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Effect of Local Cooling on Sweating Rate and Cold Sensation

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Summary. Subjects resting in a 39°C environment were stimulated in different skin regions with a water cooled thermode. This local cooling produced decreases in sweating rate measured at the thigh and increases in magnitude estimates of the cold sensation. The area of cold stimulation varied from 122 cm^2 to 384 cm^2. Sensitivity coefficients of the changes in sweating rate and magnitude estimate were corrected for differences in size of the area of stimulation and change in skin temperature and were normalized to the responses of the chest. The normalized coefficients showed the following relative sensitivities for changes in sweat rate and magnitude estimate respectively: forehead 3.3, 2.2; back 1.2, 1.4; lower leg 1.1, 0.9; chest 1.0, 1.0; thigh 0.9, 1.0; abdomen 0.8, 0.8. Varying the area stimulated from 122 cm^2 to 384 cm^2 produced greater changes in the sweating response than in the magnitude estimate. Rate of skin cooling during the period of stimulation had more effect on the sweating response than on the magnitude estimate. We conclude that cooling different body regions produces generally equivalent changes in the sweat rate and sensation, with the forehead showing a much greater sensitivity per unit area and temperature decrease than other areas.

Key words: Thermal Sensitivity — Sweating Rate — Sensation.

Cutaneous thermoreceptors play an important role in both autonomic temperature regulation and in the conscious sensation of temperature [3,5,7]. Thermal sensitivity to warm stimuli has been demonstrated to be non-uniform over the body surface. For example, if the face and chest are exposed to radiant heat of similar intensities, stimulation of the face elicits a greater sensation of warmth [11] and produces a larger increase in local sweating rate [9] than stimulation of the chest. Simultaneous measurements of autonomic and sensory responses to local cutaneous cold stimuli are unavailable.

The following study was undertaken to secure this information, allowing comparisons of the way in which thermal inputs are processed by the systems subserving autonomic regulation of body temperature and conscious temperature sensation. The relative sensitivity of different portions of the body surface to cold stimulation was also investigated.

Method

Five male subjects were initally tested, and the three whose sweating rate was most affected by local thermal stimulation were chosen for participation in the experiments. During each experimental period, up to 2 hrs in duration, subjects, minimally clothed, lay on a web cot in a 39—40° C environment.

The cold stimulus was provided by a cylindrical or oblong Plexiglas container with a bottom of thin latex rubber. By continuously pumping water from a 6.0° C source through the container, skin temperature under the stimulator (T_{sk} stim) was decreased from a resting level of 36° C to 16°—22° C at the end of the stimulation period. Areas stimulated included the forehead, chest, abdomen, thigh, lower leg, and back. The period of stimulation was always 3 min; the locations are shown in Fig. 1. The back was stimulated in a location similar to that of the chest, but on the obverse side.

Local sweating rate was continuously measured from a 12 cm^2 area on the ventral thigh by the method of resistance hygrometry [8]. A modified version of the method of magnitude estimation was used to assess the cold sensation. The subjects were provided with a dial which could be set at any number from 2 to 80. The setting of the dial procedured a voltage which was continuously recorded, thus providing a continuous record of the magnitude estimate. The subjects were instructed to adjust the dial continuously so that the number indicated on the scale would always be in proportion to the degree of experienced cold. The first several trials on each subject were not included in the analysis.

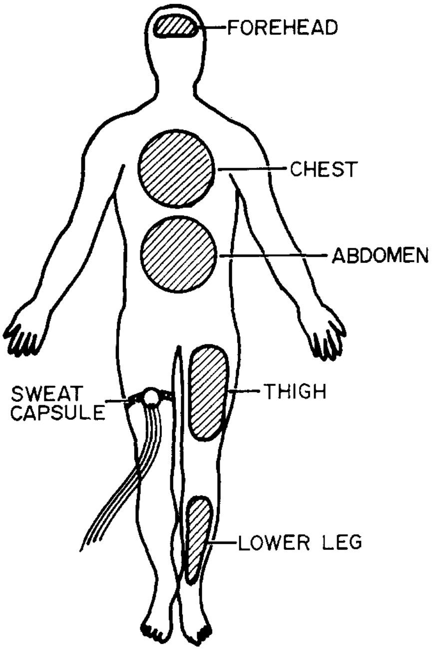

Fig. 1. Locations of the sites which were cooled. The back was stimulated in a location similar to that of the chest, but on the obverse side

A weighted mean skin temperature ($\overline{T}_{sk}$) calculated from 10 skin locations (Hardy-Dubois equation as modified by Nadel *et al.* [8]), and esophageal temperature (T_{es}) were recorded in some experiments. Since T_{es} and $\overline{T}_{sk}$ showed little or no change during the experiments, they were not routinely recorded. T_{sk}stim was continuously recorded during each cold stimulation. This temperature was not included in the calculation of $\overline{T}_{sk}$.

