THE EFFECTS OF BLACK AND WHITE GARMENTS ON THERMOREGULATION UNDER WARM CONDITIONS WITH SUN RADIATION

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INTRODUCTION

The various aspects of clothing (construction, materials, color, exposed area etc.) are dependent upon the total heat gain and loss in the hot and warm outdoor conditions. Adolph (1938) found that the total mass loss was more during sitting in the sun compared to sitting in the shade (1). Clothing color seemed also to be important for thermoregulation under the radiant conditions (2). Nielsen (1990) compared human physiological responses during exposure to solar radiation, while wearing either black or white garments made of either cotton or polyester, and reported higher clothing surface temperatures and sweat rate when black cotton garments were worn compared to white cotton garments (3). Her experiments demonstrated the importance of clothing color on thermophysiological responses. Although several studies have examined the effects of animal fur color in outdoor conditions (4), few have systematically examined the effect of clothing color, where the garments are constructed of identical materials, on thermophysiological responses in humans.

The aim of this study was to find which garment (black or white garments which were made of 100 % cotton and of same type) was recommended thermophysiologically during exposure to intense artificial solar radiation.

MATERIALS and METHODS

Subjects: Eight women subjects participated in the present experiment (24.5 ± 2.2 years, 159.6 ± 1.9 cm in height, 54.10 ± 3.30 kg in body weight and 1.51 ± 0.05 cm^2 in body surface area). For a given subject, experiments were conducted at the same time of day (9:00 - 12:00h, 13:00 - 16:00h, 16:00 - 19:00h) and at the same phase of the menstrual cycle to avoid circadian and menstrual effects on body temperature.

Experimental garments: Garments of two colors (black or white) were used in this experiment. They consisted of a T-shirt with long sleeves and long trousers of the same size, which covered same body area. The material was 100 % cotton. The physical properties of these fabrics including some characteristics against sun radiation (radiant reflectance, radiant absorbance and radiant penetration) were measured.

Artificial sun: The artificial solar radiation maintained in a climatic chamber was adjusted to simulate outdoor conditions of a typical Japanese summer. This solar machine (2 x 1.5 m) was constructed with 11 lamps on two large panels, which had similar wave length as natural sunlight. Radiant intensity emitted on the subject was maintained constant, by adjusting the intensity of the radiation so that globe temperature was maintained constant. This source of artificial solar radiation was placed 1.2 m in front of the subject.

Measurements: Rectal temperature (T_{re}) was measured using a thermistor probe (Takara Thermistor, Japan) inserted 12 cm beyond the anal sphincter. Skin temperature (T_{sk}) was measured with thermistors attached to 8 sites; forehead, chest, back, forearm, hand, thigh, leg and foot. Local sweat rate from the center of both forearms was continuously recorded by capacitance hygrometry. An acrylic capsule covering 8 cm^2 of skin surface was ventilated with dry nitrogen gas at a constant flow rate (1.5 $l \cdot min^{-1}$). The humidity of the effluent gas from the capsule was measured with a highly sensitive hygrometer (Visala, HMP-35A). The capacitance hygrometer was calibrated by two saturated salt solutions, LiCl and K_2SO_4, at a constant temperature before every experiment. Average clothing surface temperature was determined from temperature measurements obtained from two sites (upper chest and lower chest). Subject's mass was recorded on a balance (Sartorius, Germany; accuracy ± 1g) at 5 min intervals during the experiment, thus allowing the estimation of total sweat loss.

Experimental protocol: Prior to the onset of the experiment, the condition of the climatic chamber was maintained at 27°C, 50% R.H. and 0.45 $m \cdot sec^{-1}$ for a minimum of 1 hr. Once instrumented, the subjects entered the chamber, wearing only underpants and a brassiere, and remained seated on the balance for a minimum of 30 min, so that their physiological responses during exposure to a thermoneutral environment could be recorded. Thereafter, the subjects donned the experimental garments, sun glasses and hat. Two thermistors were also attached to the chest portions of the garments worn, to assess the clothing surface temperature. Once suited, the subject resumed the seated position for an additional 10 min in thermoneutral environment. Following this 10 min period during which the subjects were clothed in the experimental garment in a thermoneutral environment, the artificial solar radiation was initiated. During the period of exposure to the artificial solar radiation, globe temperature and air temperature in close proximity of the subject were measured continuously. Ambient temperature increased to 32°C and relative humidity to 60% within 10 min of the start of the artificial solar radiation. Globe temperature rose progressively attaining 43°C by the end of the experiment. Subjects were exposed to the artificial solar radiation for a total of 60 min. All variables were recorded at 6s intervals by a computer.

