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Differential Thermal Sensitivity in the Human Skin*

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Summary. Thermal irradiation was applied to selected skin areas to determine whether particular areas demonstrate a greater thermal sensitivity than others in determination of a physiological thermoregulatory response. Modifications in thigh sweating rate were related to the change in temperature of the irradiated skin and the area of skin irradiated by computing a sensitivity coefficient for each skin area. Thermal sensitivity of the face, as measured by its effect on sweating rate change from the thigh, was found to be approximately three times that of the chest, abdomen and thigh. Lower legs were found to have about one-half the thermal sensitivity of the thigh. A table of weighting factors for calculation of physiological mean skin temperature, based upon thermal sensitivity and area, is presented.

Key words: Thermal Sensitivity — Sweating Rate — Skin.

Hensel, Iggo and Witt [3] and Hensel and Kenshalo [4] have described thermosensitive receptors in the skin. Apart from their role in temperature sensation, thermoreceptors in the skin are also known to be implicated in autonomic thermoregulation; mean area weighted skin temperature has been assigned as having an important role in the determination of the rate of sweat secretion [5]. Because of the differential distribution of these peripheral thermal sensors [7], it seemed likely that area weighting of skin temperatures may not be the optimal method for approximating the physiological effect of the skin temperature. The following study was undertaken to assess the differential thermal sensitivity of different skin areas in the determination of a physiological thermoregulatory response. The sensitivity was measured by the effect of skin temperature changes on the sweating response [5].

Method

Two male adults were each exposed to constant ambient temperatures at values between 30.5 and 36.0° C for 2 to 3 h periods. Relative humidity was constant and air movement was minimal. Each subject, minimally clothed, lay supine on a 5 cm

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fish netting suspended from a rectangular aluminum frame (2.1×0.6 m). Subjects were exposed for a period of 3—7 min to constant thermal irradiation to selected skin areas by manipulating a polished aluminum shutter which shielded two Chromalox lamps situated 1.6 m above the subject. To obtain different degrees of thermal load, radiation intensity was either 350 or 700 W/m^2 and was applied to between 0.03 and 0.10 m^2 of skin surface by shielding the remainder of the skin with reflecting baffles between lamps and subject. The skin areas separately irradiated were the face, chest, abdomen, upper legs, lower legs, upper arms and lower arms. Consecutive exposures were interrupted by recovery periods lasting 3—5 min. Each skin area received at least three irradiation exposures at each ambient temperature.

The temperature at ten skin surface locations was recorded once each minute throughout each exposure and the temperature of the irradiated skin area was continuously monitored by thermocouple. Mean area weighted skin temperature was calculated from a modified Hardy-DuBois equation [2,5]. Internal temperature was recorded once each minute from a thermocouple in the esophagus at the level of the heart.

Local sweating rate was recorded from a 12 cm^2 skin area on the ventral thigh surface by the resistance hygrometry technique [1]. According to the relationship previously described [5], local sweating rate can be predicted from the following equation:

$$\text{local sweating rate mg/min} \cdot \text{cm}^2 = [\alpha\,(T_{\text{in}} - T_{\text{in}_0}) + \beta\,(\overline{T}_s - \overline{T}_{s_0})]\, e^{(T_{s1} - \overline{T}_{s0})/\delta}$$

where: α and β = proportional control constants
δ = Q_{10} constant
T_{in} = internal temperature
T_{in_0} = internal temperature threshold
$\overline{T}_s$ = mean skin temperature
$\overline{T}_{s_0}$ = mean skin temperature threshold
T_{s_1} = local skin temperature beneath sweat collection capsule.

The present experiments were designed so that only T_s in the area to be studied was varied. By necessity, $\overline{T}_s$ was varied to a proportionately lesser degree. Therefore, the change in local sweating rate was directly related to the change in skin temperature and independent of internal and local (beneath the shielded capsule) skin temperature. Modifications in thigh sweating rate could then be related to the change in irradiated skin temperature and area of skin irradiated by computing a sensitivity coefficient (S) for each skin area, where:

$$S_i = \Delta \text{ thigh sweating rate}/[\text{area}\,(\Delta T_s)]_i\,.$$

Sensitivity coefficients from different skin areas were normalized by making the thigh skin sensitivity coefficient a common reference in the following manner:

$$S_i{}^* = S_i/S_{\text{thigh}}\,.$$

In this manner the thermal sensitivity of different skin areas could be related to a standardized physiological response variable.

Results

Sudden exposure to intense radiant heat caused an immediate increase in the temperature of the irradiated skin. Non-irradiated skin did not show any consistent temperature alterations during these same

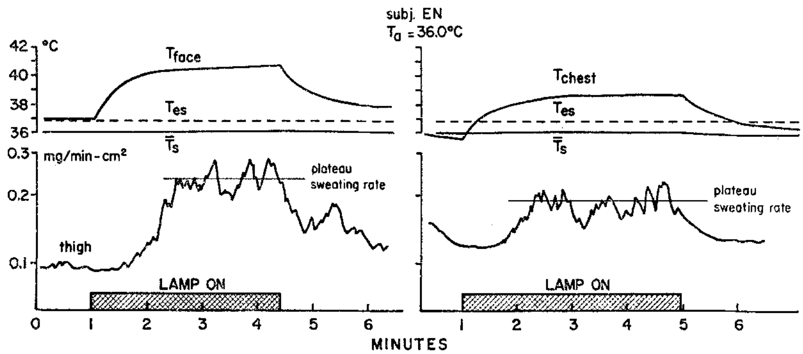

Fig. 1. Thermal and sweating rate patterns during irradiation of the face (0.03 m²) and chest (0.10 m²) with 700 W/m²

