INFLUENCE OF SOLAR RADIATION ON SKIN TEMPERATURE IN STANDING AND WALKING SUBJECTS OUTDOORS

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INTRODUCTION

Solar radiation is a source of heat for subjects outdoors. There are observed relations between the intensity of solar radiation and skin temperature (1,2). However, simultaneous direct measurements of both parameters are very rare (3,4). The aim of this paper is to present the results of studies dealing with solar radiation and skin temperature of subjects standing and walking outdoors.

MATERIAL AND METHODS

Field measurements were carried out in June 1996 in Central Poland (in the vicinity of Warsaw) and in August 1997 in the Tatry Mountains (Southern Poland). In 1996 investigations dealt with standing persons. Six healthy volunteers (4 males and 2 females), within the age category of 16 to 46 years, were examined. Solar exposures lasted 120 min. Subjects stood upright facing the sun; after 60 min they sat for 5 min and then stood 55 min. Skin temperature was measured every minute with the use of resistant (Pt100) thermometers connected to the forehead, arm, chest, back, hand, thigh and lower leg. Mean skin temperature ($\bar{T}_{sk}$) was calculated as follows:

$$\bar{T}_{sk} = 0.07\, T_{forehead} + 0.05\, T_{hand} + 0.15\, T_{arm} + 0.175\, T_{chest} + 0.175\, T_{back} + 0.2\, T_{thigh} + 0.18\, T_{lower\ leg}$$

For comparison, the surface temperature was also observed on a manikii facing the sun. The temperature sensors were located on the frontal (sunny) and back (shaded) sides of the manikin's surface.

In 1997, studies dealt with standing and walking subjects. Eight healthy volunteers (2 males and 6 females) within the age category of 20 to 38 years were investigated. Skin temperature was measured every minute on the chest (T_{chest}) and thigh (T_{thigh}) during the 160-min exposure. Subjects walked at about 4 $km \cdot h^{-1}$; after every 30 min of walking, they sat for 10 min. Standing subjects also took 10 min rest sitting at the same time as walking subjects. The subjects also reported periods with intensive sweating. In 1997, was calculated as mean value of T_{chest} and T_{thigh}. Both in 1996 and 1997, subjects used dark grey, cotton sportswear with insulation of 1 clo and albedo of 30%.

Simultaneously with skin temperature, measurements were taken for meteorological parameters (i.e., air temperature and humidity, wind speed, solar radiation [global, direct, diffuse and reflected as well as absorbed solar radiation]) with the use of special heat flux sensors, O 50 mm. (3,5).

RESULTS

For subjects exposed outdoors to solar radiation, approximately **10** to **15%** of global solar radiation reaching ground surface was absorbed, and solar radiation (R) varied fiom **5** $W \cdot m^{-2}$ at low sun altitudes (early mornings, evenings) and at thick cloud cover to **110** to **120** $W \cdot m^{-2}$ under clear sky conditions. Changes in absorbed **solar** radiation influenced skin temperature, and $\bar{T}_{sk}$ increased significantly according to increase in R value. Almost 50% of the variation in $\bar{T}_{sk}$ may be explained by the changes in R (other meteorological factors influencing $\bar{T}_{sk}$ are *air* temperature and wind speed). General relation between R and T_{sk} values were as follows: $\bar{T}_{sk} = 24.11 + 0.78$ R (Fig. **1**).

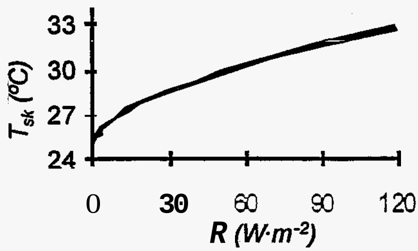

Figure **1**. Relationships between T_{sk} and absorbed solar radiation (R) for standing subjects, July **1996 (n = 2487,** r = **0.70,** $p < 0.01$**); Skin** temperature at subjects outdoors varied from **24** to **34∞C** and was influenced also by air temperature **(15-28°C)** and wind **(2-8 m/s)**

Skin temperature was significantly influenced by direct sunbeams. The temperature of the manikin's surface facing the sun was **5** to **6°C** higher then on its rear surface. Subjects' chest-to-back temperature difference was **only** 1 to **3°C** due to evaporation cooling. However, during **2-h** solar exposures chest-to-back temperature differences (d $\bar{T}_{sk}$) decreased, changing **from 2.5-3°C** to **1°C** the last **30 min** of exposure (Fig. **2**). .

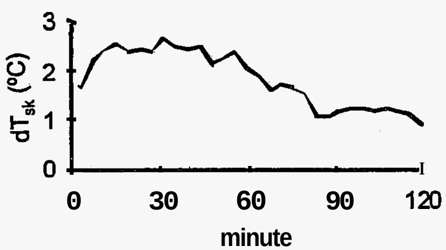

Figure **2**. Difference between chest and back temperature (d Tsk) during **120** min solar exposure; mean values for **6** subjects, July **1996,** midday hours

For walking subjects, **2** days were analyzed (sunny and cloudy) with the same air temperature (of about **18°C)** and wind speed (of about **2** $m \cdot s^{-1}$**). On** the cloudy day, $\bar{T}_{sk}$ was about **2** to **3°C** lower then during the sunny day, and it was kept at the same levels of **28** to **29** and **30** to 31°C, respectively. **Both** on cloudy and sunny days, subjects reported intensive sweating after about **20** min of walking. In comparison, for the standing person under sunny conditions, the skin was warmer than under cloudy sky conditions by about **5** to **6°C** (Fig. **3**). Also observed were significant temporary changes in $\bar{T}_{sk}$; in cloudy conditions, it decreased fiom 33 to **30°C,** and in sunny conditions, it increased fiom **32** to **39°C** during **2-h** exposure.