At the onset of each experiment the subject was placed on the webbing, the instrumentation attached, and baselines established for all variables. When the local sweating rate had reached a stable value, the cold stimulus was applied to one of the six areas. After 3 min the stimulus was removed, and several minutes later a warm compress was placed over the stimulated area to bring the tissue temperature back to pre-stimulation levels. The sweating rate was again allowed to stabilize, and another area stimulated. In preliminary experiments we found that if the same area was stimulated twice in succession, the second stimulus was relatively ineffective in producing a change in sweat rate or sensation. Consequently, during the actual experiments the same locus was never stimulated within 1.5 hr of a previous run. We also found that maintaining a constant level of arousal was very important. In preliminary runs some subjects would relax and doze between stimulus applications. It was evident that as the subject relaxed, sweating rate fell; as the subject became alert and attentive, sweating rate rose. During the actual experiments care was taken to keep the subjects awake and attentive.

Results

Fig. 2 depicts continuous records of T_{es}, $\overline{T}_{sk}$, T_{sk} stim, thigh sweating rate, and the magnitude estimate of the cold sensation during application of the cold stimulus to the abdomen, chest, and thigh. $\overline{T}_{sk}$ (exclusive of the area being stimulated) and T_{es} show little change during

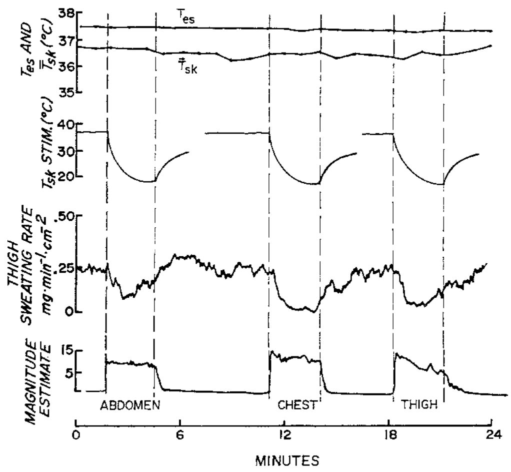

Fig. 2. Continuous records of T_{es}, $\overline{T}_{sk}$, T_{sk}stim, thigh sweating rate, and magnitude estimates of the cold sensation produced by local cooling

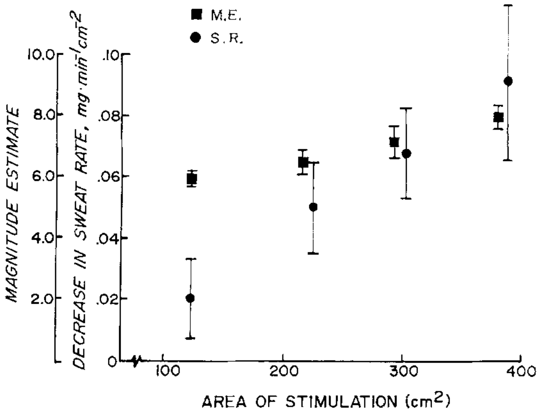

Fig. 3. Effect of varying the area of stimulation on magnitude estimates of the cold sensation (M. E.) and sweating rate (S. R.). The brackets enclose ± one standard error of the mean

the period of cold stimulation. The sweating rate, however, is markedly reduced, concurrent with an increase in the sensation of cold.

As shown in Fig. 1, the area of stimulation for the various loci was not the same. In order to compare the sensitivity of different anatomical locations, the relationship between area of cold stimulation and response output had to be determined. This determination was made from data on abdominal stimulation, as shown in Fig. 3. The areas of stimulation utilized to construct Fig. 3 bracket the areal extent of the stimuli applied to the various portions of the body. The relationship between the decrease in sweating rate (in mg · min^{-1} cm^{2}) and the area of stimulation approximates a direct proportionality; to correct the sweating data for stimulator area, then, we divided by the area (in cm^{2}) of stimulation. The areal summation for the magnitude estimates of the cold sensation, as shown in Fig. 3, is not nearly so complete. In correcting the magnitude estimates for area we equated each area of stimulation to that of the largest stimulator. First, a straight line was fitted to the mean values (solid squares) shown in Fig. 3. Then, the magnitude estimate values for each area of stimulation were determined by the point of intersection with the previously fitted straight line. For each area a factor was computed which, when divided into the magnitude estimate of the area in question, would give the value obtained with the largest stimulator. Thus 6.0, the magnitude estimate produced by stimulating an area of 123 cm^{2}, would be divided by a correction factor of 0.75 to give 8.0, the mean magnitude estimate produced by stimulation with the largest stimulator (384 cm^{2}). The fall in T_{sk}stim was not the same for different areas of stimulation. On the assumption that response outputs were

