EVALUATION OF THE HEAT STRESS IMPOSED BY A PROTOTYPE FIREFIGHTER ENSEMBLE WITH CHEMICAL/BIOLOGICAL HAZARD PROTECTION

W. Jon Williams[1], Aitor Coca[1], Raymond Roberge[1], Jeffery Powell[2], Angie Shepherd[1], Ronald Shaffer[1]

[1]NIOSH/NPPTL, Pittsburgh, PA, [2]EG&G Technical Services, Pittsburgh PA

Contact person: W. Jon Williams
aun7@cdc.gov

INTRODUCTION

Firefighters experience a high number of injuries and fatalities due to cardiovascular events and heat stress (Houser et al., 2004). On the assumption that firefighters may eventually be called, as first responders, to an event involving chemical or biological hazards, the Technical Support Working Group (TSWG) funded a proposal by the International Association of Fire Fighters (IAFF) to develop a prototype structural fire fighting ensemble with additional chemical and biological (CB) hazard protection. The prototype was designed to protect against chemical and biological hazards through improvements in the moisture barrier, innovative boots-to-pants and glove-to-sleeve interfaces, and vapour-tight-zippers. Unfortunately, these innovations could potentially lead to even greater heat stress to the wearer (Slepicka and Rogers, 2005). However, the prototype ensemble (PE) also incorporates a novel feature to both improve chemical and biological hazard protection as well as provide a reduction in thermal stress. This feature consists of a rubber hose assembly that provides a connection between the self-contained breathing apparatus (SCBA) respirator regulator exhaust valve and the turnout gear jacket that streams exhaust gases directly into the upper part of the turnout gear jacket. NPPTL was asked to evaluate the cardiovascular and thermoregulatory responses to the prototype ensemble with additional chemical and biological hazard protection, which included a hose assembly to reroute expired SCBA air into the jacket for possible cooling purposes. The purpose of the study was to evaluate the physiological responses in subjects wearing either a standard ensemble (SE) or the PE.

METHODS

Ten healthy non-smoking subjects (7 male and 3 female) were recruited to participate in this study (Table 1). Each subject was briefed on the nature and requirements of the testing and gave both oral and written informed consent. The experimental protocol was reviewed and approved by the NIOSH Human Subject Review Board. Testing was conducted in an environmental chamber at 22 ºC and 50% RH.

Table 1: Anthropmetric characteristics of the subject pool.

SUBJECT	GENDER	AGE	HEIGHT (cm)	WEIGHT (kg)	BODY SURFACE	BODY FAT %	BMI
1	F	32	157	53	1.55	13.9	22.1
2	F	28	173	73	1.87	21.3	24.7
3	M	25	168	72	1.82	14.7	24.6
4	M	21	175	68	1.83	13.1	21.8
5	M	25	183.5	92.1	2.14	18.2	25.2
6	M	38	173	88	2.02	17.6	29.2
7	F	20	165	52.3	1.56	9.54	19.2
8	M	21	183	80.2	2.02	9.94	23.9
9	M	21	173	68.2	1.81	8.06	22.7
10	M	22	185	84.5	2.08	7.45	24.6
MEAN		**25.3**	**173.6**	**73.1**	**1.87**	**13.4**	**23.8**
SD		**5.9**	**8.8**	**13.5**	**0.20**	**4.7**	**2.6**

Four sessions were carried out in order to examine the physiological responses of human subjects while wearing a standard ensemble (SE test average between two identical tests) compared to a prototype ensemble (PE with hose and PE without hose) while exercising at ~50% relative aerobic capacity ($\dot{V}O_2max$) on a treadmill. Full description of the materials used in this investigation (SE, PE, and SCBA) can be found on Coca et al. 2008. Core body temp (rectal), mean skin temp (T_{sk}), sweat rate (measured as loss of body weight during testing), and duration of exercise time (endurance time) were measured during the sessions. A repeated measures analysis of variance (ANOVA) with significance set at $p < 0.05$ was used to determine differences for rectal temperature, skin temperatures, sweat rate, and endurance time.

RESULTS

Rectal Temperature

The rectal temperature of subjects wearing either the PE or SE increased ($p < 0.01$) during 20 min of treadmill exercise in an environmental chamber. There was no significant difference in baseline rectal temperatures prior to treadmill exercise between subjects wearing the SE (37.04 ± 0.30 °C), the PE with hose (37.13 ± 0.25 °C) and PE without hose (37.05 ± 0.26 °C). After 20 minutes of exercise at 50% $\dot{V}O_2max$, there was no significant differences in rectal temperature between subjects wearing the SE (37.52 ± 0.36 °C), the PE with hose (37.66 ± 0.31 °C), and the PE without hose (37.53 ± 0.31 °C). As expected, rectal temperature continued to increase during the 5 minute post-exercise recovery period. However, rectal temperature was not significantly different between SE (37.99 ± 0.34 °C), PE with hose (38.01 ± 0.29 °C), and PE without hose (37.91 ± 0.30 °C).

Mean Skin Temperature (T_{sk})

After 20 min of treadmill exercise, the increase in subject mean T_{sk} was greater ($p < 0.01$) while wearing the PE with hose and PE without hose compared to the SE. This suggests that the PE imposed a greater overall thermal stress on the wearer compared to the SE. Mean T_{sk} increased ($p < 0.01$) in all subjects wearing either the PE or SE during 20 min of treadmill exercise in an environmental chamber. There were significant differences ($p < 0.01$) in baseline average T_{sk} between the subjects wearing SE (30.35 ± 1.53 °C), subjects wearing PE with hose (31.26 ± 0.72 °C), and subjects wearing PE without hose (32.16 ± 1.00 °C). At the end of the 20 minute bout of treadmill exercise, there were significant differences ($p < 0.01$) in T_{sk} between subjects wearing the SE (35.52 ± 0.51 °C), subjects wearing the PE with hose (36.53 ± 0.44 °C), and subjects wearing the PE without hose (36.38 ± 0.49 °C).

