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THERMAL CHARACTERISTICS OF INFRARED RADIATION PROTECTIVE VESTS

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SUMMARY: Solar heat radiation can impose significant heat stress on employees performing outdoor tasks. A prototype infrared reflecting vest was developed to offer protection to agricultural workers and constructions workers who are exposed to high levels of outdoor solar radiation. The prototype vest was tested using a laboratory based thermal manikin exposed to controlled heat radiation intensity levels. The tests showed that a vest including 3.2 cm spacers was able to reduce heat gain by 30% without imposing a significant corresponding insulation heat gain. The thermal cross-over point for such a vest was lowest in comparison to others configurations tested. Commercial development of such a vest for use by agricultural workers and construction workers in desert environments is encouraged.

Key words: *heat stress, infrared radiation, heat attenuation vest, thermal manikin*

INTRODUCTION

Solar infrared radiation can impose a significant heat load on workers who are engage in outdoor occupational activities. Agricultural workers and construction workers are known to be at high risk of heat stress. This situation is especially critical when persons are required to work in arid climates with high ambient air temperatures and intense daytime sunshine. Such conditions can lead to serious heat illnesses. Use of tents, hats, and other protective equipment are frequently used in order to help reduce solar heat exposure. However, such measures are often impractical where employees are engaged in complex manual tasks, interact with various tools and equipment, and are required to change body posture and locations frequently. Requiring employees to wear protective garments in such environments may be counter-productive because garments can impose significant heat stress by adding body insulation and thus reducing air flow over the skin. This, in turn, reduces convection and subsequent sweat evaporation capacity.

Physiologically, the human body is a metabolic heat generating system which must maintain a balance between heat loss and heat gain within a narrow temperature range. Environmental parameters such as air temperature, air velocity, heat radiation, and humidity can affect this delicate balance *(Bishop et al., 1994., Holmer, 1995., Montain et al., 1994., Reischl,*

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Stransky, 1980.). Clothing material and garment design also impact the heat balance by promoting or reducing heat exchange through sweat evaporation, convection, conduction, and heat radiation. In general, the protective performance of fabrics is related to the chemical and physical structure of the fabric material including thickness and weight. Woven textile materials generally do not offer a good barrier against infrared radiation. However, the performance is generally better when the fabric thickness is greater and when the fabric material is heavier *(Sun et al., 2000.)*.

The development of a light-weight reflective vest was undertaken to offer an alternative strategy for protecting agricultural workers and constructions workers from excessively high levels of solar radiation. Two prototype vests were assembled and tested using a thermal manikin. Data were obtained that helped identify optimal design features which will allow solar reflector vests to reducing infrared radiation imposed heat stress.

METHODS AND PROCEDURES

Two vests were assembled for testing. The vests consisted of a thin (1.0 mm) flexible CB material cut into a pattern that offered a simple vest design including a front panel and a back panel as illustrated in Figure 1. One vest used a plastic reflective surface (Berry Plastics) while the other did not. Both vests included flexible ring-spacers that provided a gap between the vest and the skin of the manikin. The spacers were distributed uniformly over the front and back panels. The spacers maintained a separation between the vest and the manikin skin of 1.6 cm and 3.2 cm. The vest consists of front and back panels that are connected to each other over the shoulders. Inside both panels are equally spaced flexible plastic rings that can be adjusted to provide either a 1.6 cm or a 3.2 cm separation between the vest and the skin.

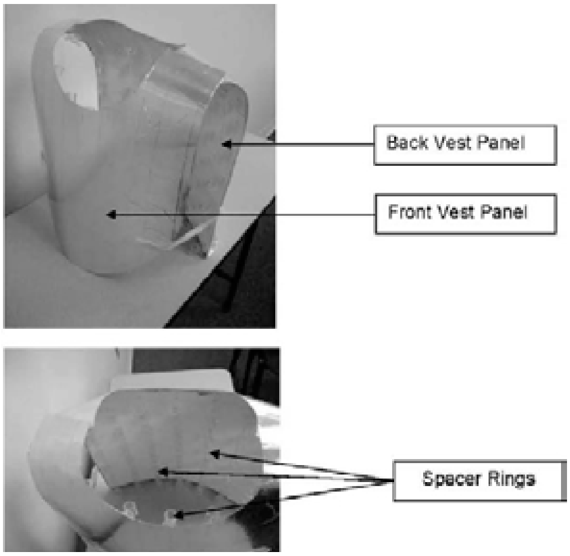

Figure 1. Prototype vest designed to reduce exposure to infrared radiation

Slika 1. Prototip prsluka za zaštitu od infracrvenog zračenja

Thermal manikin tests were conducted using the protocol described by Mijovic, Reischl, et.al. *(2009., 2010.)*. All experiments were preceded by a reference (control) run using a semi-nude manikin configuration as illustrated in Figure 2. The photograph illustrates a semi-nude (control) manikin configuration. 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.

