 "C, 60 min at -14 "C and 40 min at -22 "C at a body cooling rate of at maximum 40 $Wh \cdot m^{-2}$). Tlie total clothing insulation value was reduced by 20 % to correct for tlie convection increase during walking **(5).**

Tlie subjects walked on a treadmill at approximately 2 $km \cdot h^{-1}$ for 90 min at -6 "C and until DLE was reached in the other T_a. Thermistors (Fenwal Mil-TE-23648) were used for skin temperature measurements. Core temperature **as** represented by rectal temperature was measured with a thermistor (YSI401) inserted 10 cm beyond the anal spluncter. The temperatures were recorded at I-inin intervals on a PC. Subjective ratings of body therinal sensation (*TSb*) and thermal sensations of hands (*TSh*) were given at 10 min intervals on a 9-point scale, according to the **draft** standard (6). Thermal acceptance was also given by the subjects. To assess the oxygen consumption and the metabolic rate, expired air was collected in Douglas bags during exercise and samples were analysed for CO_2 and O_2 contents by gas analysers (AMETEK OCM-1). Mean skin temperature ($\bar{T}_{sk}$) was calculated as an average from 14 points as reported by the authors earlier (7).

RESULTS AND DISCUSSION

The $\dot{V}_{O2}$ **and** metabolic heat production rates (107, 108 and 119 W/m^2, resp.) were siinilar at all temperatures. Some of our subjects had a considerably higher $\dot{V}_{O2}$ at -22 "C compared to -14 and **-6** "C. The rectal temperature was similar in all conditions (Figure 1).

The $\bar{T}_{sk}$ is illustrated in figure 1. The T_a explained the greater part of the $\bar{T}_{sk}$ level ($p<0.0001$). The correlation coefficient (r) was 0.77 calculated on data at 40 min of the cold exposure. The correlation coefficient calculated on individual data was 0.84-1.0. According to those data, each degree of lowered ambient temperature would give a lowered $\bar{T}_{sk}$ by 0.1-0.2 "C. Among the body parts, the legs were the most influenced by the ambient temperature. The fingers, nose, cheek and **chin** were the coolest parts of the body. At 40 minutes of cold exposure, the fingers were at average 4 "C colder at 14 °C compared with -6 "C and further 7 "C lower at -22 °C compared to at -14 "C. The finger temperature varied considerably due to cold-induced vasodilatation (CIVD) response in some subjects. In **the** current version of

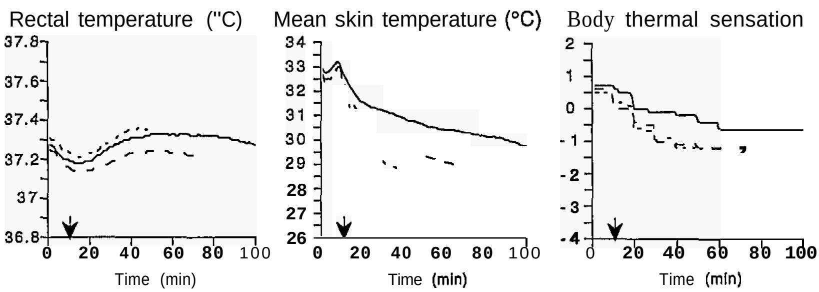

Figure 1. The rectal temperature, mean skin teinperature and body therinal sensation of dressed subjects during very light exercise at three different temperatures. The arrows show the start of cold exposure. Continuous line: -6 °C, dashed line: -14 "C and dotted line: -22 "C (n=10).

the DLE modei, the distribution of insulation has not been taken into account. The insulation of the different body parts most probably influenced the skin temperature results.

The thermal sensations of the body are illustrated in figure 1. *TSb* ranged from 'slightly warm' to 'very cold'. The subjects rated the hands as 'cold' to 'very cold'. *TSb* was colder in -14 and -22°C than in -6 "C ($p<0.05$) and similarly *TSh* also tended to be colder ($p=0.07$). The group of subjects had less acceptance the lower the ambient temperature at 40 min of exposure. The main part of the subjects accepted the exposure at least at several occasions of a day.

At the time predicted by IREQ/DLE to limit the cold exposure the rectal and mean skin temperatures were equal at -14 and -22 "C. Thus the predictions of the heat balance were accurate. Selected thermal variables at DLEneu are presented in table 1. The $\bar{T}_{sk}$ was slightly lower than predicted by the DLE model at -14 and -22 "C at DLEneu **(tab.1).** The average **hand** temperature (dorsal+palmar/2) was above 24 (tab.1), which is the lowest recommended hand temperature for low physiological strain in ISO/TR-11079 (2).

The variation **of** hand temperatures among the subjects was large. Even at -6 °C the hand temperature of one subject was **as** low as 16 °C. The fingers were much colder than the hands (9 "C or more). The finger slun temperatures also tended to be lower at *-22* °C. Although the hand temperature is above 24 °C, the finger temperature may be considerably lower and both sensory and motor function will be impaired. Manual function is impaired at hand and finger temperatures below 20 "C and an important dexterity loss occurs at about 15 "C (8,9).

Table 1. Average physiological values during walking in a cold chamber at the time limits predicted by DLE neutral at -14 and -22 °C and at the 'control' temperature -6 "C. (DLEneu at -6 "*C* was 2 h).

	-6 "C (90 min)	-14 "C (60 min)	-22 "C (40 min)
Mean **skin** temperature (°C)	29.8	29.3	28.2
Hand **skin** temperature ("C)	26.8	27.6	26.4
Finger tip skin temperature ("C)	20.1	18.8	12.3
Body thermal sensation	-0.7	-1.2	-1.2
Thermal sensation hands	-1.2	-1.4	-1.7

Heat balance, defined as preservation of the initial core temperature was maintained at all ambient temperatures at the time limits predicted by DLE, although at the expense of different levels of peripheral cooling.

CONCLUSIONS

The DLEneu predictions prevented body core cooling. However, the conditions resulted in rather low hand temperatures and very cold thermal sensations at low ambient temperatures. The prediction models should be reconsidered to avoid too low extremity temperatures and impaired manual performance during work in the cold.

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