ESTIMATION OF HEAT STRAIN INDUCED BY NOMEX® COVERALLS

M. Belokopytov, Y. Shapiro and A. Frank

Heller Institute of Medical Research, Sheba Medical Center, 52621
Tel Hashomer, Sackler Faculty of Medicine, Tel-Aviv University, Israel

INTRODUCTION

Wearing a protective garment decreases the ability of the body to dissipate heat. Various approaches are used for the calculation of heat strain in workers exposed to hot environments and wearing protective clothing (1,2). Some calculations use the values of physiological parameters themselves, their changes and combinations, while others are based on the dynamic properties of changes and have cumulative characteristics. The aim of this study was to evaluate the heat strain induced by wearing two types of Nomex® coveralls.

MATERIALS AND METHODS

Subjects. Seven healthy males participated in this study. The anthropometric data of the subjects (mean ± SD) were as follows: age 23 ± 3 years, height 173 ± 5 cm, weight 69 ± 8 kg and estimated body surface area 1.8 ± 0.1 m^2 (3). All the subjects underwent 2 weeks of exercise-heat acclimation prior to the experimental exposures and were considered to be heat tolerant. None of the subjects was under treatment with medication. All subjects were carefully instructed about the procedures and gave their written consent to be tested in this study.

Tested garments. Two types of Nomex® coveralls were tested: one, a standard coverall (type A) and the other (type B) with additional layers that improved flame resistance and also increased the clothing insulation by 0.78 clo.

Experimental setup. Volunteers underwent 2 exercise-heat exposures alternately wearing the 2 types of coveralls. The order of coverall testing was random and counterbalanced. Each exposure lasted 180 min in a climatic chamber at warm conditions (30°C, 60% relative humidity [RH]). During the exposures, a work/rest cycle of 55/5 min was followed. Exercise consisted of walking (5 $km \cdot h^{-1}$, 2% grade, $VO_2 \equiv 1$ $L \cdot min^{-1}$) and was preceded by 5 min of rest while the initial values of rectal temperature (T_r) and heart rate (HR) were measured. During the test, the subjects were allowed to drink tap water *ad libitum*.

Measurements and calculations. T_r was measured using a YSI (series 400) thermistor probe inserted 10 cm beyond the anal sphincter. Heartbeats were accumulated through bipolar chest leads using Polar belt electrodes (Polar CIC; USA). T_r and HR were accumulated on-line and processed every minute using the Alma 1000 System (Alma, Israel). The elevation of HR over the entire exercise-heat exposure (ΔHR) was calculated as a difference between final HR at the end of exercise and initial HR. The value of ΔT_r was obtained in the same manner. Two indices based on T_r and HR were chosen to calculate heat strain: the physiological stress index (PSI) (Moran DS, personal communication) and the cumulative heat strain index (CHSI). The PSI was calculated as a combined increase of weighted final T_r and HR as follows:

$$PSI = 5 \cdot (Tr_t - Tr_0) \cdot (39.5 - Tr_0)^{-1} + 5 \cdot (HR_t - HR_0) \cdot (180 - HR_0)^{-1}; \text{ (units)}$$

where Tr_t and Hr_t are rectal temperature and heart rate, respectively, at a time of measurement, and Tr_0 and HR_0 are initial rectal temperature and heart rate, respectively. The CHSI (4), based on principles of physiological cost (5,6), was calculated as the product of cardiac strain and the area under the hyperthermic curve as follows:

$$CHSI = \left[\sum_0^t hb - HR_0 \cdot t\right] \cdot 10^{-3} \times \left[\int_0^t Tr \cdot dt - Tr_0 \cdot t\right]; \text{ (units)}$$

where hb is the number of heart beats, HR_0 is initial heart rate (bpm), Tr is rectal temperature, Tr_0 is initial rectal temperature (°C) and t is the elapsed time in minutes from the first measurement. The indices were calculated for every subject and compared individually for 2 coveralls. Significant differences between experimental conditions were determined using a paired t-test. The level of significance was set at $P < 0.05$.

