HEAT EXPOSURE INCREASES ENERGY EXPENDITURE DURING REST AND WORK IN MEN DRESSED IN FIREFIGHTER ENSEMBLE AND USING A SELF-CONTAINED BREATHING APPARATUS

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INTRODUCTION

Observations of personnel conducting firefighting operations suggest that fire suppression activities demand a high level of energy expenditure (1). This could be related to breathing on a self-contained breathing apparatus (SCBA) and wearing a firefighting ensemble (FFE). Breathing from a SCBA is known to increase ventilation and breathing rate, and decrease maximal exercise capacity (2). The energy demands of firefighting may also be related to the slow and deliberate movement patterns associated with wearing the bulky FFE. Additionally, firefighting may require a high-level anaerobic energy production. Understanding how energy expenditure is affected by a SCBA and FFE is important to the development of firefighting doctrines, exercise/recovery guidelines and training procedures. Thus, the purpose of this study was to determine the effect of breathing on a SCBA and wearing an FFE on respiratory responses and energy expenditure during performance of submaximal exercise in moderate to hot environments.

MATERIALS AND METHODS

Ten males served as subjects. The physical characteristics of the subjects were 28.9 ± 4.8 years, 179.1 ± 6.6 cm and 88.6 ± 11.1 kg. All subjects were trained in the use of firefighting equipment. Each subject gave informed consent prior to participation in testing.

All subjects participated in 3 test trials and attempted to complete a test protocol of 20-min rest, 20-min exercise, 20-min recovery, 20-min exercise and 20-min recovery. Subjects wore complete FFE (coveralls, flash hood, hard helmet, gloves, single-piece Nomex protective suit and boondocker boots) and respired using a positive-pressure SCBA. Exercise ($1.1\ m \cdot s^{-1}$, 0% grade treadmill walking) occurred in 50% relative humidity (RH) air and temperatures of 21°C (MOD), 35°C (WARM) and 49°C (HOT), while rest/recovery occurred in 27°C air.

Measurements included ventilation (V_E), breath rate (f_B), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) for calculation of energy expenditure (EE) in watts. Ambient conditions inside the chamber were monitored continuously for dry-bulb (T_{db}), wet-bulb (T_{wb}), black-globe (T_{bg}) and RH, while conditions outside of the chamber were monitored for T_{db}.

Body temperatures included rectal temperature (T_{re}), and skin temperatures from the upper right chest (T_{ch}), right upper arm (T_{ar}), right mid-lateral thigh

(T_{th}), and right mid-lateral calf (T_{ca}). Calculations included mean skin temperature (T_{sk}) and heat storage (HS) ($kJ \cdot kg^{-1}$). Data analysis was conducted on steady-state respiratory and EE values obtained during the 2 exercise periods using analysis of covariance.

RESULTS

All subjects completed the 100-min test during the MOD and WARM trials. However, only 4 subjects completed the HOT trials with the others stopping at various times within the 2nd exercise period. There were significant trial and exercise period effects for V_E, V_T, VO_2, VCO_2 and EE, and significant period effects for f_B and respiratory exchange ration (RER) (Table 1). The significant exercise period effect for all variables was the result of slightly higher values during the 2nd exercise period for the WARM and HOT trials.

Table 1. Effect of trial, exercise period and interaction of trial and exercise period on . respiratory responses and energy expenditure.

Variable	Trial	Exercise Period	Trial x Exercise Period
V_EBTPS ($L \cdot min^{-1}$)	$P < 0.03$	Pc 0.0001	n.s.
f_B ($brth \cdot min^{-1}$)	n.s.	$P < 0.0001$	n.s.
V_T ($ml \cdot brth^{-1}$)	$P < 0.0001$	$P < 0.0001$	n.s.
VO_2 ($L \cdot min^{-1}$)	$P < 0.04$	$P < 0.0001$	n.s.
VCO_2 ($L \cdot min^{-1}$)	$P < 0.04$	$P < 0.0001$	n.s.
RER	n.s.	Pc 0.0001	n.s.
EE (watts)	$P < 0.04$	$P < 0.0001$	n.s.

