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Abstract title

Cutaneous warmth thresholds to conductive and radiant heat exposure: body regional differences

Purpose

The purpose of the present study was to explore cutaneous warmth thresholds during conductive and radiant heat exposure on 17 body regions

Methods

A. Conductive heat exposure

Seven male subjects participated in this study (25.7 ± 7.1 y in age, 176 ± 7.4 cm in height, 70.0 ± 7.5 in body weight, 22.2 ± 1.2 kg/m² in BMI). All tests were performed in a climate chamber and subjects were seated in a comfortable recliner posture at an air temperature of 23 °C and 50%RH. All measurements were conducted using a thermal stimulator (Intercross-210, Intercross Co., Japan, stimulating probe surface area: 2.5×2.5 cm²) and repeated three times at each of the 17 body sites (the forehead, neck, chest, abdomen, upper back, lower back, upper arm, forearm, palm, back of hand, front thigh, shin, back of foot, buttock, back thigh, calf, and sole). The values of three repetitions were averaged. A warmth threshold was measured by a methods of limit, which was that the stimuli of the probe started from baseline skin temperature (33°C) and increased at a constant rate of 0.1°C s^{-1} until the subject reported feeling warmth. Warmth sensation was defined as initially sensed warmth on the skin. Subjects pushed the button of the thermal stimulator as soon as they felt warmth.

B. Radiant heat exposure

The surface temperature of a radiant film heater increased by 0.01 A per 0.7 s (0.9°C/s increase) and the film (10×10 cm) was fixed using a wood frame to keep a distance of 10 cm from the skin. Fourteen male subjects participated in this study (age: 25 ± 5.1 y, height: 176.6 ± 5.5 cm, body weight: 70 ± 5.8 kg, body surface area (BSA): 1.89 ± 0.11 m²). Cutaneous warmth thresholds on the identical 17 body regions as the conductive heat exposure experiment. A warmth and hotness thresholds were defined as same as the definition in the conductive heat experiment. All trials were conducted in a climate chamber (23°C and 50%RH) and subjects were in a fowler's or prone position on a recliner. A one-way ANOVA was used to test the body regional differences, and Tukey's post hoc test was conducted for multiple comparisons. Statistical significance was set at $P < 0.05$.

Results

There were significant differences in warmth thresholds among the 17 body regions for both conductive and radiant heat exposure, showing higher thresholds on the forehead, back and palm when compared to the foot and sole ($P < 0.05$), which were explained higher initial skin temperatures on the forehead, back and palm. For the most body regions, warmth thresholds were higher for the conductive heat exposure than for the radiant heat exposure. The biggest

differences were found on the foot (2.6°C-difference) and sole (3.0°C-difference). The results might suggest that the skin was relatively less sensitive to catch conductive heat than radiant heat, but the surface area of heaters was 16 times greater for the radiant heating film than for the conductive heating element and the radiant heater was placed at a 10-cm distance from the skin, while the conductive heating element was contacted to the skin in direct. Therefore, direct comparison in warmth thresholds between conductive and radiant heating was not feasible, but body regional differences in both conductive and radiant heat exposures can be accepted in terms of biological and statistical significance.

Table 1 Body regional cutaneous warmth thresholds during conductive and radiant heat exposure

Body region	Cutaneous warmth thresholds	
	Conductive heat exposure (2.5 × 2.5 cm)	Radiant heat exposure (10 × 10 cm)
Forehead	34.9±1.0	34.8 ± 0.2
Neck	34.2±0.6	33.9 ± 0.5
Chest	33.8±1.1	33.1 ± 0.5
Abdomen	34.6±0.7	33.6 ± 0.7
Upper Back	35.0±1.3	33.7 ± 0.8
Lower Back	35.1±1.0	34.1 ± 1.2
Upper Arm	32.9±1.0	31.9 ± 0.9
Lower Arm	33.9±0.9	31.9 ± 0.5
Palm	34.5±0.6	34.3 ± 0.7
Hand	33.8±0.7	32.9 ± 0.7
Front Thigh	33.9±1.1	32.6 ± 0.9
Shin	33.3±1.0	31.6 ± 0.9
Foot	32.4±0.9	29.8 ± 1.9
Buttock	34.4±1.4	32.9 ± 1.7
Back Thigh	34.1±1.7	33.0 ± 0.9
Calf	33.8±1.4	32.6 ± 0.9
Sole	31.0±1.0	28.0 ± 2.1

At initial stages, mean skin temperature was $32.1 \pm 2.0^{\circ}\text{C}$ (thermally comfortable). The forehead ($34.8 \pm 0.2^{\circ}\text{C}$), lower back ($34.1 \pm 1.2^{\circ}\text{C}$) and palm ($34.3 \pm 0.7^{\circ}\text{C}$) had the highest values in warm thresholds, whereas the foot ($29.8 \pm 1.9^{\circ}\text{C}$) and sole ($28.0 \pm 2.1^{\circ}\text{C}$) had the lowest values, showing $\sim 7^{\circ}\text{C}$ difference in regional skin temperatures ($P<0.001$). The order of hot thresholds showed similar tendencies as the order of warm thresholds. The least increases in skin temperature at warm thresholds were the lower back with a rise of $0.19 \pm 0.42^{\circ}\text{C}$ and the abdomen with a rise of $0.26 \pm 0.30^{\circ}\text{C}$, while the part with the highest increase was the buttock with a rise of $0.89 \pm 0.79^{\circ}\text{C}$ ($P<0.05$). The smallest increase in skin temperature at hot threshold was also the lower back with a rise of 0.5°C , showing significant differences with the increases on the upper arm ($1.46 \pm 0.87^{\circ}\text{C}$), foot ($1.42 \pm 0.71^{\circ}\text{C}$), buttock ($1.57 \pm 0.97^{\circ}\text{C}$), and sole ($1.50 \pm 0.99^{\circ}\text{C}$) ($P<0.001$).

Conclusions

Cutaneous thermal thresholds to radiant heat exposure at a distance of 10 cm had higher on the forehead, lower back and palm than the values on the foot and sole, which were related to the level of initial skin temperatures.

Keywords: cutaneous thermal threshold, radiant heat exposure, thermal sensation, body regional differences, skin temperature