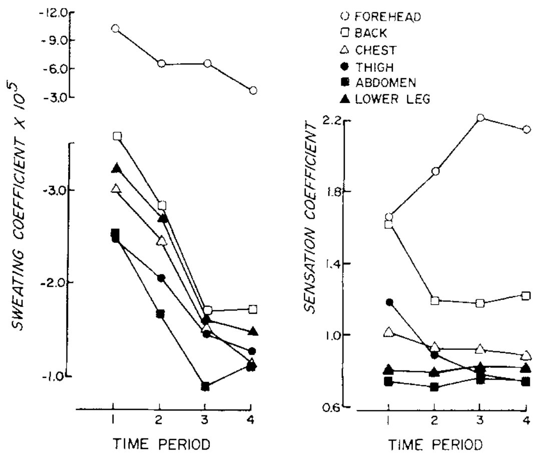

Fig. 4. Changes in the sweating and sensation coefficients over time for the different body regions

proportional to the fall in T_{sk}stim, we divided the area-corrected responses by the mean fall in T_{sk}stim for each 45 sec segment of the 3 min stimulation period. Sweating and sensation coefficients were thus obtained from the following equations:

Sweating coefficient = (Decrease in thigh Sweating rate)/(Area cooled) (ΔT_{sk}stim),

Sensation coefficient = (Magnitude Estimate)/(Area Correction Factor) (ΔT_{sk}stim).

The standard errors of the mean in Fig. 3 are much larger for the sweating response than for the magnitude estimates. This is probably because the subjects were able to focus their attention on the area stimulated, thus eliminating extraneous cues and increasing the accuracy of estimation. The sweating response, on the other hand, is the integrated outflow of a controller which is influenced by a number of thermal and non-thermal variables. All of these factors continue to exert an effect during stimulation of one portion of the skin.

In the left portion of Fig. 4 the mean sweating coefficients for each 45 sec of the 3 min stimulation period are shown. Since the rate of change of T_{sk}stim was greatest during period 1, while T_{sk}stim was lowest during period 4, it is clear that rate of change is an important aspect of the effect on sweat rate of cooling local areas of the skin. The right portion of Fig. 4 depicts the sensation coefficient for the four time periods and the different body areas. Each point represents the geometric mean of the arithmetic means of the data on each of the 3 subjects. The change in sensation over the four time periods is not consistent for different

Table 1. Sweating coefficients and sensation coefficients for each subject and each body area. Each value represents the mean of the four 45 sec periods of six trials

Subject	Forehead	Back	Chest	Thigh	Abdomen	Lower leg
BS	(4.3, 1.5)	(2.1, 1.4)	(3.4, 1.0)	(2.5, 0.88)	(2.2, 0.77)	(2.1, 0.82)
CS	(12.0, 1.3)	(2.9, 0.92)	(2.2, 0.68)	(1.5, 0.63)	(1.2, 0.41)	(3.7, 0.58)
TS	(4.2, 4.1)	(2.4, 1.9)	(0.5, 1.4)	(1.5, 1.5)	(1.2, 1.5)	(0.9, 1.2)

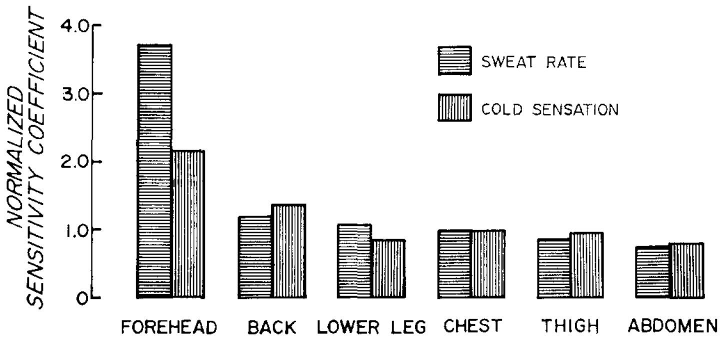

Fig. 5. Sensitivity coefficients for sweating rate and cold sensation normalized to the response of the chest

body regions. The rate of change of T_{sk}stim appears important in the determination of the response when the back and thigh are stimulated, and relatively unimportant for the chest, abdomen, and lower leg. The cold sensation on the forehead grows markedly over the four time periods. However, the forehead may be a special case because of the strong affective quality of stimulation there. Immediately after application, the stimulus was reported to feel cold, but pleasant. Later the sensation changed to one of intense cold pain. The sweating and sensation coefficients for the individual subjects are shown in Table 1. Each value represents the mean of the four 45 sec periods of six trials. In order to compare the sensitivity of the different skin loci, the sweating and sensation coefficients were normalized by comparing each subject's responses to that produced by stimulating the chest. The means of these normalized values are depicted in Fig. 5. Note the general correspondence in sensitivity between the sweat rate and the cold sensation.