Both vests were evaluated for controlled heat radiation exposure conditions and for non-heat radiation conditions. Heat radiation was generated using four 250 watt IR heat lamps directed at the chest of the manikin. The reflective vest was tested with both the 1.6 cm spacers and the 3.2 cm spacers. The non-reflective vest was tested using the 3.2 cm spacers only. For comparison purposes, a lightweight fabric jacket (2.0 mm thickness) was evaluated under both non-radiation conditions as well as for radiation conditions. There were no spacers placed into this jacket. The manikin heat radiation exposure facility is illustrated in Figure 3. The heat radiation produced by the four IR lamps was directed onto the chest of the manikin.

Figure 2. Inflatable thermal manikin used for assessing the effectiveness of the prototype reflective vests

Slika 2. Termalni maneken na napuhavanje korišten za ocjenjivanje učinkovitosti reflektirajućeg prsluka

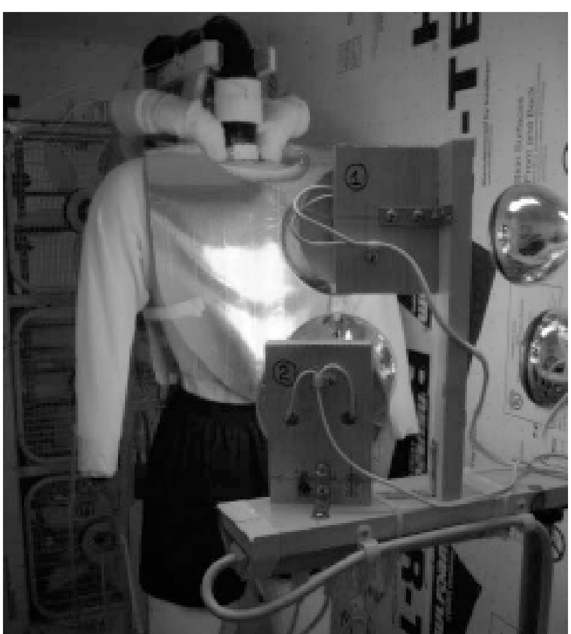

Figure 3. Illustration of the inflatable thermal manikin exposed to infrared heat radiation while wearing the prototype vest

Slika 3. Prikaz termalnog manekena na napuhavanje s prslukom izloženog infracrvenom zračenju

RESULTS

Total manikin body heat gain was used as the measure for heat stress. Total body heat gain was also used to evaluate the insulation imposed on the manikin by the garments. The test results are summarized in Table 1.

Heat gain for both the control condition (semi-nude / unprotected) and the jacket at the 900 watt exposure condition was 61.2 watts each. The Non-reflective vest exhibited a heat gain of 38.5 watts, while the aluminized vest including the 3.2 cm spacers exhibited a heat gain of 42.7 watts. The aluminized vest, including the 1.6 cm spacers, exhibited a heat gain of 47.0 watts.

Table 1. Summary of manikin infrared heat gain values for the control condition (semi-nude), for two prototype vests, and for the comparison jacket

Tablica 1. Prikaz vrijednosti toplinskog prirasta za kontrolno stanje manekena, dva prototipa prsluka i jakne za usporedbu

Garment Design	Ventilation Space between garment and skin	Measured insulation heat gain without IR exposure	Measured heat gain for IR radiation exposure
Manikin semi-nude (Control)	N/A	N/A	61.2 watts
Non-reflective Vest (CB)	3.2 cm	1.5 watts	38.5 watts
Aluminized Vest (AL)	3.2 cm	4.3 watts	42.7 watts
Aluminized Vest (AL)	1.6 cm	8.6 watts	47.0 watts
Jacket	0 cm	17.1 watts	61.2 watts

ANALYSIS

The range of infrared heat radiation protection offered by a garment can be defined by the "Thermal Inflection Point" (TIP) or temperature cross-over point as shown in Figure 4. This position identifies the infrared heat radiation intensity level above which a garment limits heat stress caused by infrared radiation. Below the TIP, a garment imposes "unnecessary" heat accumulation due to garment insulation. For protective clothing in general, the TIP moves higher as the weight and thickness of a garment material increases and moves lower when garment weight and thickness decreases.

The goal of innovative garment design should be to set the TIP as low as possible without decreasing fabric material weight and thickness to a level where the protective characteristics of a garment material is jeopardized.