Calculation and statistical analysis: A repeated-measures analysis of variances (ANOVA) was used to examine the differences in the responses of the measured variables between the two conditions.

RESULTS

Upon initiation of the artificial solar radiation, average T_{re} decreased in the first 10 min and thereafter increased progressively, attaining 37.44 ± 0.07°C in the white garment condition and 37.42 ± 0.08°C in the black garment condition, there being no significant difference in the T_{re} response between the two conditions. Similarly there was no significant difference in the average T_{sk} response between the two conditions. With the exception of foot temperature, all other skin temperature sites monitored had similar responses in both conditions. Foot skin temperature was significantly higher in the white compared to the black garment condition ($F=8.51$, $p<0.05$).

Average local sweat rate from both forearms was significantly higher in the white compared to the black garment condition ($F=16.67$, $p<0.01$). The loss of body mass was 142.6± 4.2 g in the white and 133.0 ± 6.0 g in the black garment condition. The cumulative decrease of whole body mass in the white was greater than the black garment. ($F=4.29$, $p<0.10$).

The average garment surface temperature increased immediately upon onset of the artificial solar radiation and attained significantly higher values in the black compared to the white garment condition ($F=15.67$, $p<0.01$).

DISCUSSION

The observations of higher mass loss and foot skin temperature in the white compared to the black garment condition suggest that both radiant heat load and activation of the vasomotor center were greater in the white compared to the black garment condition. What physiological mechanisms might be responsible for these different responses between the white and black garments?

The characteristics of these fabrics against radiant heat were as follows: though the radiant reflectance was clearly higher in the white than in the black, the radiant penetration was smaller in the black than in the white. Radiant absorbance was greater in the black than in the white. It should be noticed that more radiant heat could penetrate through the white clothing (3,5).

These findings suggest that the black clothing might play an important role as a thermal barrier against radiation by absorbing radiant heat, resulting in the significantly higher clothing surface temperature compared to the white clothing. And then, the conclusion could follow that higher clothing surface temperature in the black clothing has physiological significance, because dry heat loss might occur more effectively from the surface to surrounding air, and further, radiant heat gain from surrounding to clothing surface could be reduced more effectively. Similar considerations were made for desert animals (6). The finding of a smaller heat load in the black compared to the white garment condition in the present study, could be due to three factors: the greater absorption of heat into clothing, higher clothing surface temperature and more effective blocking of radiant penetration.

The skin temperatures at all sites should be expected to be higher in the white, if the radiant penetration to the skin surface through clothing was greater in the white. However, it was not the case except for the foot temperature. The higher sweat rate in the white might have cooled down the skin in the white garments. Furthermore, the higher clothing surface temperatures in the black might have caused the skin temperatures to be higher by conductance. These might be responsible for the identical skin temperatures between the white and the black.

Thus, it is concluded that the selection of black clothing color could be of physiological significance for the reduction of heat strain in warm ambient conditions under intense sun radiation.

REFERENCES

1. Adolph, E.F. 1938, Heat exchanges of man in the desert. *American Journal of Physiology* **123**: 486-499
2. Adolph, E.F. 1968, Desert, in: LH Newburg, MD (ed.). Physiology of heat regulation and the science of clothing, Hafner publishing Co, New York and London, 330-338
3. Nielsen, B. 1990, Solar heat load: heat balance during exercise in clothed subjects. *European Journal of Applied Physiology* **60**: 452-456
4. Finch, V.A. and Western, D. 1977, Cattle colors in pastoral herds: natural selection or social preference? *Ecology* **58**: 1384-1392
5. Ingram, D.L. and Mount, L.E. 1975, Man and Animals in Hot Environments. Springer-Verlag, Berlin Heidelberg New York, 160-162
6. Schmidt-Nielsen, K., Schmidt-Nielsen, B., Jarnum, S.A. and Houpt, T.R. 1957, Body temperature of the camel and its relation to water economy. *American Journal of Physiology* **188**: 103-112