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Evaluation of thermal and evaporative resistances in cricket helmets using a sweating manikin

Toh Yen Pang*, Aleksandar Subic, Monir Takla

School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Bundoora, VIC 3083, Australia

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A B S T R A C T

The main objective of this study is to establish an approach for measuring the dry and evaporative heat dissipation cricket helmets. A range of cricket helmets has been tested using a sweating manikin within a controlled climatic chamber. The thermal manikin experiments were conducted in two stages, namely the (i) dry test and (ii) wet test. The ambient air temperature for the dry tests was controlled to ~23 °C, and the mean skin temperatures averaged ~35 °C. The thermal insulation value measured for the manikin with helmet ensemble ranged from 1.0 to 1.2 clo. The results showed that among the five cricket helmets, the Masuri helmet offered slightly more thermal insulation while the Elite helmet offered the least. However, under the dry laboratory conditions and with minimal air movement (air velocity = 0.08 ± 0.01 ms^{-1}), small differences exist between the thermal resistance values for the tested helmets. The wet tests were conducted in an isothermal condition, with an ambient and skin mean temperatures averaged ~35 °C, the evaporative resistance, R_{et}, varied between 36 and 60 m^2 Pa W^{-1}. These large variations in evaporative heat dissipation values are due to the presence of a thick layer of comfort lining in certain helmet designs. This finding suggests that the type and design of padding may influence the rate of evaporative heat dissipation from the head and face; hence the type of material and thickness of the padding is critical for the effectiveness of evaporative heat loss and comfort of the wearer. Issues for further investigations in field trials are discussed.

1. Introduction

In Test Cricket, players typically spend considerable amounts of time under conditions of high thermal stress, both externally from environmental factors, and internally from increased heat production by the body, resulting in higher body temperature. To reduce the high temperature, the body perspires or produces sweat. As the perspiration evaporates and is transmitted to atmosphere, the body temperature is reduced and the body feels cooler (Özdil et al., 2007). Research has established that the human head plays an important role in thermoregulation; up to 50% of latent and sensible heat produced by the body is dissipated through the head, as an effect of increased temperatures and sweat production (Rasch et al., 1991; Desruelle and Candas, 2000; Jun et al., 2010).

The primary function of protective helmets is to prevent wearers from impact-related head injuries. The helmet shell, generally constructed with either composite or polymeric materials, and foam padding have been found to impede the transfer of moisture and heat, and hence reduce the head's ability to cool through the evaporation of sweat (Brühwiler, 2003; Mccullough and Kenney, 2003; Song et al., 2011). As a result, helmet usage and design could have a considerable bearing on thermal comfort. Hence, understanding the thermal behaviour of the head is important to form a basis for design and optimization of helmets for thermal comfort and to reduce heat strain to wearers (Bogerd and Brühwiler, 2008; De Bruyne et al., 2010).

Many researchers have developed a number of theories and models to analyse and understand thermal comfort (Lotens and Havenith, 1991; Fan and Chen, 2002; Mccullough and Kenney, 2003; Oğulata, 2007; Qian and Fan, 2009; Wang et al., 2011). In general, research in thermal comfort to date has primarily focused on how humans perceive thermal comfort of different textiles and apparel rather than on objective quantitative measures. For the purpose of this study, proven theories and models that are related to sports apparel comfort will be adopted.

Most of the recreational and international cricket games are played in an environment with little wind effect or low air velocity conditions (McGrath and Finch, 1996; Joshi, 2009), hence, for a

* Corresponding author. School of Aerospace, Mechanical and Manufacturing Engineering, College of Science, Engineering & Health (SEH), RMIT University, Bundoora, VIC 3083, Australia. Tel.: +61 3 9925 6128; fax: +61 3 9925 6108.
E-mail address: tohyen.pang@rmit.edu.au (T.Y. Pang).

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player wearing a helmet and standing in such an environment, and when the player's body is in thermal equilibrium with the environment, the heat gain from the body equals heat loss to the immediate surrounding, as follows:

$$M_{\mathrm{net}} \pm (C + R) - H_{\mathrm{e}} = 0 \tag{1}$$

where M_{net} is the heat generated by metabolism in the human body (Mccullough and Kenney, 2003;ASHRAE Handbook, 2009). This heat will be transferred from the body to the environment through three basic mechanisms by: (i) conduction; (ii) convection; and (iii) radiation. However, conduction is not relevant in thermal interaction of human body and environment (ASHRAE Handbook, 2009). Hence, the mechanisms of heat transfer from the human body to the environment can be classified as (a) the dry heat transfer ($C + R$ = the sum of the convection C and radiation R heat transfer), which is mainly governed by the mean temperature gradient between the clothed body surface and the environment (see Fig. 1), and (b) the evaporative heat transfer (H_{e}) governed by the difference between the water vapour pressure at the skin and that of the ambient air and by the degree of skin wetness (Mccullough and Kenney, 2003;Voelker et al., 2009; Cengel and Ghajar, 2011).