Sweat Rate

All subjects lost weight due to sweating during the treadmill exercise testing while wearing either the PE or SE during treadmill exercise in an environmental chamber. The loss of nude body weight averaged between 0.45-0.95 kg. This translates into an average sweat loss of 0.45-0.95 L over the 20 minute treadmill exercise test. Thus, the average sweat rate for subjects wearing the SE was 22.39 ± 9.8 g/min, 31.79 ± 13.9 g/min for subjects wearing the PE with hose, and 27.24 ± 10.4 g/min for subjects wearing the PE without hose. Although sweat loss tended to be greater in subjects wearing PE with hose, the results did not reach significance ($p = 0.16$). There were not significant differences in sweat rate per unit time between subjects wearing SE, PE with hose, or PE without hose.

Endurance Time

Overall endurance time (Figure 1) varied between subject based on their overall fitness and body size. However, each subject exercised for at least 20 minutes. However, overall endurance time in subjects wearing the SE (28.58 ± 7.4 min) was significantly longer ($p < 0.05$) than subjects wearing either the PE with hose (23.65 ± 3.9 min) or the PE without hose (25.4 ± 6.6 min).

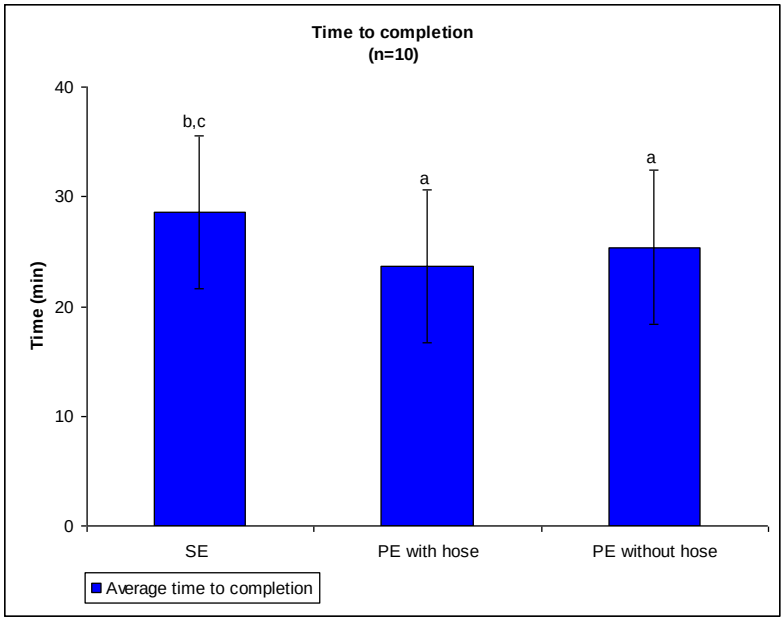

Fig. 1: Time to completion for subjects wearing either the PE or SE during treadmill exercise in an environmental chamber. *There was a significant difference between the standard ensemble (SE) and the prototype ensemble ($p < 0.05$). Superscripts indicate statistically significant differences ($p<0.05$) between tests; SE = a; PE with hose = b; PE without hose = c.

DISCUSSION

"Core" temperature data suggest that there is no difference in the thermal stress imposed on the subject between the PE (with or without hose) and the SE. Mean T_{sk} suggest that the subjects wearing the PE with exhalation hose attached to the jacket experienced an elevated thermal stress compared to subjects wearing the PE without the hose or wearing the SE.

There was a trend toward an increase in sweat rate in the PE compared to the SE; however, the differences did not reach statistical significance. Subjects' time to completion wearing the PE with the exhaust hose was significantly less ($p < 0.05$) than the time to completion of the subjects wearing the SE. Subjects wearing the SE exercised on the treadmill an average of 5 min longer than while wearing the PE with the exhaust hose attached and an average of 3 minutes longer than while wearing the PE without the exhaust hose attached.

CONCLUSIONS

Our study data indicate that the increased encapsulation modifications incorporated into a prototype fire fighter ensemble to enhance chemical and biological hazard protection do not result in a significant elevation in core temperature over that of the standard ensemble at 50% of maximal work rate while wearing a SCBA. This dampening effect on anticipated greater core temperatures of the prototype fire fighter ensemble is arrived at by an increase in the physiological burden to the wearer as manifested by associated increases in sweat rate, and skin temperatures, as well as a decrement in endurance times. However, the additional chemical and

biological hazard protection offered by the PE still allows the wearer to exercise for at least 20 minutes which is the practical duration of an SCBA while fighting a structural fire.

REFERENCES

Coca A, Roberge R, Shepherd A, Powell JB, Stull JO, Williams WJ (2008). Ergonomic comparison of a chem/bio prototype fire fighter ensemble and a standard ensemble. European Journal of Applied Physiology 104 (2), 351-359.

Houser AN, Jackson BA, Bartis JT, Peterson DJ (2004). Emergency responder injuries and Fatalities: An analysis of surveillance data. TR-100-NIOSH, Pittsburgh, PA: RAND Corporation.

Slepicka, L., Rogers, T., 2005. Project Heroes creates PPE of the future. Firehouse magazine. (http://www.firehouse.com/news/2005/ppe.html)

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