EFFICACY OF 3 PROTECTIVE CLOTHING IN VERY SEVERE HOT ENVIRONMENT

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INTRODUCTION

The number of workers exposed to hot environments and the severity of the heat stress have decreased in the last decade. Nevertheless, there are still particular situations where workers have to be exposed to hot environments [1]. It is the case for workers in paper-mill industry where they have to work few hours a week, in a very severe hot environment wearing Ventilated Protective Clothing (VPC). The purpose of the present study was to evaluate the efficacy of 3 VPCs (MARS of VTN®, MSA®, MATISEC®) in a situation involving 75°C dry bulb temperature and 60°C wet bulb temperature. MARS of VTN® and MSA® VPC have a vortex system to cool the input air and MATISEC® have not.

METHOD

The subjects were 3 workers of the paper-mill : their age was respectively subject 1 = 38 ; subject 2 = 24 ; subject 3 = 37 years old. The subjects had never worn any of the 3 VPCs prior to their participation in the study. Each subjects tested the 3 VPCs. The efficacy of the 3 VPCs was assessed from the responses of heart rate (HR) and rectal temperature (Tre). Measurements were taken before, during and after the exposure. Before the experiments subjects performed a submaximal exercise on a cycle ergometer, for determination of their physical fitness (indirect $\dot{V}O_2max$ evaluation). The following values were found for the 3 subjects respectively : subject 1 = 53, subject 2 = 74 and subject 3 = 36 mlO2/min.kg. Nine experiments (3 subjects x 3 VPCs) were carried out and maximal duration of exposure never exceeded 30 minutes because the duration of exposure in actual working situation is always lower than 20 minutes. In the hot environment, the subjects remained standing without moving or working. Thus, metabolism was low, estimated close to 70 W/m^2.
As Tre and HR were not stable during the exposure time in hot environment, 2 regressions lines were calculated between each of these two variables and time for each experiment.
In this study the Threshold Limit Values (TLV) for the workers exposed to heat were also determined :

- TLV.HR : 0,75 x (220-age) b/min [3] respectively subject 1 = 137, subject 2 = 147, subject 3 = 137 b/min
- TLV.Tre : 38.0 °C [4].

In addition to the fact that the subjects were free to withdraw from the experiment at any time, the continuous recordings of HR and Tre were used by the experimenter for imposing the cessation of exposure.
The design is too small for statistical analysis, so that only impressions are obtained.

RESULTS

Table 1 indicates the exposure time, and the changes in HR and Tre (= slope of the regressions lines) during exposure for each subject in each of the 3 conditions. Three experiments were stopped because HR value had exceeded the fixed TLV for a certain duration of time. From the results, it appears that the highest average Tre increase was found under MATISEC® condition (1.35°C per hour for Tre) associated with the larger average heart-rate (HR) rise with time (2.6 b/min^2). The VTN®) ensemble allowed some reduction of this physiological cost (1.0°C/h of Tre drift and 1.4 b/min^2 for HR drift). The efficacy of MSA® appeared very good since both Tre and HR were minimal (0.3°C/h and 0.5 b/min^2 respectively).

Table 1 also indicates the Duration Limit for Exposure (DLE), which was derived for each subject in each condition. DLEs were determined by assuming a constant rate of change of HR and Tre, and estimating the time required to attain DLE for HR (DLE HR) and Tre (DLE Tre).

Type of clothing	Subject	Elapsed time, min	dHR/dt b/min^2	dTre/dt °C/h	DLE HR min	DLE Tre min
VTN®	1	26	1.8	1.5	18	51
	2	30	1.1	1.0	51	60
	3	30	1.2	0.4	23	114
MSA®	1	30	0.6	0.6	73	103
	2	30	0.4	0.1	120	109
	3	30	0.4	0.2	35	106
MATISEC®	1	23	2.8	1.7	16	35
	2	30	1.1	1.1	49	63
	3	15	3.9	1.2	7	54

Table 1 : Durations of exposure, slopes of HR and Tre during heat exposure and DLE for each experiment.

The values of DLE HR in Table 1 confirm that in 3 cases (subject 1 wearing VTN®, and subjects 1 and 3 wearing MATISEC®) the experiments would have to be terminated prematurely due to HR reaching TLV. Two of these interruptions had to be done while subjects were wearing the MATISEC® garment which have the lowest efficacy because of its weak thermal protection.

An interesting point is that DLE depends upon the type of clothing and thus upon its efficiency to retard heat accumulation, but DLE were also found to depend upon the physical fitness of the subjects. Table 2 shows the relative cardiac cost (in %) in the 9 experiments calculated from HR at the last minute of each heat exposure (exposure time is indicated in column 3 of Table 1).

Type of clothing	VTN®	MSA®	MATISEC®	Mean
Subject	%	%	%	%
1	68	27	71	55
2	36	27	37	33
3	67	43	78	63

Table 2 : Relative cardiac cost [(HR of the last min.) minus reference HR (= average of HR calculated in neutral condition, subject wearing VPC, standing without moving, during 10 min.)] divided by [(220-age) minus (reference HR)].

Although the very limited number of subject in the present investigation does not allow any statistical analysis, it can be concluded however that no DLE in industry could be proposed as an average, but that DLE should be determined for each worker, taking into account his physical fitness.
In the present study, the subjects did not perform any physical effort, thus heat generated by muscular contraction did not contribute to the thermal strain of the workers. In our conditions, the thermal stress is originated in the standing metabolic heat production and external heat load, the consequence of which being and imposed thermal limit values better reflected by Heart Rate measure than by rectal temperature one. Thus, HR measurement is necessary and sufficient to evaluate the efficacy of the 3 VPCs tested.

CONCLUSIONS

In a very severe environment :
- the thermal strain of subjects wearing ventilated protective clothing remained important in 2 cases out of 3,
- DLE imposed by the thermal stress can be determined from heart rate measures, and much easier to obtain than the rectal ones,
- intensity of thermal strain depends on the clothing and the physical fitness of the subject, both of which should be carefully considered before severe heat exposure.

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