THERMOREGULATORY AND CIRCULATORY REACTIONS IN SUBJECTS EXPOSED TO THE SUN AND WEARING WHITE AND BLACK CLOTHING

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INTRODUCTION

Studies dealing with thermoregulatory reactions to solar exposure are not undertaken frequently (1,2,3), and affects on circulatory function have not been reported previously. The aim of this paper is to present preliminary results of the studies dealing with responses of both thermoregulatory and circulatory systems during solar exposure outdoors when wearing white and black clothing.

MATERIAL AND METHODS

Field measurements were carried out in July 1997 in Central Poland. Meteorological elements—air temperature and humidity, wind speed, cloudiness, intensity of solar radiation (global, direct, diffuse and reflected) as well as sky and ground thermal radiation—were observed.

Four volunteer subjects (1 male and 3 female) between 17 to 32 years of age were examined. In every 2-hour run, 2 subjects were exposed facing the sun, standing, in relaxed posture: 1 wore white, and the 2nd wore white clothing with insulation of 0.5 clo (briefs, T-shirt, long trousers, sandals). After 1-hour exposure they changed clothing from white to black or vice versa. Every subject was exposed to the sun 2 times, once starting with black and next with white clothing, always at the same time of the day (morning or midday hours). One shade exposure was also examined in the afternoon hours.

Ear canal temperature and absorbed solar radiation (R) and skin temperature on forehead, chest, back, forearm, hand, thigh, lower leg and foot were measured every minute. Mean skin temperature (T_{sk}) was calculated using the modified Hardy-Dubois formula:

$$T_{sk} = 0.07\,T_{forehead} + 0.05\,T_{hand} + 0.14\,T_{forearm} + 0.35\,(T_{chest} + T_{back}) + 0.19\,T_{thigh} + 0.13\,T_{lower\ leg} + 0.07\,T_{foot}$$

The same weightings were also used to calculate mean values of absorbed solar radiation. For the comparison, absorbed solar radiation and surface temperature were measured on the upper legs of a manikin under black and white clothing. Absorbed solar radiation (R) was extracted from *dry* heat flux taking into account constant values of workload and Basal Metabolic Rate (BMR was mea-

sured for each subject in standard, thermoneutral conditions). To eliminate the influence of the time of exposure on Tsk and R values, they were correlated with global solar radiation intensity (K_{glob}) during exposure in the sun and in the shade.

Twenty-four-hour heart rate (HR) and blood pressure (BP) measurements were recorded (during experiment, leisure time and sleep) using a Medilog

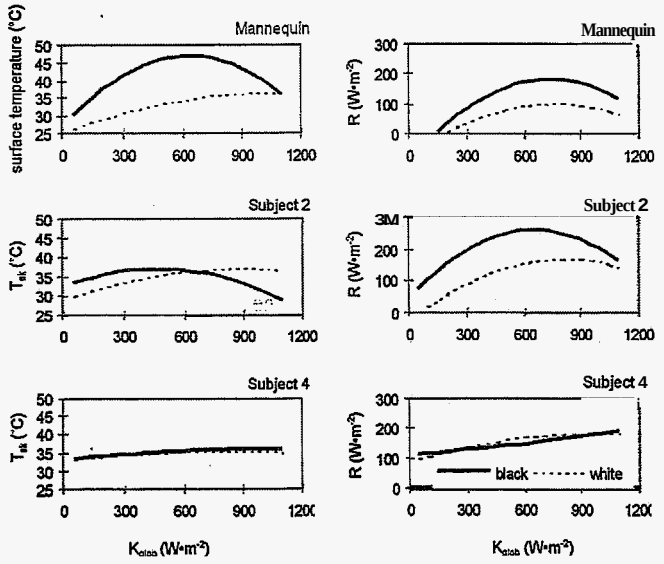

Figure 1. Relationships between intensity of global solar radiation (Kglob) and skin temperature (Tsk) as well as absorbed solar radiation (R) in two subjects with clothing; for the comparison R values and surface temperature of a mannequin are plotted.

(Oxford) device. Measurements were carried out automatically, every 5 minutes during experiment, every half hour during leisure time and every hour during sleep. Mean systolic (BPS), diastolic (BPD), average (AVG) BP and HR for exposure in white (w), black (b) and shade (sh) as well as for 24-h (OVER) and night (NIGHT) were calculated.

Differences in BP and HR in each subject and in whole group during exposure in (w), @) and (sh) were analyzed using t-Student and Mann-Whitney tests. The relation between physiological indices (BP, HR, T_{sk}) and parameters referring to exposure to sun (K_{glob}, R) was analyzed using multiple linear regression.

RESULTS

Physical process of solar radiation absorption can be observed clearly on a manikin. Under black clothing R was 50 to 100 $W \cdot m^{-2}$ higher than under white clothing, and surface temperature was 10 to 15°C higher, respectively (Fig. 1).

No significant differences were observed in ear channel temperatures for subjects exposed to the sun in black and in white textile. However, **skin** temperature and intensity **of** absorbed solar radiation depended on clothing color.

