2002

The effect of fire simulation on clothing and tissue temperatures

Alison L. Fogarty  
*University of Wollongong*

Karen A. Armstrong  
*University of Wollongong*

Brian F. Woods  
*New South Wales Fire Brigades*

Nigel A. S Taylor  
*University of Wollongong, ntaylor@uow.edu.au*

Publication Details

The effect of fire simulation on clothing and tissue temperatures

Abstract
A series of field trials was undertaken to evaluate the thermal properties of five different personal protective ensembles, under more realistic experimental conditions. This project was designed to address the following applied questions, which could assist in the selection of suitable ensembles for the New South Wales Fire Brigades: (a) Are there between-ensemble differences in the storage of metabolically-produced heat? (b) Are there between-ensemble differences in physiological strain during real-task simulations? (c) Are there between-ensemble differences in the penetration of external heat? These field trials included two simulated fire exposures (Hot Fire Cell and Flashover Simulator), during which, from a physiological perspective, we observed remarkable clothing and local tissue temperature changes (Taylor et al., 2001). Herein we describe some of those observations.

Disciplines
Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details
THE EFFECT OF FIRE SIMULATION ON CLOTHING AND TISSUE TEMPERATURES

Alison L. Fogarty1, Karen A. Armstrong1, Brian F. Woods2 and Nigel A.S. Taylor1.

1Department of Biomedical Science, University of Wollongong, Australia
2New South Wales Fire Brigades, Sydney, Australia.

INTRODUCTION
A series of field trials was undertaken to evaluate the thermal properties of five different personal protective ensembles, under more realistic experimental conditions. This project was designed to address the following applied questions, which could assist in the selection of suitable ensembles for the New South Wales Fire Brigades:
(a) Are there between-ensemble differences in the storage of metabolically-produced heat?
(b) Are there between-ensemble differences in physiological strain during real-task simulations?
(c) Are there between-ensemble differences in the penetration of external heat?

These field trials included two simulated fire exposures (Hot Fire Cell and Flashover Simulator), during which, from a physiological perspective, we observed remarkable clothing and local tissue temperature changes (Taylor et al., 2001). Herein we describe some of those observations.

METHODS
Two field studies were undertaken. In the first project, eleven firefighters (4 females, 7 males; aged 22-51 y; mean 35.3 ±9.8 y) completed an alternating work and rest trial, lasting approximately 70 min. The tasks performed in each trial included: warm-up activities (walking, hose drill), a Hot Fire Cell exposure, tower climbing, and an exposure within a Flashover Simulator. Twelve trials were performed involving the five ensemble configurations, with subjects being tested in pairs. Maximal daily air temperatures ranged between 23-27°C, while Hot Fire Cell temperatures, at three positions, were 124-128°C (ceiling), 114-117°C (middle) and 97-107°C (floor). Temperatures in the Flashover Simulator were not able to be recorded. The Hot Fire Cell exposure was not observed by the experimenters, but was controlled by a fire officer, and involved a simulated search and rescue training exercise. The tower drill involved completing four trips from to the top of the tower (15 metres) and back, without breathing apparatus. Each cycle was paced to be completed in approximately 90 sec. The Flashover exposure varied in intensity between trials, with subjects varying their posture as the thermal load increased. However, all subjects commenced these exposures standing, then moved to seated and then to lying positions, so that exposure duration could be maximised.

Rectal (Tₑ), local and mean skin (Tₛ), clothing (inner and outer shirt and inner tunic) and inner helmet temperatures were recorded at 0.25 Hz using a data logger (Yellow Springs Instruments Co. Inc., Yellow Springs, OH, U.S.A; 1206 Series Squirrel, Grant Instruments Pty. Ltd., Cambridge U.K.). Each subject carried a data logger in a bag placed outside the shirt, but under the tunic.

To more closely examine heat penetration with each garment, a second experiment was performed, in which three subjects sat in a Flashover Simulator for 34 min, with each officer wearing one of the clothing ensembles. The trial started with subjects seated inside the simulator chamber, 40 cm above the floor, with baseline data recorded before the fire was ignited (5 min). The trial was terminated when the intensity of the fire had decreased beyond its peak. The simulator was prepared to provide the most realistic flashover. Temperatures in the Flashover Simulator exceeded the upper limit of the thermistors, and were not able to be recorded. Each subject reported slight skin burns after exposure, but none were withdrawn from the simulator during the flashover.

For this second set of exposures, only skin and clothing temperatures (outer shirt and inner tunic) were measured (0.25 Hz: Yellow Springs Instruments Co. Inc., Yellow Springs, OH, U.S.A.; 1206 Series Squirrel data logger, Grant Instruments Pty. Ltd., Cambridge U.K.). Skin temperatures were recorded at the chest and the front of the leg (shin). The following clothing temperatures were measured in the same horizontal plane as the two skin measures: inner shirt, outer shirt, inner tunic, inner trouser, inner overpant. A final thermistor was positioned on the outer surface of the tunic, but under the flame protective cover of the tunic.

