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# Influence of different types of the internal system of the ballistic helmet shell on the thermal insulation measured by a manikin headform

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A R T I C L E I N F O

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A B S T R A C T

The head is a part of the body whose temperature influences not only physiological parameters of the whole body but also the perception of a thermal environment and psychomotor parameters of a human. For this reason, it is important to prevent the head from overheating and to use head covers which render it possible to release heat from head surface to the environment.

There exist a number of professions where head covers serve as protection against injuries caused by an accident, trip, or striking the head against a fixed or protruding object. Ballistic helmets are one of such elements, their crucial parameter being ballistic resistance against dynamic deflection caused by a bullet or bullet-fragment. To enhance security and comfort of use of ballistic helmets internal systems are used underneath. Their character depends on the type of a helmet.

Thermal insulation is a parameter defining the amount of heat which can be released from a human body to the environment using all types of body covers.

The objective of the research was to compare thermal insulation of 4 ballistic helmets with different types of the internal system.

The conducted research showed the lowest thermal insulation was noted for the helmet D (with a suspension system made of cotton technical straps), the highest for the helmet B (with multi-segments pads, made of polyurethane). As the structures of the helmets did not differ significantly, it can be assumed that a decisive influence on thermal insulation was exerted by the internal system and the application of a suspension system results in better heat release than it is the case with the padding system.

*Relevance to industry:* The knowledge about the thermal insulation of the ballistic helmets and the effect of diversity of internal system on their thermal insulations provides information that extends current understanding of the risks faced by soldiers using ballistic protections. This information may be particularly useful in the design and implementation of the different kind of head protections.



## 1. Introduction

The basic function of helmets is to protect a wearer's head against injuries caused by an accident, trip, or striking it against a fixed or protruding object (Bogerd and Bruhwiler, 2008; Bruhwiler, 2009; Kirk, 1999). Ballistic helmets have to satisfy an additional requirement, namely to minimize the consequences of the dynamic deflection caused by a bullet or bullet-fragment. Ballistic resistance of helmets is greatly diversified and depends on e.g., their function, conditions in which they are used or a tactical situation (NIJ 0108.01:1985).

**Although the** *head* represents approximately 9% of the body area, it plays a vital role in a thermoregulatory process and maintaining thermal comfort (Carey et al., 2000). Its potential in heat exchange is attributable to a *richly vascularized* **brain part (scalp) whose blood vessels do not constrict under the influence of a low temperature.** Studies by Bogerd (2009) revealed that a relatively large part of heat was lost through the head. Likewise, Nunneley et al. (1982) pointed to an influence of head temperature (controlled by a heated cap covering only 3–4% of the total body area) on esophageal temperature and subjective comfort of human subjects. Furthermore, Nunneley et al. (1982) observed an influence

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of head temperature on reaction time and performance accuracy which tended to improve when the head was cooled down, as compared to conditions without its cooling.

From the above observations it follows that the value of thermal insulation of a given head covering, which has a direct influence on the amount of heat released from head (and consequently on its temperature), should be known in advance. That knowledge will help to determine whether the head protection is not realized at the expense of disorder the thermal balance of a body.

Studies on thermal insulation of head coverings can be performed with the so-called thermal head (manikin headform) (Zwolińska and Bogdan, 2012) whose role is to **simulate**, in thermal terms, a real human head. First reports on a manikin headform were published in 1974 when Fonseca (Fonseca, 1974) had used the head of a thermal manikin to study military helmets. The studies served to examine relative humidity or heat losses. Since then, manikin headforms have *undergone* **several** *technological advancements and now* they are mainly used to examine motorcycle (Bruhwiler, 2003; Bogerd and Bruhwiler, 2008) or bicycle (Bruhwiler, 2003, 2009) helmets. In the subject matter literature, however, there is a paucity of reports on ballistic helmets. It is only possible to find information on research into materials which are used to construct helmets (Marissen et al., 2010) but there is no data on their thermal insulation.