In subjects, physiological responses are different than physical ones. Two types of reaction on solar exposure were observed. For 2 subjects, significant differences in R and T_{sk} under black and white textile were observed. R values were 50 to 100 $W \cdot m^{-2}$ higher under black then under white clothing. T_{sk} depended on solar radiatfon **(K_{glob})** intensity: at low K_{glob} it was higher under black, and at high K_{glob} it was higher under white clothing (subject 2 on Fig. 1). However, for the other 2 subjects, no significant differences were observed in T_{sk} or R values when wearing white and black clothing (subject **4** on Fig. **1).** When analyzing T_{sk} for the whole group, it was found that it was significantly higher when the subjects were exposed to sunshine in black clothes (Table 1).

Table 1. Physiological indices in subjects wearing white and black clothing

Subject	Color	*BPS*	*BPD*	*AVG*	*HR*	T_{sk}
1	**white**	96.5 ±7.8	64.7k4.6	75.0 ±4 5	93.4k13.9	35.7 ± 1,0
(female)	**black**	99.9k8.7	61.5 ± 5.2	73.9 ±4 8	95.2 ±7.9	35.5 ± 1.2
2	**white**	110.6 ± 16,9	75.4 ± 8.8	86.9 ±8 4	100.0 ± 11,3	35.4 ± 1.2
(female)	**black**	106.1k8.1	72.4 ±11.4	83.3 ±7 4	102.0k13.7	36.3k1.4
3	**white**	105.2k8.4	73.2k6.5	83.4 ±6 2	89.3 ±7.0	35.6 ± 1,5
(male)	**black**	101.2 ± 4,8	72.2k5.2	81.6 ±4 5	90.1 k12.5	36.5k0.9
4	**white**	108.1 ± 5.4	63.4k5.4	78.0 ±3 7	98.4 ± 13.0	35.4 ± 0.4
(female)	**black**	110.3k6.1	61.1k5.7	77.1 ±4 8	94.2 ±11.6	35.5 ± 0.5
Whole	**white**	105.1 ± 11.9	69.0 ± 8.3	80.7 ±7 6	95.6 ±12.3	35.5 ± 1.1
Group	**black**	104.6 ± 8.15	66.8 ± 8.9	79.1 ±6 5	95.2 ±12.3	35.9 ± 1.1

In all subjects, **BPS** and **BPD** during exposure to the sun were lower than in the shade, and HR was higher **(1** vs. 3, 2 vs. 3). When comparing individual physiological reactions to sunshine we have found that **BPS** did not depend on the clothing color **(BPS** was lower in **2** subjects wearing white clothes and in 2 wearing black ones). HR in subjects wearing white clothes was lower in **3** cases, while in one it was higher (Table 1).

On the other hand, **BPD** and AVG in all subjects wearing white clothes were higher in comparison with black clothes. However, **no** differences were statistically significant.

Table 2 gives the results of our analysis **of** the relationship between particular physiological parameters **(BPS, BPD,** AVG and HR) and the intensity of K_{glob} or the absorbed solar radiation (R). In subjects wearing white clothes, the exposure parameters were significantly correlated only in 2 cases: HR **vs.** K_{glob}

Table 2. Relationships between physiological indices, and intensity of (K_{glob}) and (R) in subjects wearing white and black clothing*

Relationship	white clothing		black clothing	
	correlation coefficient	*probability*	*correlation coefficient*	*probability*
BPS vs. *R*	***0.074***	***0.526***	-0.0004	**0.997**
BPD vs. *R*	0.248	0.031	0.401	0.0005
AVG vs. R	0.214	***0.063***	0.365	0.002
HR vs. R	**0.195**	0.091	0.288	0.015
BPS vs. K_{glob}	***-0.038***	0.745	0.124	0.277
BPD vs. K_{glob}	-0.105	0.366	0.231	0.041
AVG vs. K_{glob}	-0.098	0.394	0.276	0.014
HR vs. K_{glob}	0.391	0.0004	0.238	0.014

*Shaded *values* indicate significant findings.

and BPD vs. R. In subjects wearing black clothes, the correlation was significant for almost all observed parameters except BPS.

DISCUSSION

As it was expected, the color of clothing influenced both T_{sk} and R. Almost the same T_{sk} values under black and white clothing, as noticed for 2 subjects, were also observed by M. Kato et al. **(4).** It seems that it can be explained by individual, immediate decrease in metabolic heat production, which leads to reduction of additional heat income from the sun under black clothing. However, this hypothesis must be verified in further studies when temporary changes in metabolism during exposure to the sun will be controlled. Significant decrease of T_{sk} for subject 2 in high K_{glob} refers to intensive heat stimulation of sweat glands under black clothing and then skin cooling by evaporation (2,5).

Lower BPD and higher HR in subjects wearing black clothes may indicate that the thermal load associated with black clothes is higher. The significant correlation found to occur between the physiological parameters and solar intensity in sun-exposed, black-dressed subjects and no correlation in white-dressed subjects also suggests that white clothes provide better protection from environmental heat than black ones.

CONCLUSIONS

Significant R increase under black clothing was observed. This was probably the reason for BPD decreasing and HR rising. It also provoked the rise of T_{sk}. In some subjects it affected increase of evaporation skin cooling, and in some, a decrease of metabolic heat production. However, the results presented are only preliminary in character and more detailed studies are necessary.

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