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

R.D. Hagan, G.K. Vurbek and J.H. Heaney
Naval Health Research Center, San Diego, CA 92186-5122 USA

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 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 (Ve), breath rate (fR), oxygen uptake (VO₂) and carbon dioxide production (VCO₂) for calculation of energy expenditure (EE) in watts. Ambient conditions inside the chamber were monitored continuously for dry-bulb (Tdb), wet-bulb (Twb), black-globe (Tbg) and RH, while conditions outside of the chamber were monitored for Tdb.

Body temperatures included rectal temperature (Tre), and skin temperatures from the upper right chest (Tch), right upper arm (Tar), 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·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 VE, VT, VO_{2}, VCO_{2} and EE, and significant period effects for f_B and respiratory exchange ratio (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>
<thead>
<tr>
<th>Variable</th>
<th>Trial</th>
<th>Exercise Period</th>
<th>Exercise Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{E} (L·min^{-1})</td>
<td>P &lt; 0.03</td>
<td>P &lt; 0.0001</td>
<td>n.s.</td>
</tr>
<tr>
<td>f_{B} (brth·min^{-1})</td>
<td>n.s.</td>
<td>P &lt; 0.0001</td>
<td>n.s.</td>
</tr>
<tr>
<td>V_{T} (ml·brth)</td>
<td>P &lt; 0.0001</td>
<td>P &lt; 0.0001</td>
<td>n.s.</td>
</tr>
<tr>
<td>VO_{2} (L·min^{-1})</td>
<td>P &lt; 0.04</td>
<td>P &lt; 0.0001</td>
<td>n.s.</td>
</tr>
<tr>
<td>VCO_{2} (L·min^{-1})</td>
<td>P &lt; 0.04</td>
<td>P &lt; 0.0001</td>
<td>n.s.</td>
</tr>
<tr>
<td>RER</td>
<td>n.s.</td>
<td>P &lt; 0.0001</td>
<td>n.s.</td>
</tr>
<tr>
<td>EE (watts)</td>
<td>P &lt; 0.04</td>
<td>P &lt; 0.0001</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

During the 3 trials, f_B averaged 17 brth·min^{-1} during rest and 22 brth·min^{-1} during exercise. During MOD, WARM and HOT, resting V_{E} averaged 13.8, 14.8 and 15.6 l·min^{-1}, respectively, while exercise V_{E} averaged 23.8, 24.7 and 26.4 l·min^{-1}, respectively (Fig. 1). For all tests, resting VO_{2}, VCO_{2} and EE averaged 0.50 l·min^{-1}, 0.41 l·min^{-1} and 175 ± 15 watts, respectively. For MOD, exercise VO_{2}, VCO_{2} and EE averaged 0.93 l·min^{-1}, 0.74 l·min^{-1} and 314 watts, respectively (Fig. 2). For WARM, exercise VO_{2}, VCO_{2} and EE averaged 0.96 l·min^{-1}, 0.77 l·min^{-1} and 333 watts, respectively. For HOT, VO_{2}, VCO_{2} and EE averaged 1.00 l·min^{-1}, 0.82 l·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
Gain in heat storage averaged 38.2°C and 6.7°C, respectively, while during HOT, T_e and storage averaged 37°C and 2.5°C, respectively. However, during the second exercise period of WARM, T_e and increase in heat storage remained low at 37°C and 0.23°C, respectively.

The second period of HOT and during WARM, T_e remained high and increased by increases in T_e and heat storage during WARM, HOT, and MOD. However, the increase in heat storage remained low at 37°C and 0.23°C, respectively.

Even costs reduced to athletic removal and oxidation, for oxidation and ventilation (3). Gen costs reduced to athletic removal and oxidation for oxidation and ventilation (3). 20-min rest period in cool air, if it is unlikely that the higher EE was a function of O2-
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.

REFERENCES

