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Thermal Properties of Reflective Helmet Exposed to Infrared Radiation

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The thermodynamic properties of a model infrared heat reflective helmet were evaluated using an advanced thermal manikin technology. The aluminized model helmet was tested for infrared (IR) radiation attenuation properties. Total manikin heat gain and changes in surface temperature were documented for controlled IR radiation exposure levels. The results illustrate the benefits offered by an aluminized reflective surface in attenuating IR radiation and the advantages of using a spacer harness system to minimize radiant heat transfer from the helmet to the head.

INTRODUCTION

Solar infrared radiation can impose a significant heat load on persons engaged in outdoor activities related to work, sports, or leisure. However, agricultural laborers and construction workers in desert climates are especially at high risk from excessive heat stress. In occupational environments, use of traditional safety helmets frequently contribute to heat stress by adding insulation to the head which inhibits air flow over the skin (Davis et.al. 2001; Hsu et.al., 2000; Johnson et al., 2010)

A new thermal manikin system was developed to help provide product designers and ergonomists with a new tool for evaluating the thermodynamic characteristics of head protective gear under various environmental conditions. To demonstrate the performance of this technology, the thermal characteristics of an aluminized reflective foil applied to the exterior of a model helmet and the role of a spacer harness in mitigating heat transfer inside the helmet were investigated. Results suggest that the new thermal manikin technology will be able to help designers develop new products exhibiting improved thermal characteristics.

METHODS

The thermal manikin system used in this study consisted of a light-weight plastic human-shaped head ventilated with ambient air at a constant temperature and volume flow rate. The temperature of the input air and the temperature of the output air were recorded at thermal equilibrium using an Extech Dual K thermometer with type K thermocouples. Using the volume flow rate

value and information of the temperature difference between the input air and the output air permitted the calculation of total manikin heat loss. The manikin design included sealed perforations on the skull to enhance heat transfer. Additional insulation padding on the face and neck reduced heat loss to the environment. The design of the thermal manikin is shown in Figure 1.



Figure 1. Illustration of thermal manikin system used in evaluating the thermodynamic characteristics of protective headwear.

A model helmet was assembled for testing purposes. The model consisted of a 0.03 mm liner of reflective aluminum foil (Silver cap, SC). A spacer harness providing a 2.5 cm separation (gap) between the helmet shell and the surface of the manikin head was used. The spacer harness (SH) design is illustrated in Figure 2.

All tests were conducted inside a controlled laboratory setting. Each test series was preceded by a reference (control) which consisted of an uncovered (bald)

manikin configuration. Infrared radiation was generated using three variable intensity 250 Watt infrared heat lamps which were directed onto the manikin head. The thermal characteristics of the model cap and the spacer harness system were evaluated for 200, 400 and 600 watt infrared power input levels. Reid and Wang (2000) showed that the temperature is not uniform on the skin surface. Therefore, three thermocouples were used- left temple, center, and right temple - to obtain the mean surface (“skin”) temperature on the head.



Figure 2. Illustration of thermal manikin wearing the spacer harness and reflective helmet.

RESULTS

Changes in head surface temperature and changes in total head heat in response to the controlled IR exposure intensity levels are summarized in Table 1.

Table 1. The changes for the three levels of head protection

Protection	IR Level	Mean Manikin Surface Temp. (°C)	Constant * Calculated Heat Gain (W)
Control	0	19.1	0.0
Control	200	29.0	3.3
Control	400	41.0	8.9
Control	600	52.7	14.3
Silver Cap	0	19.4	0.0
Silver Cap	200	20.8	0.0
Silver Cap	400	23.4	2.2
Silver Cap	600	26.5	2.2
SH	0	20.4	0.0
SH	200	21.2	0.0
SH	400	22.9	1.1
SH	600	25.0	1.1

Figure 3 illustrates the relationship between the IR lamp input power levels and the manikin heat gain (times a constant) for the control configuration, for the aluminized reflective cap without the spacer harness, and for the cap with the spacer harness.

