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Thermal comfort of cricket helmets: An experimental study of heat distribution

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Abstract

This research aims to characterize thermal comfort of sports helmets. For this purpose heat distribution of four selected cricket helmets was investigated using a special purpose thermal mannequin head. The tests were conducted in a laboratory with still air and controlled indoor temperature. K-type thermocouples and an infrared imaging camera were used for the study of temperature distribution. Mean temperature increment varied from 0.9 ± 0.1°C (temporal region) to 1.7 ± 0.1°C (parietal region). Temperature increment largely depended upon the location under the helmet at which temperatures were measured - higher temperatures were recorded around the frontal and parietal regions of the mannequin head. However, the differences in mean temperatures between these regions were not statistically significant ($p > 0.005$). It was found that under standard laboratory test conditions with still air, some helmet vent designs enable more effectively heat to radiate out, and vice versa depending upon the temperature gradient. The paper presents the results of this experimental investigation with specific reference to thermal comfort.

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Keywords: Cricket helmet; thermal comfort

1. Introduction

It has been reported that wearing helmets reduces airflow around the head and leads to an increase in heat-related stress in occupational and recreational sports contexts [1-4]. To our knowledge, little research has been conducted to assess improvements in cricket helmet technologies in terms of thermal comfort.

Cricket players have frequently indicated that traditional helmets cause discomfort due to heat generated within the helmets, especially when worn during the warmer months, or during more vigorous

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parts of the game, such as during cricket batting. Inefficient dissipation of heat from the helmet to the environment induces heat stress in the head region. Heat stress not only results in discomfort but can impair batting performance by compromising correct and rapid decision making, and focused attention [5]. If a method can be found to reduce the level of heat stress associated with wearing helmets, the overall performance of players could potentially be improved.

Over the years, a number of mannequin heads have been built in order to study thermal comfort and physiological aspects of helmets with varied success [2, 6-8]. The results from these studies have revealed that the head is the most effective body part for heat dissipation. Heat is transferred between the head and the environment through thermal radiation and convection, and additionally by evaporation of sweat [9].

Most of the abovementioned studies have focused on industrial [4, 8], bicycle [2, 10] and motorcycle [2, 7] helmets . However, the thermal comfort of cricket helmets has not yet been systematically studied or characterised. The aim of this study is to investigate the thermal comfort performance of selected commercially available cricket helmets that are widely used in Australia and in international test cricket.

2. Experimental Set-up

2.1. Test set-up

Figure 1 shows the test rig used to carry out the experimental study. It consists of an aluminium mannequin head, insulated pipes, a water pump and a water boiler. The pumping system was used to supply and draw warm water from the boiler (a metal urn) to the mannequin head through insulated pipes. The head was heated to around 36°C (normal body temperature). The surface temperature of the helmet was recorded by a high resolution and emissivity correcting infrared camera ThermaCAM® PM595, manufactured by FLIR System Company, USA. The surface of the mannequin head was painted white to increase the emissivity of the surface and hence reduce the likelihood of emissivity-induced errors on temperature readings.

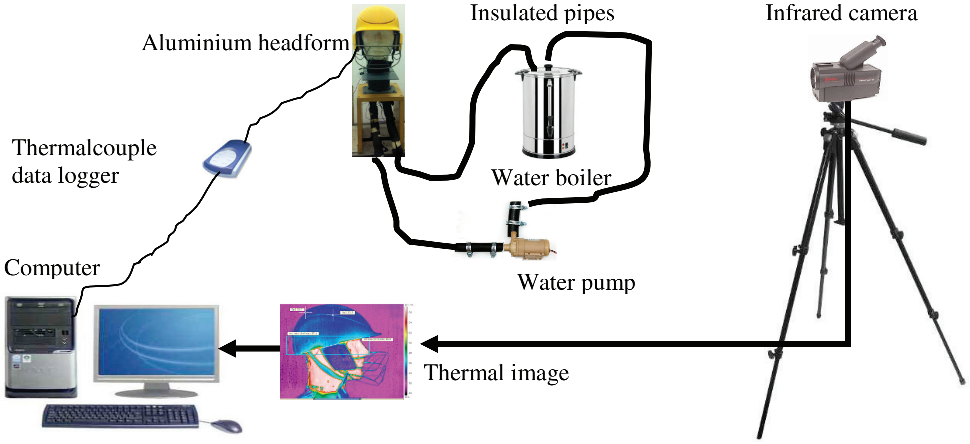


Fig. 1. Schematic diagram of experimental set-up

2.2. Temperature measurements

A total of 8 k-type thermocouples were attached to the mannequin head, as shown in Figure 2, to measure the temperatures between the helmet shell and liner. The temperatures of all thermocouples were taken at three different times, namely (i) at 0 - 2minutes where no helmet was attached, (ii) with the helmet securely fastened and when a steady-state condition was reached after 30 minutes into the experiment, (iii) after the helmet was removed from the mannequin head. Each test was performed for a period of 45 minutes and each test was repeated five times. The temperature and humidity in the laboratory were also recorded using a humidity/temperature measurement instrument, testo® 610.