The influence of clothing on heat stress depends on the extent to which the clothing affects the heat and moisture transfer between the wearer and the environment. The two main properties of the clothing that affect the thermal balance between the wearer and the environment are the thermal resistance (R_{ct}) and the evaporative resistance (R_{et}) (Song et al., 2011). In helmets the intrinsic thermal resistance (R_{cf}) represents the resistance to heat transfer between the helmet surface and the skin and is a characteristic of the helmet ensemble itself, which is independent of the external environment and the body's condition.

Previous research has concentrated on the evaluation of heat transfer of cricket helmets without taking into consideration the sweating effect (Pang et al., 2013). However, a complete understanding of human heat exchange requires not only the convective, conductive and radiative heat losses to be measured but also this other important mechanism of heat dissipation, namely sweat evaporation (Celcar et al., 2008). In recent years, in order to fully understand the thermal behaviour of clothing systems, thermal manikins with human features (i.e. capable of generating heat and perspiration), have been used successfully in experimental investigations (Chen et al., 2003; Oğulata, 2007; Celcar et al., 2008; Wang et al., 2011).

Among several known sweating thermal manikins (Chen et al., 2003; Oğulata, 2007; Celcar et al., 2008; Wang et al., 2011), the

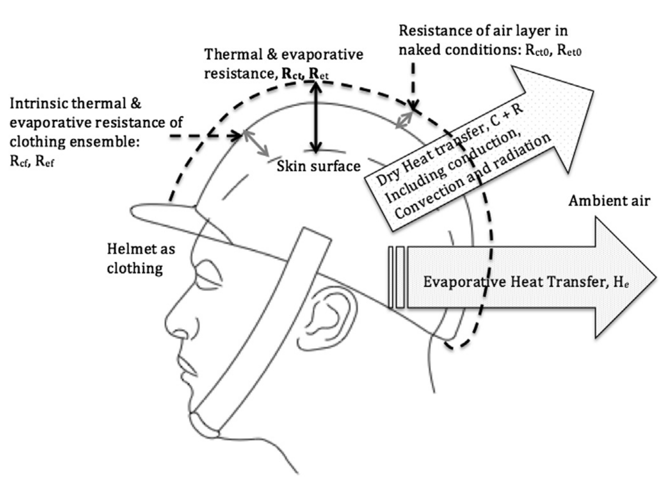

Fig. 1. Simplified clothing/helmet heat transfer model.

thermal manikin 'Newton' from Measurement Technology Northwest is built in accordance with ASTM and ISO standards and is widely used for garment and environmental heat loss evaluation. The manikin surface is divided into separate sections, each of which has its own sweating, heating and temperature measuring system. Each thermal zone has sweat control through evenly distributed fluid ports on its surface and sweating rate can be controlled by an operator (Wang, 2008; Measurement Technology Northwest, 2010) The whole 'Newton' manikin system produced reasonable results as compared against human trial studies (Blood and Burke, 2010).

The aim of this experimental study is to establish an approach to determine the thermal and evaporative resistance of a range of cricket helmets using the sweating thermal manikin measurements. These measurements would provide physical values related the heat and moisture transfer properties of helmet ensemble. Such values could contribute to the evaluation of the thermal comfort of helmet assembles, and could be used to improve helmet design by maximizing protection and minimizing thermal insulation and water vapour resistance for summer wear.

2. Materials and methods

2.1. Helmets

Five different models of commercially available cricket helmets were selected and tested in this research (Fig. 2). These reference helmets were the same as those used in the previous study conducted by the authors (Pang et al., 2013) to quantify the net heat transfer of the headgear under non-sweating conditions.

2.2. The sweating manikin

The sweating manikin called the 'Newton', operated by the automatic control software ThermDAC (Measurement Technology Northwest), was used in this research (Measurement Technology Northwest, 2010). The manikin was installed hanging in an upright standing position in the centre of a climatic chamber at the Manikin Laboratory of the School of Fashion and Textile, RMIT University. The manikin was operated statically without any body movement.

The manikin consists of 20 independently controlled thermal zones (see Fig. 3). All thermal zones are fitted with heaters to simulate metabolic heat output rates and use distributed wire sensors for measuring skin temperatures. The surface temperatures of all zones were set to 35.0 °C. The surface temperature, heat flux and heat loss were measured continuously at 10 s intervals for at least 80 min.

2.3. Experimental procedure

All the tests were conducted in a controlled laboratory within the acceptable ranges as specified in the International standards (ISO, 1995; ASTM F1291, 2010; ASTM F2370, 2010). The air was steady flowing from the chamber roof and was controlled under minimal air velocity at 0.08 ± 0.01 m/s for both dry and wet tests. Since the manikin 'Newton' is not design to measure clothing thermal insulation and moisture vapour resistance at the same time. Therefore, two separate measurements were required: (1) dry test, and (2) wet test (Measurement Technology Northwest, 2010).

2.3.1. Dry test

In the dry test condition the manikin was covered with a 'skin' suit where sweat is absent (Fig. 4). The testing environment was set at a Temperature (T) of 23 ± 0.5 °C, and a Relative Humidity (RH) of 50 ± 5% to simulate the dry conditions. The dry heat loss was