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A physiological evaluation of shelters that might sustain life during an Australian bushfire

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A physiological evaluation of shelters that might sustain life during an Australian bushfire

Abstract

South-Eastern Australia experiences the most frequent and severe bushfires in the world. In 2009, bushfires in Victoria claimed 173 lives and cost more than \$4 billion in structural damage. As a consequence, the establishment of building standards that might govern the construction of bushfire shelters was recommended. Since no relevant standards existed, it was suggested that if these shelters could keep the internal conditions to a maximal mean Modified Discomfort Index (MDI) of 39_o for 60 min, then they could restrain the rise in core temperature to no more than 2_oC. The current investigators were invited to test this hypothesis and, in this communication, provide a physiological evaluation of this recommendation across two experiments. In the first experiment, the aim was to evaluate the physiological impact of a 10_oC variation in air temperature that could be encountered at a constant Modified Discomfort Index of 39_o. The objective of the second experiment was to explore changes within the internal environment of an air-tight shelter containing pre-heated and sweating occupants.

Keywords

might, sustain, life, that, during, physiological, australian, bushfire, shelters, evaluation

Disciplines

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A physiological evaluation of shelters that might sustain life during an Australian bushfire

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Introduction

South-Eastern Australia experiences the most frequent and severe bushfires in the world. In 2009, bushfires in Victoria claimed 173 lives and cost more than \$4 billion in structural damage. As a consequence, the establishment of building standards that might govern the construction of bushfire shelters was recommended. Since no relevant standards existed, it was suggested that if these shelters could keep the internal conditions to a maximal mean Modified Discomfort Index (MDI) of 39° for 60 min, then they could restrain the rise in core temperature to no more than 2°C. The current investigators were invited to test this hypothesis and, in this communication, provide a physiological evaluation of this recommendation across two experiments. In the first experiment, the aim was to evaluate the physiological impact of a 10°C variation in air temperature that could be encountered at a constant Modified Discomfort Index of 39°. The objective of the second experiment was to explore changes within the internal environment of an air-tight shelter containing pre-heated and sweating occupants.

Methods

The first experiment involved 96 separate trials performed using 16 healthy adults (males ($n=8$) and females: 19-24 y). Semi-naked subjects were exposed (at rest) to three thermal conditions, each with a Modified Discomfort Index of 38-39°, but covering a 10°C temperature range and 40% range in relative humidity: **Condition 1:** 40°C, 70% RH; **Condition 2:** 45°C, 50% RH; **Condition 3:** 50°C, 30% RH. These conditions were held stable throughout each exposure, and subjects were tested under two pre-heated states: mild hyperthermia (core temperature 37.5°C) and moderate hyperthermia (38.5°C). These states were induced using hot-water immersion and exercise, and each was accompanied by mild dehydration (2%). Physiological strain was quantified from heart rate, and from the core, mean skin and mean body temperature responses.

The second experiment took place in an air-tight chamber (shelter simulator: 1.2 m³) housed within a larger climate chamber (Figure 1). This inner chamber was constructed to conform with the likely requirements of a bushfire shelter. Sixteen pre-heated (core temperature 38.0°C), semi-naked males (mass >75 kg) participated. Dehydration was prevented by drinking water to match mass loss, in an attempt to optimise sweating within the shelter. Upon attaining the desired pre-experimental state, subjects entered the inner chamber, which had been equilibrated to 45°C and 50% RH (**Condition 2**), and commenced a 60-min resting exposure. During this time, the physical characteristics of air sealed within the simulator were free to change. Physiological strain was again quantified, as were changes in air temperature, water vapour pressure, and the fractional concentrations of oxygen and carbon dioxide within the inner chamber.

Results and Discussion

During experiment one, subjects experienced greater cardiovascular strain in **Conditions 2 and 3** when moderately hyperthermic, reflecting a protracted elevation in skin blood flow. Indeed, three subjects had heart rates >170 beats.min⁻¹ in **Condition 2**, with six returning such values in **Condition 3**. Whilst cardiovascular strain was significant, this is well tolerated by healthy individuals. Core temperature data were inspected for evidence of hyperthermia. However, for

every individual, core temperature remained below 38°C at the end of each trial, and across both pre-heated states. That is, all participants lost heat to the air even though, in the hottest state (**Condition 3**), the air was about 11.5°C hotter than body core temperature. This observation highlights the well known power of evaporative cooling.



Figure 1: An air-tight chamber: bushfire shelter simulator.

Whilst the three **conditions** from experiment one were of an equivalent Modified Discomfort Index, they were not equally stressful. Across the three **conditions**, physiological strain became significantly greater with each increment in air temperature. Thus, when subjects were moderately hyperthermic, the respective terminal heart rates and core temperatures were (last 15 s): 96 beats.min⁻¹, 37.2°C (**Condition 1**); 115 beats.min⁻¹, 37.5°C (**Condition 2**); 119 beats.min⁻¹, 37.8°C (**Condition 3**). These step-wise elevations were expected since the Modified Discomfort Index is a derivation of the effective temperature scale, and, as such, it is merely a modified sensation index. The effective temperature scale was never designed to predict physiological responses or survival probabilities. Instead, its purpose was to define thermal comfort limits for people within air-conditioned spaces by identifying combinations of air temperature, air motion and relative humidity that would elicit equivalent comfort. Notwithstanding this limitation, it was clear that the suggestion for using a Modified Discomfort Index of 39° did not result in subjects experiencing unacceptable levels of physiological strain.

Within the air-tight chamber (experiment two), water vapour pressure and carbon dioxide concentration both climbed, whilst air temperature and the fractional concentration of oxygen were reduced. The carbon dioxide and oxygen concentrations changed linearly over the duration of these exposures, reflecting respiratory gas exchanges. However, both water vapour pressure and air temperature revealed curvilinear response characteristics. Over the last minute of these exposures, the following states were recorded within the inner chamber (bushfire shelter simulator): air temperature 40.5°C (SD 0.5); relative humidity 90.5% (SD 1.9); fractional concentrations oxygen 16.7% (SD 0.9) and carbon dioxide 3.88% (SD 0.77). The terminal heart rates, core and mean skin temperatures (last 15 s) were 139 beats.min⁻¹ (SD 11), 39.3°C (SD 0.2) and 38.8°C (SD 0.2).

Conclusions

From a purely thermal perspective, the first experiment provided support for the recommendation that bushfire shelters should aim to keep the internal conditions to a maximal mean Modified Discomfort Index of 39° for 60 min. These data show that core temperature will not rise excessively under these conditions, providing air temperature and water vapour pressure remain stable. However, these states cannot be expected to exist within an air-tight shelter, and this was the focus of the second experiment.

From experiment two, one may conclude that, within a sealed bushfire shelter, physiological strain will be progressively elevated. However, even under these conditions, it appeared that the resultant strain, whilst now being profound, would be tolerable within an emergency bushfire shelter, in which the anticipated occupancy should be limited to approximately 60 min.

In the third experiment within this series, trials involving **Conditions 1 and 2** will be repeated, but now with the air temperature and water vapour pressure progressively rising, and tracking the average changes measured during experiment two. These trials are aimed at approximating worst-case conditions within a shelter, and will also explore the impact of pre-heating and mild dehydration, as in the first experiment. This research is currently being completed, and will be communicated at the conference.