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Conceptual development and evaluation of heat relief principles for the application in bicycle helmets

Stefanie Passler*[a], Jürgen Mitternacht[a], Marius Janta[a], Veit Senner[a]

Technical University of Munich (TUM), Sport Equipments and Materials, Boltzmannstraße 15, D-85748 Garching, Germany

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Abstract

The head is one of the most heat sensitive parts of the human body. In various sports head protection is obligatory resulting in a dilemma. In situations of high metabolism heat is accumulated due to insulation properties of the helmet, leading to enormous heat stress and discomfort. Today one way to improve heat dissipation from the head is via ventilation openings. But thermodynamically, further opportunities exist either active or passive. In this paper one material- and one technology-based concept are presented and evaluated with a physical thermal head model. The former uses evaporative cooling (convection). It consists of a water reservoir, a small pump to transport the water beneath the helmet, tubes and a textile for a homogeneous water distribution. The second uses materials with beneficial conductive properties (conduction) in direct contact to the head. This concept is realized by the use of heat pipes that are integrated in the structure of the helmet and a heat sink. Cooling effect of the concepts is evaluated in two controlled thermal environments (T_1=15°C; T_2=28°C; RH=70%). Thereby the head is heated up to a constant inner temperature of T_{hy}=39°C that arises during high activity. The surface temperatures on the head are recorded by 61 evenly distributed temperature sensors, representing skin temperatures. Finally, cooling effect results from the heating energy that is needed to keep a constant core temperature. The analysed data relating to the required heating energy shows no differences between the HRSs and compared to the reference measurement. In contrast, a considerable effect of HRSs is determined, locally. Applying the HRS *Heat pipe & Heat sink* skin temperatures show decreases both at 15°C and at 28°C compared to the reference measurement. At sensor position 3 the maximum decrease can be seen by 25 %. By using the HRS *H_2O* at sensor position 3 skin temperature decreases by 13 % at 15°C and by 8 % at 28°C in comparison to the values of the reference measurement. Concerning the cooling effect, the comparison of both of the HRSs shows up to 17 % better values at 15°C using the HRS *Heat pipe & Heat sink*. At 28°C no differences can be seen. Concerning the cooling effect and the disadvantages of the evaporative cooling principle, the HRS *Heat Pipe & Heat sink* is more suited for such an application in bicycle helmets. For applying this HRS to a bicycle helmet it has to be adapted to the entire helmet and to its shape.

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* Corresponding author.
E-mail address: passler@lfe.mw.tum.de

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1. Introduction

Various scientific studies have demonstrated that bicycle helmets may protect the human head against severe injuries caused by accidents [1]. However, wearing ratio in Europe is still rather low [2]. Low thermal comfort may be one of the main reasons [3].

Over the past decades, safety standards of bicycle helmets have been improved, considerably. In contrast to these improvements, there is no standard concerning thermal comfort and ventilation of helmets. Thermal comfort of bicycle helmets depends on heat transfer from the head and to the head. The main mechanisms are convective heat loss and radiating heat absorption. The human head is one of the most thermal sensitive parts of the body [4]. Although, the surface of the human head only corresponds to 9 % of the entirely body surface, one third of the produced body heat is emitted by the head [4, 5]. In order to optimize the cooling of the head during cycling, heat transfer alternatives should be considered. In addition to bicycle helmets [6 - 10] also motorcycle helmets [11, 12] and cricket helmets [13, 14] were investigated concerning their ventilation properties and their thermal comfort. Unfortunately, the expanded polystyrene liner of the bicycle helmet appears like an excellent insulation. Thus, heat accumulation arises beneath the helmet. The combination of a high heat emission of the head, its excellent insulation due to the construction of the helmets and the insufficiently cooling of the head via ventilation openings cause uncomfortable temperatures and humidity. Nowadays, bicycle helmets have numerous vents. Generally, helmet with vents increases thermal comfort. Besides the size, the number, the arrangement and the geometry of the vents [6, 15], the ventilation of the head is influenced obviously by the head inclination angle [10, 15].

The purpose of this study is to implement two selected concepts for cooling of the human head beneath bicycle helmets to evaluate them by means of a thermal head model. These HRSs are intended to counteract a strong rise in core body temperature and skin temperature and thus improve thermal comfort.

Nomenclature

T_{hy}	Temperature of hypothalamus
RH	Relative Humidity
D	Diameter
l	Length
b	Wide
h	Height
R_{thKf}	Thermal resistance (free convection)
Q	Heat flux
HRS	Heat Relief System

2. Methodology

Measurements performed with respect to the insulating effect of bicycle helmets indicated that the heating energy to the helmet (T_{hy}=39°C) used in this study decreased by 5 % and 12 % at ambient conditions of T_1=15°C (32.7 kJ) or T_2=28°C (71.5 kJ) and RH=70 % in contrast to needed heating energy without wearing the helmet (37.1 kJ at 15°C and 81.2 kJ at 28°C). This is due to the excellent insulation of the expanded polystyrene liner and shows the importance of a cooling system integrated in helmets.

In this paper one material- and one technology- based HRS are presented and evaluated by the use of the thermal head model. The former uses evaporative cooling (convection). The second uses materials with beneficial conductive properties (conduction) in direct contact to the head. In this study both concepts are evaluated in terms of their local cooling effect as first explorations. For this reason the area is limited to 78.5 cm^2 in both concepts.

The evaporative cooling concept (Fig. 1) consists of a water reservoir, a small pump and a tube to transport the water beneath the helmet and furthermore a textile for homogeneous water distribution.

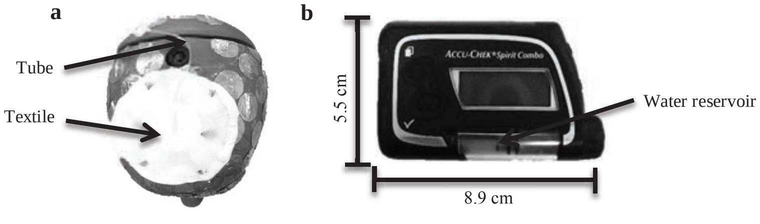

Fig. 1. (a) Textile (D=10 cm; A=78.5 cm^2) for homogeneous water distribution fixed on the thermal head model; (b) insulin pump ACCU-CHEK Spirit Combo (5.5 x 8.9 cm) with a water reservoir (3.15 ml) used for pumping cooled water onto the textile.