

THERMAL PROTECTION OF TWO GARMENTS DURING HEAT EXPOSURE AT 180°C

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INTRODUCTION

During firefighting operations personnel need to be protected from excessive heat. The Fearnought suit (FN) is the Royal Navy's (RN) current firefighting garment which is heavy and insulative and thus is likely to increase thermal stress. Aural temperatures in excess of 38°C have been recorded after just one 10 minute work period during firefighting trials at sea'. Heat stress and therefore the risk of heat illness would be reduced if the FN suit was replaced by a garment which retained less body heat and was more permeable to water vapour, allowing greater heat loss during rest periods. However this may increase heat transfer from the environment and therefore also the risk of burns when exposed to high temperatures during firefighting. The Action Coverall (AC) is a double layered Proban treated cotton garment designed to protect personnel from **flash** in the event of an explosion and has been proposed as a possible replacement garment. This study was conducted to assess the thermal protection offered by both clothing ensembles. Previous trials^{2,3} have measured ship compartment temperatures in the range 120-160°C during fires at sea. RN firefighters are normally protected from such high temperatures by a sea water delivery system which provides a near vertical sheet or wall of water in front of the firefighting team reducing the thermal load experienced. In a pilot study this 'water-wall' protection reduced compartment temperature from 160 to 30°C behind the 'water-wall'⁴. However, in the event of a failure of water this protection is lost and firefighters would have to evacuate the fire compartment. Following a series of experiments' at progressively higher ambient temperatures from 80 to 160°C, this final study was carried out to assess the performance of the two clothing ensembles at 180°C to determine if the proposed firefighting garment, the AC, provided sufficient protection against skin burns and to quantify safe exposure times to ensure that personnel would have enough time to escape in the event of a failure of the water supply. Firefighting garments have to prevent skin temperatures reaching 45°C as skin temperatures as low as this have been reported to cause 1° (superficial) burns, although this burn threshold depends greatly upon the rate of warming of the skin⁵. However, pain receptors have a sensory threshold of 43.2°C independent of the rate of rise of skin temperature⁶ and provide a warning that the skin is about to burn'. Therefore during these experiments the skin temperature safety limit was set at 42°C.

METHODS

Following local ethical approval volunteer subjects were recruited. A series of experiments were carried out at an RN Firefighting School to compare the thermal protection offered by the AC and FN ensembles, during single and repeated entries into a hot compartment at 180°C. Four subjects participated in the trial on each day. Each underwent four conditions on separate days namely single and repeated entries wearing each clothing ensemble. The experiment was repeated on the following week to provide up to 8 data sets for each condition. Subjects were instrumented with thermistors to measure rectal (T_{rect}) and skin (T_{sk}) temperatures (forehead, left and right neck, back, chest and arm) and a three lead ECG to measure heart rate (hr) with all measures recorded electronically at 1 minute intervals by a data logger (all equipment - Grants Instruments, Cambridge). The data logger was connected to an audible alarm that sounded if any of the safety limits were reached ($T_{rect} = 38.5^\circ\text{C}$, $T_{sk} = 42.0^\circ\text{C}$ and $hr = 210\text{-age bpm}$). The subjects entered a compartment at 180°C and walked slowly in a circle for 20 minutes. During the first 10 minutes they were protected with a 'water-wall', the water supply was then turned off and subjects were exposed to the full heat of the compartment for the latter 10 minutes. During the double entry experiments subjects rested in a warm compartment at 30°C for 20 minutes before returning to the hot compartment for another 20 minutes using the same procedures as the first entry.

RESULTS

During the first 10 minutes, 'water-wall' protection reduced compartment temperatures to around 30°C. When the water was switched off the compartment temperature, measured at head height, rose to 180°C within 5 minutes. During the first 10 minutes skin temperatures did not rise significantly because of the protection offered by the 'water-wall' and in the AC ensemble they often fell because of wetting through to the skin. In the FN ensemble water did not penetrate to the skin. The following-10 minute exposures without 'water-wall' resulted in rapid rises in skin temperature (the last two minutes were excluded from analysis due to occasional subject removal after 8 minutes of exposure: 5 due to skin temperature limits ($\geq 42^\circ\text{C}$), 5 due to inspired air limits ($\geq 80^\circ\text{C}$), 2 equipment failures and 1 heart rate limit (210-age of subject). There was an indication that

the mean rise of chest and upper arm temperatures in 8 minutes were greater in the AC, (5.5 and 7.7°C respectively) compared to the FN. (3.5 and 4.8°C mins respectively ($P < 0.1$). The only statistically significant difference in skin temperatures, with respect to the 2 garments was measured on the back, after 8 minutes of heat exposure (without 'water-wall'). Subjects wearing the AC had a back temperature (mean 39.1°C) significantly lower ($P < 0.01$) than when wearing the FN (mean 39.8°C). This apparent anomaly can be explained by the local cooling by water which soaked through the thinner AC ensemble. The back temperatures were also the highest of all sites measured in either ensemble followed (in order) by the upper-arm, forehead and neck.. During double entry exposures, skin temperatures measured during the rest period remained above 35°C. Furthermore, rectal temperatures rose throughout the double entry experiments at a rate of 0.72°C/hr, indicative of progressive heat strain. However absolute skin temperatures reached during the second entry exposure were not significantly higher than those attained during the first entry for either clothing ensemble.

CONCLUSIONS

This study has shown that with a 'water-wall' both ensembles provide adequate protection for RN firefighters. As the mean skin temperature at each measurement site were all under 40°C, 8 minutes after removal of 'water-wall' protection then both garments can be considered to protect personnel for this time in the event of a failure of water. Calculations from the rates of rise of skin temperatures at each site indicate that the time before burns were likely would be in excess of 10 minutes. This would allow adequate time for personnel to escape in the event of a failure of the water supply during firefighting. The weakest point of each clothing ensemble *i.e.* that area of the body surface which had the highest temperature during the heat exposure, was the back. This appeared to be a result of the metal backplate of the breathing apparatus (BA) compressing the clothing, reducing thermal insulation and conducting heat through to the back. This occurred in both ensembles. Further trials⁸ were carried out to investigate the effect of using Fearnought material to insulate the BA backplate and bottle (also presented at this meeting). These trials indicated that this insulation reduced the resultant back temperature during heat exposure in both ensembles although only for the FN ensemble was this reduction statistically significant (temperatures reduced from 39.8 to 37.5°C $P < 0.01$). However, although the safe exposure time for this site was increased, the overall increase in safe exposure time for the whole ensemble was limited due to the risk of burning to the upper-arm closely followed by the head which, in both clothing ensembles, was only protected by a thin cotton anti-flash hood.

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