

EMPIRICAL PREDICTION OF PHYSIOLOGICAL RESPONSE TO PROLONGED WORK IN ENCAPSULATING PROTECTIVE CLOTHING

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INTRODUCTION

Workers wearing protective clothing (PC) required to perform physical labor in hazardous environments at temperatures greater than 21°C (70°F) incur a risk of heat-injury, and a reduced work capacity (1,2,3,4). Current prediction methods, although useful in many applications, do not provide sufficient accuracy for individualized prediction. The use of group mean predictions such as the American Conference of Government Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) puts some personnel at risk, while at the same time other workers are under-utilized (3) and this presents two major disadvantages: 1) Individuals are too much constrained by the very conservative limits needed for protection of almost all workers, such that their individual productivity is substantially reduced, 2) Because productivity is so compromised, and because some managers undoubtedly consider the TLVs to be overly conservative, it can reasonably be presumed that the TLVs are violated frequently. Since there are no alternative resources for managing personnel in this situation, the net result can be increased, rather than decreased risk to workers.

The purpose of this study was to develop a technique for predicting physical work capacity of individuals in these situations, based upon field measurements gathered in a short-term work task performed in protective clothing in a mild ambient environment (i.e. bench stepping in PC at room temperature). This research was built upon recent work done in our laboratory (5) as well as earlier work of Kenny et al. (6), and Shvartz et al. (7).

MATERIALS AND METHODS

Fifty unacclimatized young fit males performed a VO_2 max test, then performed two identical bench stepping tests wearing PC (one-piece Saranex suit with respirator PVC shoe covers and gloves) on a 40 cm bench at a metronome paced rate of 24 steps/min in an environment of $WBGT=18^\circ C$.

Work VO_2 , rectal (T_{re}) and mean skin temperatures (mT_{sk}) (8), and qualitative ratings of comfort (modified from 9), and Rating of Perceived Exertion (RPE) (10) were measured during the bench-stepping.

Subjects then performed the following in counterbalanced order:

- 1) Continuous work at 177 W/m^2 (300 Kcal/hr, VO_2 of 1 L/min, at WBGT= 18°C (i.e. room temperature), referred to as 18/1.0
- 2) 30 min work at 235 W/m^2 (400 Kcal/hr, VO_2 of 1.33 L/min) succeeded by 30 min rest 35 W/m^2 (60 Kcal, time weighted avg of 135 W/m^2) all at WBGT= 18°C referred to as 18/1.3
- 3) Same as #1 in WBGT= 26°C , referred to as 26/1.0
- 4) Same as #2 in WBGT of 26°C , referred to as 26/1.3.

All rest was performed with the gloves and gas protective mask removed and PC removed to the waist. Resting metabolic rate was assumed to be 35 W/m^2 . Work consisted of 15 min of walking at 1.34 m/sec (3 mph) followed by 5 min of arm curls with 14.6 kg of weight, with this work sequence repeated until the specified time limit.

Subjects were stopped by investigators if: 1) rectal temperature (T_{re}) exceeded 38°C , or 2) heart rate (HR) was within 10 beats of measured maximal heart rate, or 3) subject evidenced symptoms of heat injury or extreme fatigue. Subjects were able to stop work at any time. When T_{re} fell below 37.5°C , and HR and subject felt rested, work resumed. Subjects were allowed water *ad libitum* during both exercise and rest. Work continued for 8 hours total time including donning the PC, or subject refusal to continue. Total work time (TWT) was total number of minutes worked. Rest time was the time sitting quietly in the same environment with the mask and gloves removed and the upper half of the protective coveralls pulled down to the waist.

RESULTS

Equations were derived as shown in Table I. The variance in work time accounted for by easily measured variables was much lower than was seen in pilot work in military PC (5).

CONCLUSIONS

In *summary*, it does not appear that our bench step field test of work tolerance in PC permits highly accurate predictions of performance. However, this approach could be broadly useful in determining which workers are most at risk, and which are most suited for work in warm environments in PC. Despite objections to screening workers for particular jobs, it would be reasonable from both the safety and productivity perspectives, to attempt to classify workers as tolerant to PC use in

Table 1. Regression equations for best prediction of total work time for each work and environmental condition for all subjects (n=50).

Variable	Beta Weight	R ² (ADJ.)	S _{yx} (mill)	C.V. (%)
WBGT=18 °C/ Work rate=1.0 L/min				
Intercept	179			
Bench 1 time	2.7			
Bench 1 Comfrating	16.6			
Bench 1 RPE	-8.4			
Bench 1 HR2	-1.8	(Heart rate at 2 min)		
Bench 1 HR5	1.4	(Heart rate at 5 min)		
WT	1.5	.26(.13)	51	21
WBGT=18 °C/ Work rate= 1.3 L/min				
Intercept	312			
Bench 1 time	0.8			
Bench 1 RPE	1.0			
Bench 1 HR2	-0.9			
HT	0.4			
WT	-2.9	.13(.02)	43	23
WBGT=26 °C/ Work rate= 1.0 L/min				
Intercept	87			
Bench 1 time	2.1			
Bench 1 Comfrating	12.5			
Bench 1 HR0	-0.2	(Heart rate at 0 min)		
HT	0.6	.18(.09)	37	36
WBGT=26 °C/ Work rate= 1.3 L/min				
Intercept	331			
Bench 1 time	0.35			
Bench 1 RPE	-9.1			
Bench 1 HR0	-1.7			
Bench 1 HR2	1.0			
HT	1.1			
AGE	-3.8	.29(.18)	43	35

ADJ. is the R² adjusted for variable number and sample size (11), S_{yx} is the standard error of prediction and C.V. is the coefficient of variation .

heat or intolerant to this work. Such classifications might be very useful in safely increasing productivity.

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This study was funded in part by a grant from NIOSH # 1R01 OH0301501A1.