Ballistic resistance of helmets depends on the properties of a composite material, a type of fibers and matrix, composition of fibers in the matrix, interaction of fibers with a matrix and parameters of the composite manufacturing process. A majority of currently available helmets is based on the construction model of the Personal Armour System for Ground Troops helmet (the PASGT) (Ivins et al., 2007). Shells of bullet and fragment-proof helmets are now made of *fibrous polymer composites (*Ivins et al., 2007) obtained from continuous filaments: *para-aramid, polyethylene, polypropylene and* **carbon fibers. At present, tests are being carried out on the shell of helmets, which are made of the hybrid composites (of** the ultra-high-molecular-weight polyethylene fibers (UHMWPE) or polypropylene (PP) and carbon fibers (Carr, 1996; Cheeseman and Bogetti, 2003**))**

**Designers of ballistic-resistance body armour are paying** *increasing attention* to additional elements of a ballistic helmet. Those elements constitute an internal system (a shock-absorbing and fitting system). Hence the objective is to design and manufacture helmets in such a way so that a wearer can carry out tasks in high *risk* **environment with** *maximum* **wearing** *comfort*. There exists a variety of internal systems. One of the most commonly used is a system based on a band that encircles the circumference of the head with supporting straps intertwined on top. However, at present, a padding system is increasingly often applied. This kind of a system ensures better protection and shock absorption thus preventing a wearer from head injuries. A system of pads can be made from p*olyethylene foam with* **closed-**cell structures or polyurethane foam with canals (Courtney and Oyadiji, 2001; Georgiades et al., 2007). Furthermore, it can be made from thermoplastic foam (foam with shape memory – slow memory) (Courtney and Oyadiji, 2001; Georgiades et al., 2007) or from gelling material.

Studies into ballistic helmets which have been undertaken so far focused mainly on the ballistic and safety aspect. Amongst others, Tan et al. (2012) examined different interior cushioning systems in ballistic impact and Kulkarni et al. (2013) described dependencies between the structure of the helmet and traumatic brain injury. Yet, other properties having a direct influence on a human body and performance, such as thermal insulation or thermal comfort, should also be taken into consideration.

Thermal comfort could be described by the Predicted Mean Vote (PMV) index (Fanger, 1970). Fanger showed dependencies between thermal insulation of the clothing used and indices describing thermal comfort ($-0.5<\mathrm{PMV}<+0.5$). The PMV index is based on the guidelines of the ISO 7730:2005 standard. The value of the index is estimated mainly on the basis of the parameters such as thermal insulation and metabolism.

So far thermal insulation of the ballistic helmets has not been studied. In order to examine thermal insulation of helmets and to establish which type of the internal system of the ballistic helmet shell had the lowest thermal insulation, tests were performed using the manikin headform.

The objective of this article was to compare thermal insulation of 4 ballistic helmets with a different type of the internal system. The helmets were selected for testing within the framework of key project No. POIG.01.03.01-10-005/08 Modern ballistic body armours and covers for transportation means as well as for buildings made on the basis of textile composites.

## 2. Material and methods

### 2.1. Tested helmets

Subject to examination were 4 bullet- and fragment-proof helmets with the same structure of the shell (in terms of the material used). Helmets only differed in their finishes (Fig. 1) and used the internal system and pads.

Shells were made from composites consisting of pre-impregnate, para-amid fiber encased with thermosetting resin and the ultra high molecular weight polyethylene (UHMWPE). A hybrid arrangement of material in the construction of helmet enabled reduction of mass in a ready-made product and increased its ballistic resistance.

Tested helmets differed in terms of the internal system applied. In the helmets of the A and B type a multi-segment pad placement system was used. Pads were mounted to the shell by naps and stuck to its internal part. Such a solution ensures a snug, secure fit to the shape of a wearer's head while maintaining appropriate parameters of impact performance. Additionally, it allows the helmet to rest against the top of the head and achieves the optimum stability. Pads were made from two types of foamed material differing in mechanical properties (Table 1).

In the C helmet, the new design of shock absorbing system (so-called NOSHA) was applied. It is the internal suspension system containing a polymer liner with stud spacers protruding towards the interior of the shell.

Inside the D helmet, in turn, the suspension system was used, made of cotton technical straps.

### 2.2. Methodology

Thermal insulation is expressed in SI $m^2K/W$ or clo (1 clo = 0.155 $m^2K/W$) units. This value is mainly used for clothing ensembles to properly select protective clothing for a specific work tasks and to protect a worker against excessive cooling or overheating. In case of head coverings tests are performed with a thermal manikin (Chen et al., 2006) or with a thermal manikin headform (Zwolińska and Bogdan, 2012).

Measurements of helmets thermal insulation were carried out using a thermal head (manikin headform) called Thomas (Fig. 2). Thomas was made from a high quality glass fiber. The nickel wires were placed all over thermal manikin headform. Thomas consists of 6 independently controlled segments: 1 – *face*, 2 – *scull*, 3 – *left side*, 4 – *right side*, 5 – *back head* and 6 – *neck* (Fig. 2). Each section has its controller system which can: calculate the temperature of the entire surface (by measuring the resistance of the nickel wire), calculate the needed power and also control a power switch for