Figure 4 illustrates the relationship between IR lamp input power levels and the manikin surface temperature changes for the control configuration, the aluminized reflective cap without the spacer harness, and the cap with a spacer harness.

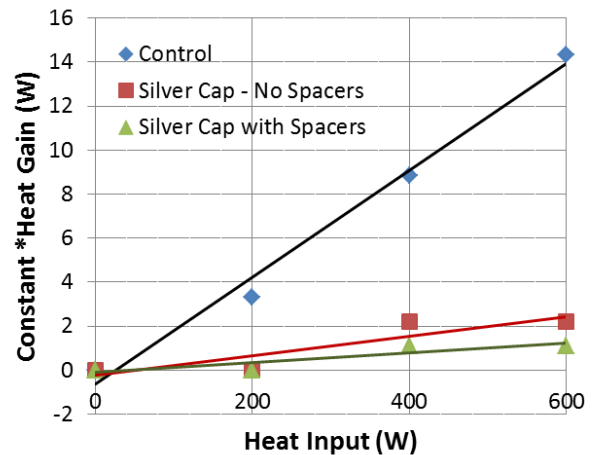


Figure 3. Data summary of manikin heat gain in response to infrared heat radiation exposure. The impact of the reflective helmet and spacer harness in attenuating heat gain is seen relative to the control configuration.

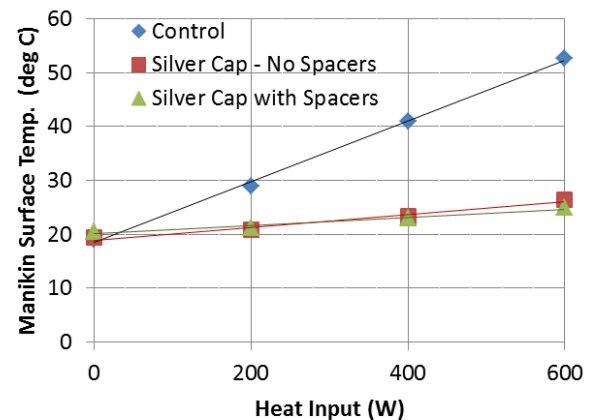


Figure 4. Manikin surface temperature changes in response to infrared heat radiation exposure showing the impact of the reflective helmet and spacer harness in attenuating surface temperature increases relative to the control configuration.

DISCUSSION

The manikin IR exposure tests documented the performance of the aluminized reflective surface in attenuating the manikin heat gain and attenuating the manikin surface temperature increases. The data also show the additional improvements offered by using a spacer harness inside the helmet. Previous studies (Brühwiler, 2003; Liu and Holmer, 1995; Reischl, 1986; Spaul et al. 1987) addressed ventilation issues associated with protective helmets but did not investigate the impact of infrared heat radiation. Providing a reflective aluminized surface to reduce the overall IR heat load is clearly beneficial. However, the low heat capacity of aluminum results in the material to heat up quickly. Such heating imposes conductive heat gain for the head. To reduce this heat gain, additional insulation material is often introduced. However, such material can prevent the helmet from dissipating metabolic heat through sweat evaporation. This, in turn, can lead to further heat build-up inside the helmet. Therefore, keeping insulation material to a minimum by using a spacer harness can overcome such a negative trade-off.

A limitation of the study was that all measurements were carried out using a “bald” or hairless thermal manikin. Furthermore, the tests were conducted under “0” air velocity conditions. Both factors can impact the heat transfer from the head (Brühwiler et al., 2006) and need to be evaluated separately.

CONCLUSIONS

The advanced thermal manikin technology used in this study showed that such a system can provide an effective tool for assessing the complex thermodynamic characteristics associated with protective headwear. The use of aluminized reflective material coupled with a spacer harness exhibited high infrared heat radiation attenuation characteristics. These features are simple and cost-effective components. The value of such an investigative approach in product design and development to optimize the thermal characteristics, safety, and comfort of new products is high.

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