Management of Outdoor Heat Stress: Reducing Exposure to Solar Heat Radiation

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Abstract. Heat transfer characteristics of a prototype light-weight protective vest were evaluated under controlled laboratory conditions. Vest surface temperatures, manikin skin temperatures, and total body heat gain profiles were documented. The new protective vest design, including spacers and an aluminized external surface, was found to provide an infrared heat radiation attenuation level of 53.7%. The results indicate that use of such a novel reflector garment vest can help reduce heat stress for persons exposed to intense outdoor sunlight conditions.

Keywords. Infrared radiation, heat stress management, protective vest

1. Introduction

1.1 Background

Solar infrared radiation can impose a significant heat load on persons engaged in outdoor physical activities. Agricultural workers and construction workers in desert climates are especially at risk. Use of tents, hats, and other protective equipment are sometimes used to reduce solar heat exposure. However, such measures are often impractical especially when employees are engaged in tasks that involve frequent changes in posture and location. Requiring employees to wear standard protective garments in such environments may be counter-productive because such garments may contribute to additional heat stress by adding body insulation and thus inhibiting air flow over the skin which subsequently reduces the evaporation capacity of sweat.

Physiologically, the human body is a metabolic heat generating system which must maintain a balance between heat loss and heat gain within a narrow range of body temperature. Environmental parameters such as air temperature, air velocity, radiant heat, and humidity can affect this delicate balance (Bishop, 1994; Montain, 1994; Holmer, 1995). Clothing material and garment design can also influence the heat balance by promoting or reducing heat exchange through sweat evaporation, convection, conduction, and heat radiation (Reischl, 1980). Specifically, the protective performance of fabrics is related to the chemical and physical structure of the material including thickness and weight. It has been shown that woven textile materials do not offer a good barrier against infrared radiation. However, the performance is better when the fabric thickness is greater and when the fabric material is heavier (Sun, 2000).

1.2 Project Objective

The development of a light-weight heat attenuation vest was undertaken to offer an alternative strategy for protecting workers against excessive levels of solar radiation. Prototype versions of a new garment design were assembled for testing. A thermal manikin which was exposed to controlled levels of infrared radiation was used in this study. Data were sought to help identify design features that would allow a garment to reduce infrared radiation exposure significantly. It is believed that such a product could help reduce heat related illnesses and improve comfort while also enhancing employee productivity.

2. Methods

2.1 Materials

Three prototype vests were assembled for testing. Each prototype consisted of a 1.0 mm flexible CB material which was cut into a pattern that offered a simple vest design that included a front panel and a back panel as illustrated in Figure 1. The first prototype consisted of a front and a back panel only. The second prototype included flexible ring-spacers that were distributed uniformly over the front and back panels of the vest. These spacers provided a 2.5 cm separation (gap) between the vest and the skin of the manikin. The third prototype included an aluminized surface in addition to the flexible ring-spacers.