During the 3 trials, f_B averaged 17 $brth \cdot min^{-1}$ during rest and 22 $brth \cdot min^{-1}$ during exercise. During MOD, WARM and HOT, resting V_E averaged 13.8, 14.8 and 15.6 $l \cdot min^{-1}$, respectively, while exercise V_E averaged 23.8, 24.7 and 26.4 $l \cdot min^{-1}$, respectively (Fig. 1). For all tests, resting VO_2, VC02 and EE averaged 0.50 $l \cdot min^{-1}$, 0.41 $l \cdot min^{-1}$ and 175 ± 15 watts, respectively. For MOD, exercise VO_2, VCO_2 and EE averaged 0.93 $l \cdot min^{-1}$, 0.74 $l \cdot min^{-1}$ and 314 watts, respectively (Fig. 2). For WARM, exercise V_{O_2}, V_{CO_2} and EE averaged 0.96 $l \cdot min^{-1}$, 0.77 $l \cdot min^{-1}$ and 333 watts, respectively. For HOT, VO_2, VCO_2 and EE averaged 1.00 $l \cdot min^{-1}$, 0.82 $l \cdot min^{-1}$ and 347 watts, respectively.

DISCUSSION

Exercise in WARM and HOT lead to higher V_E, VO_2, VCO_2 and EE with the rates for the second exercise session on average greater than those of the first exercise session. f_B was unaffected by environmental conditions, while tidal volume (V_T) increased with exposure to both WARM and HOT. This is contrary to the findings of others (3) who have suggested that increases in V_E during exercise

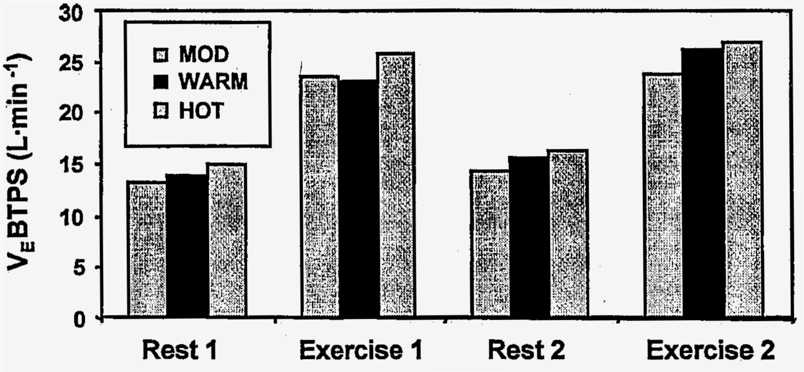

Figure 1. Ventilation during Rest and Exercise for MOD, WARM, and HOT trials.

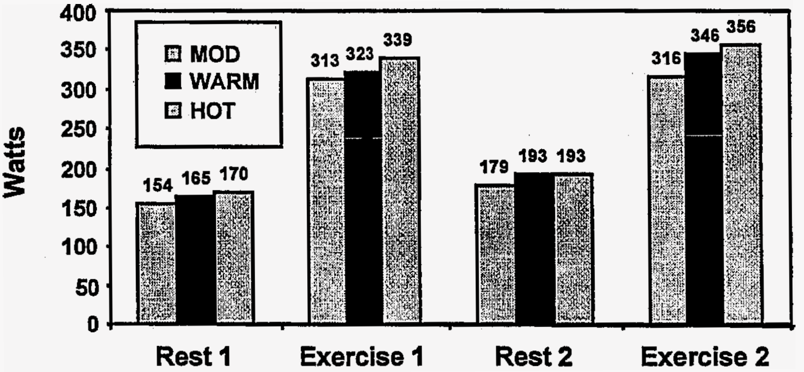

Figure 2. Energy expenditure during Rest and Exercise for MOD, WARM, and HOT trials.

are due primary to increases in f_B. The higher V_T may in part be related to elevated inspired CO_2 levels due to the dead space volume of the SCBA facepiece.

Since the exercise periods were only 20-min in duration and separated by a 20-min rest period in cool air, it is unlikely that the higher EE was a function of oxygen costs related to lactate removal and oxidation, fat oxidation, and ventilation (3). The consistently higher V_T and V_E during WARM and HOT suggest that the higher EE is best explained by increases in T_{re} and heat storage. During MOD, Tre and increases in heat storage remained low at 37.2°C and 0.23 kJ·kg^{-1}, respectively. However, during the second exercise period of WARM, Tre and increases in heat storage averaged 37.6°C and 2.5 kJ·kg^{-1}, respectively, while during HOT, T_{re} and gain in heat storage averaged 38.2°C and 6.73 kJ·kg^{-1}, respectively.

CONCLUSIONS

Our findings suggest that elevated environmental temperatures increase V_E, V_T and EE in individuals dressed in complete FFE. These findings have application to the management of damage control personnel conducting shipboard firefighting operations.

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