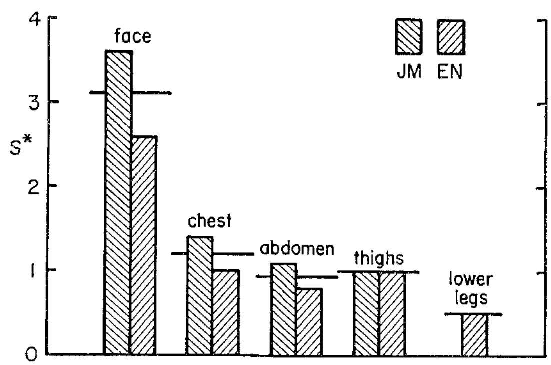

Fig. 2. Mean thermal sensitivity coefficients for a variety of skin regions normalized to the thigh sensitivity coefficient

intervals. Therefore, mean area-weighted skin temperature ($\overline{T}_S$) was increased, albeit very slightly, during irradiation intervals. Internal temperature measured in the esophagus was not affected by the brief periods of irradiation. Hence, we have inferred that brain temperature was also constant; however, it is conceivable that brain temperature could be affected by irradiation to the face.

Fig. 1 illustrates the typical pattern of thermal and sweating rate changes during irradiation of two different skin areas.

Within 1 min the local temperature of the irradiated skin (T_S) had increased to roughly a new steady state level. In response to the increased level of T_S (and $\overline{T}_S$), sweating rate from the thigh was elevated to a new level. Esophageal temperature (T_{es}) was not altered during irradiation of local skin areas; thus, the increase in sweating drive [5] could be entirely attributed to the increase in skin temperature. Thigh sweating rate was elevated in response to the increase in local skin temperature and achieved a plateau level that was proportional to the new level of T_s (Fig. 1) and the irradiated area.

Average thermal sensitivity coefficients were computed for each skin area for each subject and average values of S^* appear in Fig. 2.

It was found that a temperature change of the face, in eliciting a given change in sweating rate at the thigh, and adjusted for surface area was approximately three times as effective as the same stimulus on the thigh. Irradiating a given area of the chest resulted in a slightly greater sweating response (about 20%) than irradiating a similar area of the thigh, although the chest, abdomen and thigh areas were relatively similar in their sensitivities. The lower legs were relatively insensitive as compared to other skin areas and what would be predicted on the basis of their surface area.

Discussion

The uneven distribution of thermal sensors over the skin implies that the contribution from the skin to the central sweating drive cannot be correctly estimated from an area weighted mean skin temperature but should be derived from a sensitivity and area weighted mean skin temperature. We would therefore advocate the use of the weighting factors appearing in Table 1 for the calculation of mean skin temperature ($\bar{T}_s'$) in physiological studies involving the regulation of sweating rate.

Accordingly, the face has been assigned with three times the thermal sensitivity that would be ascribed to it from area weighting. The lower arms and legs have been assigned with one-half the thermal sensitivity that would be ascribed to these surfaces by area weighting.

Table 1. Mean skin temperature weighting factors as determined by area weighting (2) and as weighted by area and thermal sensitivity

	$\bar{T}_s$ (area weighting only)	$\bar{T}_s'$ (S and area)
Face	0.07	0.21
Chest and back	0.18	0.21
Abdomen	0.18	0.17
Upper legs	0.16	0.15
Lower legs	0.16	0.08
Upper arms	0.13	0.12
Lower arms	0.12	0.06
	1.00	1.00

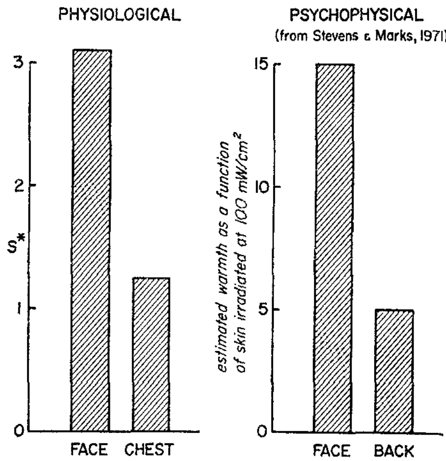

Fig. 3. Similarity between physiological and psychophysical assessment of the importance of thermal sensitivity in the face

There is some psychophysical evidence from thermal sensation data that the face has a relatively greater thermal sensitivity than other skin areas. Stevens and Marks [6] irradiated different areas of forehead and back with a range of intensities and recorded subjective estimates of warmth from their subjects. By selecting and extrapolating their warmth estimate data for similar areas and irradiation levels comparable to those in the present study, a marked similarity could be demonstrated between the psychophysical function of estimated warmth and the physiological thermal sensitivity coefficients for the face and upper body (Fig. 3).

Although it has long been recognized that the face has a preferential thermosensitivity, it may be concluded from the physiological data presented here and the psychophysical data of Stevens and Marks [6] that the face does have a greater proportion of warmth receptors per unit area than any other skin surface. This observation should be taken into account in evaluating the physiologic effect of skin temperature, which cannot be predicted by an area-weighted mean skin temperature. This may be of special importance in clothed man, where the face is the most exposed surface.

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