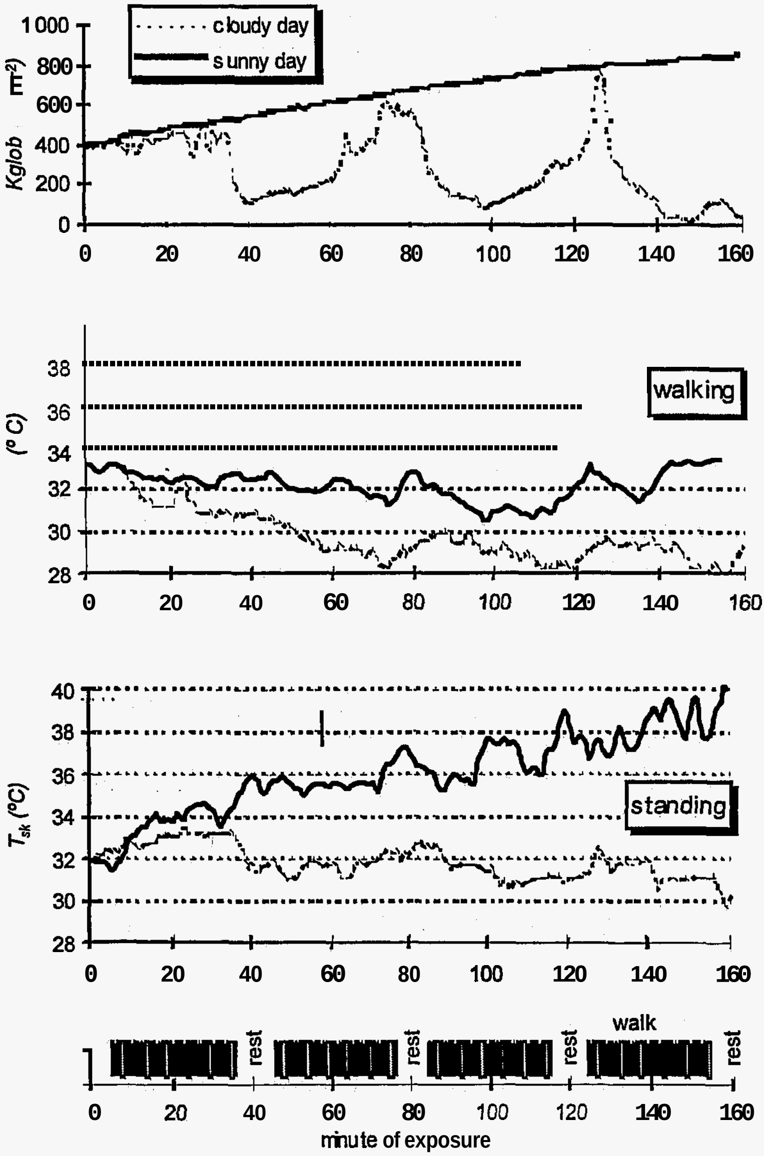

Figure **3.** Changes of global solar radiation (Kglob) as well **as skin** temperature **(Tsk)** in walking and standing subjects during sunny and cloudy day, August 1997; the lowest panel illustrates walking and resting periods during solar exposition; during sunny day.

In walking subjects, both on sunny and cloudy days **skin** started to *dry* and $\overline{T}_{sk}$ increased during rest periods (especially 2^{nd} and 33. Then, when subjects walked again $\overline{T}_{sk}$ declined significantly. In standing subjects who did not report sweating, changes in $\overline{T}_{sk}$ can be explained by the temporary fluctuations in meteorological parameters and body position.

DISCUSSION

The recent papers reporting changes of skin temperature in subjects outdoors (3,4,5) pointed to the influence of solar radiation on $\overline{T}_{sk}$. Nielsen et al. **(4)** observed a reduction in $\overline{T}_{sk}$ of about 1 to 2°C when subject exercised in the shade in comparison to sunny conditions. Similar relations were observed by Blazejczyk ***(5)*** in standing subjects.

In walking subjects, skin temperature was influenced both by solar radiation (mainly direct radiation) and by evaporation of sweat from the body surface (air temperature and wind speed did not change significantly). Thus, for standing subjects, sunny conditions produced a gradual increase in skin temperature. Then during walking, $\overline{T}_{sk}$ varied, decreasing during exercise and rising while resting but did not exceed pre-exercise $\overline{T}_{sk}$. This latter observation points to the great importance of evaporation cooling on body temperature regulation, especially during exercise.

CONCLUSIONS

For subjects outdoors, skin temperature depends on various meteorological factors (air temperature, wind speed, solar radiation--especially direct solar radiation). However, approximately 50% of the changes in $\overline{T}_{sk}$ may be explained by changes of absorbed solar radiation. Solar radiation influences skin temperature both in standing and in walking subjects. However, in walking subjects, evaporative heat loss plays a very important role.

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