2.3. Cricket helmets

In this study, four different types of commercially available cricket helmets were tested in this investigation. These helmets are shown in Figure 3.

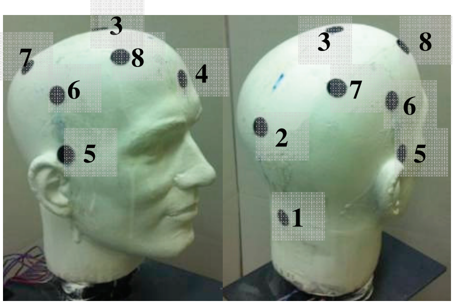


Fig. 2. Thermalcouple sampling positions

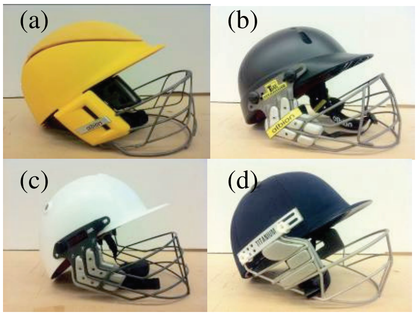


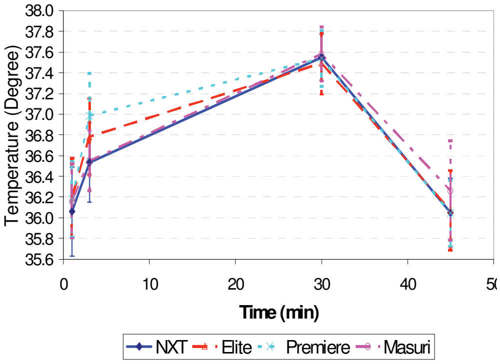
Fig. 3. Helmets used in the study (a) NXT, (b) Elite, (c) Premiere, (d) Masuri

2.4. Statistical analysis

Student's t-test for paired samples was used to compare differences between sensor locations after 30 minutes of conducting the experiment. Values of $p < 0.05$ were considered statistically significant. Data points were mean (± standard deviation) unless otherwise stated.

3. Results

The average temperature variation for all four helmets over the period of 45 minutes is shown in Figure 4. The temperature of the mannequin head increased immediately after the helmet was securely fastened, and on average the temperature increased by 1.4 °C. There was no statistically significant difference in temperature increment between the tested helmets. Temperature changes according to thermocouple position on the mannequin head are presented in Figure 5. Positions 2 and 7, which are at the rear side of the helmet, recorded the highest temperature increment as compared to other positions. On the other hand, Position 5, at the side of the helmet, showed a relatively low temperature increment. However, the difference between the former and latter is not significant.



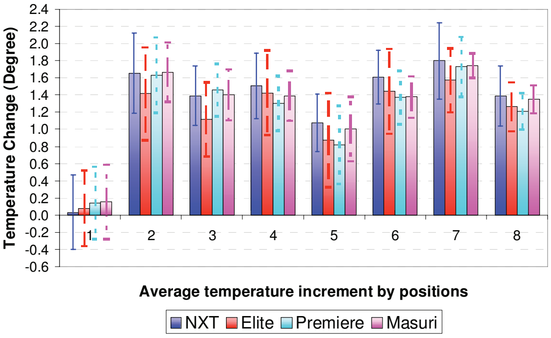
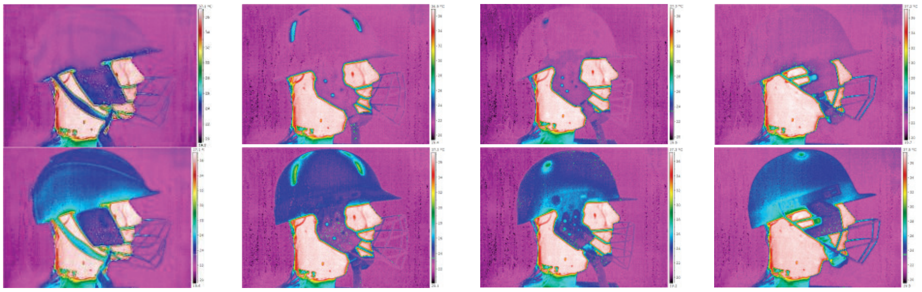


Fig. 4. Average temperature measurements of the mannequin head during the alternation interval, i.e at the beginning of experiment, < 2 min, 30 min and 45 min

Fig. 5 The distribution of mean temperature versus thermocouple positions

Figure 6 shows infrared images of the surface temperature distribution on the tested helmets. It can be seen that at the beginning of the experiment the surface temperature of the helmet shell is similar to ambient temperature. After 30 minutes, thermal images revealed an apparent temperature increment on the surfaces of the helmets due to heat transfer. Surface thermal distribution varied between models depending on the design and construction of ventilation holes of the helmet.