RESULTS

All the subjects successfully completed exercise-heat exposures. The mean values of the measured physiological parameters are presented in Table 1.

Table 1. Physiological Responses[1] to Exercise-Heat Exposures.

	Coverall A	Coverall B
Final HR (bpm)	117 ± 11	121 ± 12
Final T_r (°C)	37.72 ± 0.34	37.96 ± 0.21
ΔHR (bpm)	48 ± 14	52 ± 14
ΔT_r (°C)	0.96 ± 0.40	1.07 ± 0.41
PSI (units)	3.9 ± 1.0	4.3 ± 1.0
CHSI (units)	742 ± 368 *	914 ± 386

[1]Values shown are means (± SD).
*Significant difference between coveralls, $P < 0.05$.

The 2 types of Nomex® coveralls induced a significant physiological strain. There was a tendency for lower heat strain while wearing type A. While the final HR and T_r, and thereby ΔHR, ΔT_r and PSI, were lower for type A than type B coverall, the differences between the two ensembles were not statistically significant. However, a statistically significant ($P < 0.05$) difference in strain was seen in the CHSI (914 ± 386 and 742 ± 368 units for suits A and B, respectively).

DISCUSSION

The PSI as suggested by Moran indicates the level of physiological strain; accordingly, a significant strain develops while wearing the 2 types of coveralls. The PSI is based on the calculation of the relative increase in HR and T_r for a given interval without accounting for the momentary dynamics within this period. The cumulative properties allow CHSI to take into account the dynamic pattern of changes in HR and T_r, and differences in additional strain during exercise and rest intervals (Figure 1) accounting for individual differences. Thereby, it reflects miniature differences in the pattern of changes in the dynamics of HR and Tr.

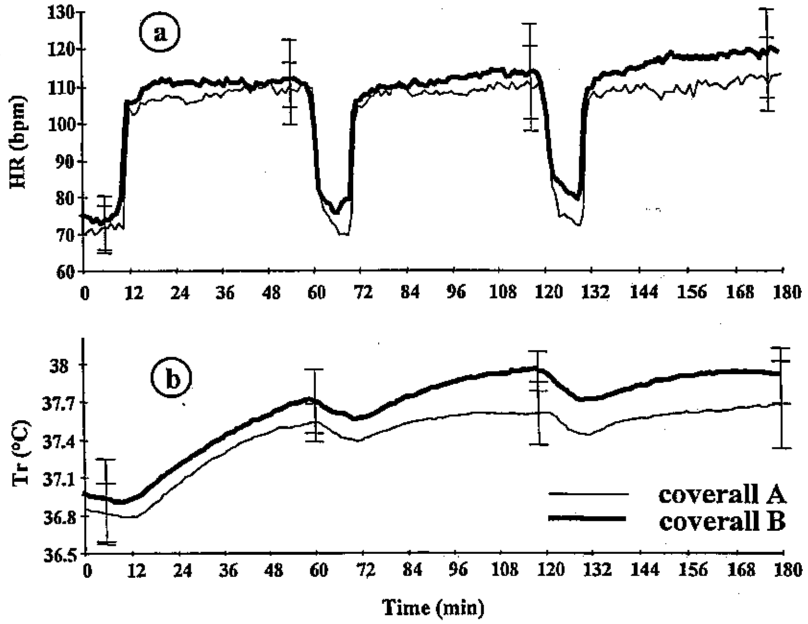

Figure 1. The mean values of HR (a) and Tr (b) during exercise-heat exposure wearing two tested coveralls.

Due to cumulative properties of the CHSI, the higher strain induced by coverall B was detected. The additional layer of this type of coverall is the only reasonable explanation for such results. The absence of statistical differences between 2 types of coveralls by other parameters may be explained by a wide inter-individual dispersion in a small group of subjects.

CONCLUSIONS

PSI is a useful index for the characterization of heat stress in large samples in which individual variations are masked and is advantageous for norm setting of heat strain owing to its standardized 10-point scale. Because of its cumulative nature, the CHSI might be a more sensitive tool for evaluation of heat strain under various levels of heat stress in small experimental groups.

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