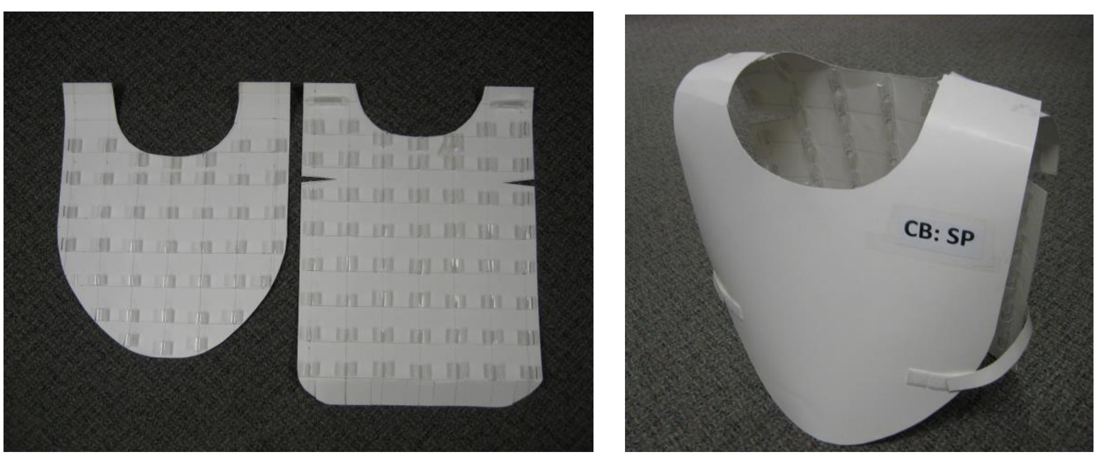

Figure 1. Illustration of the prototype heat radiation attenuation vest consisting of a front panel and a back panel with ring spacers distributed symmetrically over both panels. When the two panels are combined, they form a protective garment.

2.2 Procedures

Changes to garment surface temperatures in response to exposure to IR radiation were evaluated by exposing each of the three prototype vests to 750 Watts of IR radiation. The temperatures of the exposed side (exterior side) and the inside (interior side) of the vests were measured using thermocouple thermistors.

The manikin tests were conducted according to the protocols described by Mijovic (2009) and Reischl (2010). All tests were preceded by a reference (control) setting using a semi-nude manikin configuration as illustrated in Figure 2. Environmental air temperature conditions were maintained between 22.5 ^{0}C and 23.5 ^{0}C, relative humidity between 40% and 45%, and no external heat radiation exposure sources were present.

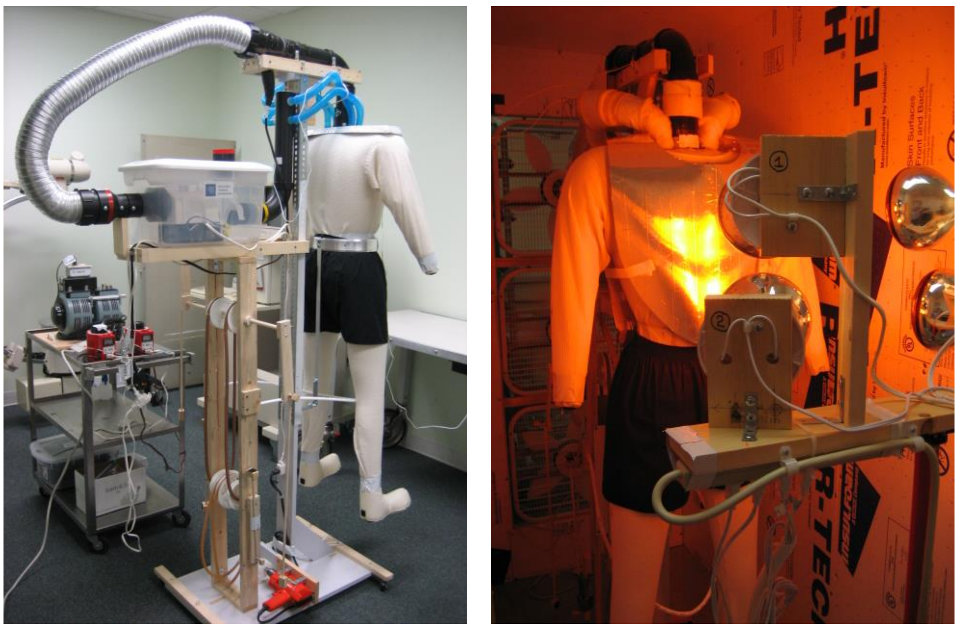

Figure 2. Thermal manikin used in the evaluation of heat transfer characteristics of prototype IR attenuation vests. The photographs show the semi-nude configuration.

Infrared radiation was generated using a variable intensity 2000 Watt infrared heater which was directed perpendicularly to the vest. The heater was centered 1.0 meter in front of the vest. The thermal characteristics of the three prototype vests were evaluated for both the heat radiation condition and the non-heat radiation condition.