(a) NXT (b) Elite (c) Premiere (d) Masuri

Fig. 6. Exemplar thermal images of tested helmets during the experiment: (Top) at the beginning of experiment, (Bottom) after 30 minutes when a steady-state condition was achieved.

4. Discussion

This study is the first to our knowledge to describe and quantify the heat distribution under the cricket helmets under controlled laboratory test conditions. The effects of wind and surrounding temperature were not considered at this stage. Figure 4 and Figure 5 summarised the changes of temperature distribution observed on the mannequin head when securely placed under the four different types of cricket helmets being tested. The present study showed that head temperature increased on average between 1 - 2°C, which may cause thermal discomfort to the wearer. It has been observed elsewhere that, in general, thermal comfort (in relation to the head region) occurs when temperature is maintained within a narrow range, i.e within 34-35°C [11]. When the temperature rises above this narrow range, helmet wearers may experience thermal discomfort.

Temperature distributions under the helmet were measured according to sample positions, with Position 1 (temperature of warm water supplied from the water boiler) being used as a reference. Test results indicate different magnitudes of temperature increment according to head region (see Figure 5). One would note that all these zones do not react to thermal stimulations in the same way. The parietal and frontal regions recorded a higher temperature on average while the temporal side was cooler than other regions. This effect may be explained by the structure of the helmet - where there are openings or gaps on the side, there is less resistance, resulting in increased airflow, and increased heat dissipation.

The four different helmets tested have different designs and locations of ventilation holes: The NXT helmet, for example, has an inner liner to assist with heat dissipation. It also has a large number of holes that serve to enable constant cooling. The Elite helmet, has four ventilation holes on the side and one on the crown region of the shell. The Premier helmet contains three circular and one cross-shaped air ventilation opening at the top. Finally, the Masuri helmet has two circular holes in the crown area for air ventilation. Despite the variation in design and location of holes for ventilation between the tested helmets, results indicate no significant differences in temperatures tested at the specified thermocouple positions on the different helmets. Importantly, this study shows that the ventilation openings provide little advantage in increasing heat loss through convection from the head in 'still' air conditions.

The distribution of the radiant heat was investigated using a thermal imaging camera. This method provides a more comprehensive approach to quantifying the changes in surface temperature as compared to single point measurements such as thermocouples [12]. The emissivity factor in the camera settings was altered until the temperature measured by the camera agreed with the thermocouple. The resulting emissivity factor of 0.98 was then used for the rest of the study.

Thermal imaging was used to analyse patterns of temperature change, in order to locate areas of maximum heat generation. NXT helmet radiated more heat from the side rim, whereas the other three helmets, which contain ventilation holes, tended to radiate heat through these holes (Figure 6). The physical vent holes are effective in allowing more radiant heat to transfer from the heated mannequin head to the outer surroundings of the helmet, when the surrounding temperature is lower relative to the temperature of the head's surface. However, when the surrounding temperature is higher, vent holes will allow more radiant heat transfer to the head, which will result in heat gain rather than heat loss [10].

The helmets investigated in the present study contain vents that permit radiant heat to transfer from the head's surface to the outer surroundings of the helmets, and vice versa, depending upon the temperature gradient. This suggests that the overall design of the vents should be improved in order to optimise for heat loss, rather than to function in conflict with its fundamental purpose. Further research is needed to improve the design and ventilation of helmets in order to better facilitate convective heat loss from the head, thereby playing an important role in reducing head stress in players.

In the presented study, temperatures were measured during static and still wind conditions, which do not realistically replicate real-life conditions. Likewise, surrounding temperature has been reported as an important factor on helmet wearer comfort [13]. Therefore, further investigation on the influence of climate temperature and air velocity on cricket helmet comfort is required.

5. Conclusions

A thermal mannequin head was used to analyse heat distribution and transfer between the helmeted head's surface and the surrounding environment under controlled laboratory conditions. Four commercially available cricket helmets were selected for this study. When the mannequin head was equipped with the selected helmets, on average the head temperature increased between 1 - 2°C which may cause thermal discomfort to the wearer. The results showed that vents provide little advantage in increasing convective heat loss from the head in ‘still’ air conditions. However, they are effective in allowing more radiant heat to transfer from the heated mannequin head to the surrounding environment if the surrounding environment is of a lower temperature than the head surface. Note that the present study was conducted in ‘still air’ and static temperature laboratory conditions. The authors have considered current results as working progress and future research will include further investigation of thermal distribution of perspiring mannequin head under different external temperatures of the surrounding environment and taking into consideration different wind velocities.

Acknowledgements

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