Discussion

Cutaneous temperature receptors constitute the primary input elements in the autonomic regulation of body temperature. These sensors are also essential in the production of conscious sensation of ambient thermal conditions [3,5,7]. This study compared the way these two systems utilize peripheral thermal information. The overall sensitivity of the two systems to cold stimulation of different skin regions showed a general correspondence. For both the autonomic and the sensation responses, the forehead was by far the most sensitive per unit area and temperature decrease. Other skin areas were less different in responsiveness. Our findings are quite similar to those of a number of studies which utilized a warm stimulus and measured either autonomic responses or recorded subjective warm sensations. Belding *et al.* [2] found that at low ambient temperatures, warming the face induced peripheral vasodilatation, while warming a similar area of the chest or a much larger area of the leg had no effect. Nadel *et al.* [9] demonstrated that heating the face in a warm environment produced considerably greater increases in thigh sweating rate than heating other skin areas. Hardy and Oppel [6], studying threshold responses to non-penetrating infra-red radiation, found that the forehead was subjectively more than twice as sensitive as the forearm and hand. Recently, J. C. Stevens *et al.* [11] studied the degree of warmth sensation aroused by different levels of heat irradiation of various regions of the body. They found that the relative sensitivities of areas relevant to the present study (in descending order) were forehead, chest, abdomen, back, thigh, and calf. High stimulus intensities reduced the differences in sensitivity among the various areas. The relative sensitivities found by J. C. Stevens *et al.* agree closely with those found by Nadel *et al.* [9] for the sweating response.

Thus, when different areas of the body surface are heated, the relative sensitivities for increases in heat sensation and sweating rate are quite similar. The present study demonstrates a similar finding for increases in cold sensation and decreases in sweating rate following cold stimulation. When we compare regional sensitivities to hot and cold stimuli, the agreement is not good for areas other than the face. The lower leg, for example, is particularly insensitive to heat but has about the same sensitivity to cold as the chest, thigh, and abdomen. This implies that functional warm and cold input may not be similarly distributed. Therefore, if a functional mean skin temperature is to be determined by thermal sensitivities as well as area weighting, the weighting factors may differ depending on whether the stimulus is warm or cold. Table 2 indicates a first approximation of how the weighting factors might differ.

Changes in sensation and sweating rate in response to the rate of change of the stimulus and area of stimulation were not concordant in the present study. As is the case with cold stimulation of the whole body [1,8,12] the effects of skin cooling on sweat rate in the present study were strongly rate dependent. The effect of the rate of fall in skin temperature on sensation, however, was ambiguous. Rate of change

Table 2. Mean skin temperature weighting factors as determined by weighting for area (Hardy, 1949), for area and sensitivity of local sweating rate to warming (Nadel *et al.*, 1973), and for area and sensitivity of local sweating rate to cooling. Since data on sensitivity to cooling is not available for the upper and lower arms, these regions were given simple area weightings

	$\overline{T}_{sk}$ (area weighting only)	$\overline{T}_{sk}$ (area and sensitivity to warming)	$\overline{T}_{sk}$ (area and sensitivity to cooling)
Face	0.07	0.21	0.19
Chest	0.09	0.10	0.08
Upper back	0.09	0.11	0.09
Abdomen	0.18	0.17	0.12
Upper legs	0.16	0.15	0.12
Lower legs	0.16	0.08	0.15
Upper arms	0.13	0.12	0.13
Lower arms	0.12	0.06	0.12
	1.00	1.00	1.00

appeared important on the back and thigh, but relatively unimportant on the chest, abdomen, and lower leg. Stimulation of the forehead appeared to be a special case probably due to the strong affective quality of stimulation there. Because the cold stimulus was relatively intense, differential involvement of cold-pain may be involved in the different relations between sensation and rate of stimulus change seen for the various body areas.

In the abdominal area the relationship between the area of stimulation and the decrease in sweat rate approximated a direct proportionality. The regulator of body temperature, then, was able to activate responses of appropriate magnitude to rapid thermal changes in relatively small areas of skin. Similar changes of stimulation area had much less effect on the cold sensation. Since only one level of cold stimulation was used in the present study, it may be that different relationships would pertain for less intense stimulation. For the warmth sense, J. C. Stevens and Marks [10] found that spatial summation was less important at high levels of experienced sensation.

We conclude that changes in sweat rate and sensation produced by cooling different body regions show a general correspondence, with the forehead showing a much greater sensitivity per unit area and temperature decrease than other areas. For relatively large areas, spatial summation and rate of change of temperature have more effect on the sweating response than on cold sensation. The high sensitivity of the face to thermal stimuli may have evolved at a time when it was a thinly furred and therefore thermally responsive skin region of otherwise well insulated primitive mammals. In donning clothing, man has recreated these conditions, re-establishing the relative importance of the face in the regulation of body temperature.

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