HEAT STRAIN DURING SHIPBOARD FIREFIGHTING: SKIN AND CORE TEMPERATURE CONVERGENCE

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INTRODUCTION

The U.S. naval shipboard firefighting ensemble enables the firefighter to approach and effectively combat fires. However, after prolonged use this protective overgarment restricts body heat transfer and causes an increase in heat strain. The combined effects of high metabolic rates, protective overgarments, and rapid exposure to high heat and steam, makes it difficult to identify the factors that limit work tolerance time. Pandolf and Goldman (4) postulated that subjects, working in a hot environment and wearing protective overgarments, would be near collapse shortly after mean skin temperature approached core temperature. Recently, Nunneley et al. (3) challenged the position that convergence of mean skin and core temperature was not a good predictor of work tolerance in heat. Previous studies suggested that reductions in work tolerance may be better explained by the magnitude and/or rate of body heat storage (1,2). This paper presents the preliminary findings of skin and core temperature convergence during active shipboard firefighting.

METHODS

Controlled fire tests were conducted onboard the USS Shadwell (decommissioned LSD-15) located at Little Sand Island, Mobile, Alabama. Participants were active duty U.S. Navy personnel. Nine subjects had their physiological responses recorded during three days of active fire suppression. Four site skin temperatures, rectal temperature and heart rate were continuously recorded from four subjects per test by a data logger, worn underneath the firefighting ensemble. After ignition of the fire and sounding of the shipboard damage control alarm, subjects moved quickly to a damage control locker to dress in the standard Navy firefighting ensemble (single piece semi-impermeable fire retardant suit (Nomex), gloves, rubber boots, flash hood, hard helmet, and oxygen breathing apparatus). After dressing, the subjects performed activities to contain and suppress the fire. Mean body temperature (MBT) was calculated at three time periods: (1) at the convergence of mean skin and core temperature (MBTc); (2) at the maximal difference between mean skin and core temperature beyond the convergence point (MBT max); and (3) at the peak MBT temperature beyond the convergence point (MBT peak). The maximal difference was calculated between mean skin and core temperature (Tre-Tmsk) beyond the convergence point. Finally, the rate of increase for rectal temperature (Tre slope) and mean skin temperature (Tmsk slope) was calculated for the active firefighting period.

RESULTS

Indicators of heat strain during active firefighting are presented as group means in Table 1. Peak fire temperatures reached 600°C, while temperatures in the adjoining firefighting compartments were 76°C, 66°C, and 44°C for Day 1, 2, and 3. The different absolute temperatures partially account for the progressively lower magnitude of heat strain across all three days. During the fire tests, firefighting produced peak core temperatures of 39.9±1.2, 38.4±0.2 and 38.9±0.1°C, and peak heart rates of 200±4, 184±10 and 174±10 bpm for Day 1, 2, and 3, respectively. MBTc ranged from 37.5 to 38.3°C. The maximal difference between skin and core temperature beyond the convergence point ranged from -0.04 to -1.9°C, and occurred at a MBT maximal difference which ranged from 38.5 to 38.9°C. These points are equal to or slightly less than the MBT peaks for Day 1, 2, and 3, respectively. The change in body heat storage was 93.5±24.1, 72.0±20.7 and 70.7±11.5 kcal•m^{-2}, while rates of body heat storage during active firefighting were 224, 191, and 78 kcal•m-2•hr^{-1}, for Day 1, 2, and 3, respectively.

Table 1. Heat strain and skin and core temperature convergence variables.

Test	Tre slope (°C/min)	Tmsk slope (°C/min)	MBTc (°C)	MBT max diff(°C)	Tre-Tmsk (°C)	MBT peak (°C)
Day 1	.06±0.03	.20±0.12	38.1±0.3	38.9±0.4	-0.6±1.1	39.6±1.2
Day 2	.05±0.02	.15±0.10	37.5±0.1	38.6±0.2	-1.9±0.5	38.6±0.2
Day 3	.04±0.01	.07±0.02	38.3±0.2	38.5±0.2	-.04±0.2	38.7±0.1

CONCLUSION

We have documented the physiological strain of firefighting during actual shipboard conflagrations. Dressing in the standard Navy firefighting clothing ensemble and equipment, and performing physical activities during active firefighting produced a high level of individual heat strain when air temperatures in the firefighting compartment reached 76°C. Heat strain during firefighting is characterized by increases in, and convergence of rectal and skin temperatures, high level of body heat storage, high body temperatures, and high heart rates. The subjects reported no physical complications or an inability to sustain work as a result of convergence of skin and core temperatures during these three tests. If the issue of skin and core temperature proves to be a predictor of heat tolerance, then the application of this criterion measure may be dependent on steady state environmental temperature, metabolic rate and the type of protective overgarment. Work tolerance in high heat may be related more to the magnitude and rate of heat storage as previously shown by Blockley et al. (1) and Craig et al. (2), than the convergence of skin and core temperature. Future research will examine the best predictors of decreased work tolerance associated with firefighting ensemble and chemical protection overgarments.

REFERENCES

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