For both sets of trials, the subjects and researchers were blind to the thermal protective qualities of each ensemble, which were revealed to the researchers only after data analysis, and the provision of a preliminary report. Each ensemble was cleaned five times before testing commenced. For each trial, subjects wore their own underclothing, and their standard-issue boots, socks, drill shirt and woollen pants, along with the standard-issue helmet, flash hood, and gloves. Self-contained breathing apparatus, with a fully-charged cylinder, was also worn with subjects breathing cylinder air during the Hot Fire Cell and Flashover Simulator exposures. Cylinders, gloves and flash hoods were removed during the rest periods, and the tunics were opened, as would be the case within the operational setting.
RESULTS
In the first trial, the average $T_{ac}$ across all ensembles, was 38.2°C, with the greatest rate of increase being 1.7°C·hr$^{-1}$. The highest $T_{ac}$ (42.1°C) occurred in the Flashover Simulator, but $T_{ac}$ greater than 40°C were also recorded during the Hot Fire Cell. The peak helmet temperature was 44.2°C, immediately after leaving the Hot Fire Cell. The highest average tunic temperatures were 44.2°C (Hot Fire Cell) and 51.5°C (Flashover Simulator).

During the second flashover simulation, air temperature, recorded under the flame protective cover, ranged from 31.7°C to 145.1°C, averaging 63.7°C over the 34-min exposure. The highest upper-body clothing and local skin temperatures were: 91.1°C (inner tunic), 59.4°C (outer shirt), 53.5°C (inner shirt) and 41.7°C (chest). The corresponding lower-body temperatures were: 102.7°C (outer pant), 86.9°C (inner trouser) and 46.7°C (leg). These data are summarised for three different ensembles in Table 1.

Table 1: The peak clothing and skin temperatures during a Flashover Simulator exposure.

<table>
<thead>
<tr>
<th>Site</th>
<th>Ensemble</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{air}$</td>
<td>A</td>
</tr>
<tr>
<td>145.05</td>
<td>145.05</td>
</tr>
<tr>
<td>$T_{outer}$</td>
<td>41.05</td>
</tr>
<tr>
<td>53.50</td>
<td>48.00</td>
</tr>
<tr>
<td>$T_{inner}$</td>
<td>59.40</td>
</tr>
<tr>
<td>81.70</td>
<td>85.65</td>
</tr>
<tr>
<td>$T_{leg}$</td>
<td>46.65</td>
</tr>
<tr>
<td>58.90</td>
<td>86.85</td>
</tr>
<tr>
<td>$T_{lower}$</td>
<td>83.35</td>
</tr>
</tbody>
</table>

Abbreviations: $T_{air}$ = air temperature, $T_{outer}$ = temperature of inner surface of tunic; $T_{outer}$ = temperature of outer surface of shirt; $T_{inner}$ = temperature of inner surface of shirt; $T_{chest}$ = chest temperature, $T_{leg}$ = leg (anterior shin) temperature. **Ensemble characteristics:** A: Heat transmission index (16), outer (Nomex delta $T$), inner (dual-layer Sontara quilted with Nomex/FR viscose scrim); B: Heat transmission index (17), outer (Nomex delta $T$), inner (dual-layer Sontara quilted with Nomex/FR viscose scrim); and C: Heat transmission index (14), outer (Nomex IIIA), inner (dual-layer Sontara quilted with Nomex/FR viscose scrim).

The peak temperature change at the inner tunic was 56.8°C (ensemble A) during the second flashover. In this case, both the inner and outer shirt temperatures were lower than observed in either of the other ensembles. This difference can only be attributed to the volume of trapped air, and must therefore be associated with uniform fit, rather than to differences in the insulative qualities of the uniforms.

DISCUSSION
A skin temperature between 39-41°C represents the threshold for transient pain, the threshold for burning pain occurs between 41-43°C, and local skin temperatures >45°C are accompanied by tissue damage (2). A second-degree burn would be anticipated from a contact exposure to ~50°C for ~4 min (3). Accordingly, these data indicate that, despite the use of thermal protective ensembles, skin temperatures during such simulations approach, and exceed, levels associated with skin burns, and each of the subjects in the second flashover experienced minor skin burns.

While such case-study experiments are limited in their ability to contribute to clothing evaluation, they do provide a means by which a more realistic assessment of heat penetration may be undertaken. Such data provide great insight into the magnitude of the thermal load transmitted through thermal protective clothing, and the thermal micro-environment within each ensemble, during extreme heat exposures. Indeed, it is this environment which most immediately impacts upon the firefighter.

The inner tunic temperatures increased dramatically during the Hot Fire Cell and the Flashover Simulator exposures, yet these changes were markedly reduced at the outer surface of the shirt. This thermal gradient highlights the insulative power of trapped air, and has considerable practical significance. Whilst the prescribed operational clothing for firefighters is well established, it is also recognised that adherence to this prescription is not complete. The above observations reinforce the importance of clothing worn below the tunic, as providing part of the total thermal protection for the firefighter. For instance,
the insulation provided by the tunic, whilst considerable, would be inadequate on its own to prevent second-degree skin burns during a flashover simulation, in the absence of a long-sleeved shirt. Thus, the shirt, which offers negligible thermal protection, becomes an integral part of the total thermal insulation of the firefighter, due to its ability to trap air both between the skin and the shirt, and between the shirt and the tunic.

ACKNOWLEDGEMENTS

The project was funded by a research grant from the New South Wales Fire Brigades (Australia).

REFERENCES