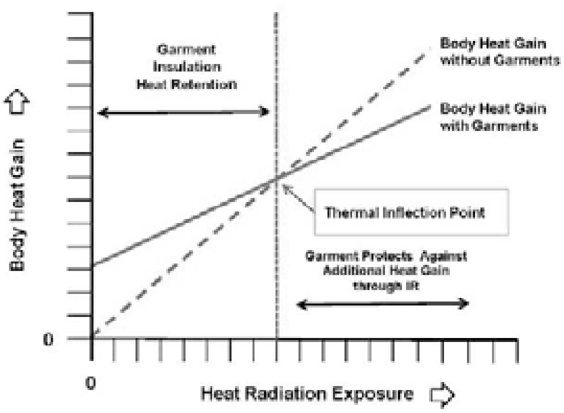

Figure 4. Illustration of the relationship between body heat gain due to heat radiation exposure and garment imposed heat gain as a result of garment insulation

Slika 4. Prikaz veze između tjelesnog prirasta topline zbog izloženosti zračenju i toplinski prirast zbog izolacije odjećom

A simple method for moving the TIP lower, while maintaining garment integrity (weight and thickness), is to increase the ventilation characteristics of a garment. This can be achieved by providing separation between the garment and the skin. This space will allow convective and evaporative heat exchange to remove body metabolic heat freely. Such an approach can include the use of spacers that maintain the necessary separation between the protective garment and the skin.

Table 1 illustrates the performance of the reflector vest which includes 3.2 cm spacers. It can be seen that the vest offered the highest IR heat protection while imposing the least insulation heat load. The difference between the vest with an aluminized reflective surface and the vest with the non-reflective surface was not substantial. However, all configurations some heat gain as a result of vest insulation.

The relationship between the four vest designs, the jacket, and the semi-nude control configuration is illustrated in Figure 5. It can be seen that all of the garment configurations provided beneficial shielding. The beneficial effects increased as the heat radiation exposure levels increased.

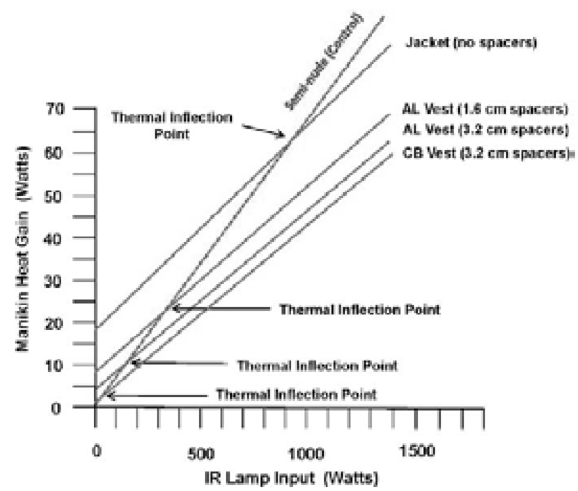

Figure 5. Relationship between IR exposure and manikin heat gain observed for the semi-nude control configuration, three vest configurations, and comparison jacket configuration

Slika 5. Odnos između infracrvenog zračenja i prirast topline manekena promatrane za kontrolno stanje, tri prsluka i jaknu za usporedbu

Figure 5 also shows that the non-reflective (CB) vest exhibited the lowest TIP cross-over point and shown in Table 1 with an insulation heat gain of only 1.5 watts. The graph is based on data obtained for the "0" IR exposure level and the 900 watt IR input level. The highest temperature TIP cross-over point (and the highest baseline insulation value of 17.1 watts) was exhibited by the jacket used for comparison purposes.

CONCLUSIONS

Our results show that the use of a properly designed solar reflector vest can significantly reduce infrared heat stress exposure. A vest with 3.2 cm spacers was able to provide substantial protection against infrared heat loading while imposing only very minor insulation heat gain. The application of an aluminized reflective surface did not measurably increase the infrared reflection efficiency of the vest. The Thermal Inflection Point (TIP) for the vests with 3.2 cm spacers was much lower than any of the other configurations tested. Development of a reflector vest for use by agricultural workers and construction workers exposed to high intensity sunlight environments is recommended. We believe that the application of this technology in arid regions of Africa and the Middle East may provide economic advantages by promoting occupational health and safety and improving productivity in the field.

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TERMIČKA SVOJSTVA PRSLUKA ZA ZAŠTITU OD INFRACRVENOG ZRAČENJA

SAŽETAK: Sunčevo toplinsko zračenje može prouzročiti toplinski stres radnicima koji se bave poslovima na otvorenom. U ovome radu prikazan je prototip prsluka koji može pružati zaštitu od infracrvenog zračenja poljoprivrednim radnicima te radnicima u građevini koji su izloženi visokom stupnju sunčevog zračenja na otvorenom. Prototip prsluka je bio ispitan pomoću laboratorijskog termalnog manekena u uvjetima kontroliranog intenziteta toplinskog zračenja. Testovi su pokazali da je prsluk s udaljenosti između kože i odjevnog predmeta od 3,2 cm smanjio toplinski prirast za 30% bez značajnog toplinskog porasta zbog izolacije. Takav prsluk imao je najnižu termalnu prijelaznu točku u usporedbi s ostalim testiranim postavama. Komercijalni razvoj takvog prsluka za poljoprivredne radnike i radnike u građevini je poticaj.

Ključne riječi: *toplinski stres, infracrveno zračenje, prsluk za smanjenje topline, termalni maneken*

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