3. Results

3.1 Vest Surface Temperatures

The equilibrium surface temperature of the exposed side of the prototype vest at the 750 watt IR exposure condition was 76.3 ^{0}C. The inside surface temperature was 58.1 ^{0}C. This represents a temperature attenuation of 18.3 ^{0}C. The equilibrium temperature of the exposed side of the aluminized vest at the 750 watt IR exposure condition was 46.1 ^{0}C. The inside surface temperature was 27.9 ^{0}C. This represents a temperature attenuation of 18.2 ^{0}C. The results are summarized in Table 1.

Table 1. Summary of vest surface temperatures at the 750 watt infrared radiation exposure level.

Vest Material	Exposed Surface Temp. (^{0}C)	Inside Surface Temp. (^{0}C)	Δ (^{0}C)
CB Construction	76.3	58.1	- 18.3
CB Construction + Aluminum Surface	46.1	27.9	-18.2

3.2 Manikin Heat Gain and Skin Temperature Changes

Total body heat gain for the control condition (semi-nude / unprotected) at the 750 watt exposure condition was 37.0 watts with a chest skin temperature increase of 18.0 ^{0}C. The non-reflective CB vest, without ring spacers, contributed to a total body heat gain of 30.3 watts and a chest skin temperature increase of 7.6 ^{0}C. The non-reflective vest, including the ring spacers, contributed to a total body heat gain of 24.2 watts with an associated chest skin temperature increase of 4.1 ^{0}C. The aluminized vest, also including the ring spacers, contributed to a total body heat gain of 17.1 watts with an associated increase in chest skin temperature of 1.8 ^{0}C. The results are summarized in Table 2.

4. Discussion and Conclusions

4.1 Vest Surface Temperatures

Table 1 shows that both the CB and the Aluminized vest exhibited similar temperature attenuation characteristics, i.e., 18.3 ^{0}C and 18.2 ^{0}C, respectively. However, the surfaces themselves exhibited significantly different temperature profiles. The aluminized vest, both exterior (exposed) side and inside surfaces, exhibited much lower temperature values than the CB material. A reduction of 39.5% is seen for the exposed aluminized surface while a reduction of 51.9% is seen for the inside surface. This is important because the inside surface temperature condition of the vest impacts directly the skin temperatures through a "re-radiation" of heat. A lower inside surface temperature, therefore, contributes to less heat stress.

4.2 Manikin Total Body Heat Gain

Table 2 illustrates the impact by the specific design features on total body heat gain. The CB vest, without any additional features, provided an IR heat radiation attenuation of 18.1%. However, adding ring spacers increased the attenuation level to 34.5%. Adding the aluminized surface increased the attenuation further to 53.7%.

Table 2. Manikin body heat gain and skin temperature changes associated with three prototype vests for a 750 watt infrared radiation exposure condition.

Vest Design	Total Body Manikin Heat Gain (Watts)	Manikin Chest Skin Temperature Change (^{0}C)
"Control" Semi-Nude No vest	+37.0	+18.0
CB Construction No spacers	+30.3	+7.6
CB Construction + 2.5 cm spacers	+24.2	+4.1
CB Construction + 2.5 cm spacers + Aluminum Surface	+17.1	+1.8

4.3 Outcome

The study describes the level of performance that might be expected from an IR attenuation vest in reducing heat radiation exposure. The importance of ring spacers in promoting convection is clearly observable. In comparison to the simple CB vest design, the use of ring spacers reduced the skin temperature by 46.0% and reduced total body heat gain by 20.1%. In comparison to the prototype vest with ring spacers alone, the addition of an aluminized surface reduced the skin temperature by 56.0% and the total body heat gain by 29.3%. It is evident that application of such design features in a vest can promote better occupational health and safety, improve worker comfort, and enhance worker productivity.

4.4 Further Development

Use of nano-materials in the construction of the vest is being investigated. Based on the performance of the prototype vest in reducing infrared heat radiation exposure, efforts are being undertaken to commercialize this product for use in work environments.

5. References

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