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The Effect of Skin and Central Cooling on Human Thermoregulation

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Normal man regulates his internal temperature at or near a constant level most of the time despite exposure to a wide range of environmental temperatures. The afferent or sensory side of this response has been a matter of investigation particularly as to the relative contribution of the thermo-sensitive structures in the skin and in the deep or central regions of the body. One of the problems in separating the responses to central and peripheral cooling has been the difficulty in cooling the skin without causing a change in central temperature and vice versa. In patients with spinal cord transaction it is possible to control and change the deep body temperature by using the insensitive portion of the body as a heat exchanger, while at the same time regulating the sentient skin temperature by adjusting the ambient temperature. The present report is of such studies in which it was found that skin cooling alone caused a rise in oxygen consumption and shivering but that simultaneous central and skin cooling caused an even greater response.

METHOD

A total of 27 studies were performed on three men with chronic, functionally complete spinal cord transections (Table 1). The studies were performed in the morning with the patients fasting, off medications and with their bladders empty.

TABLE 1. Characteristics of subjects

Subject	Age (yr)	Height (m)	Weight (kg)	Level cord lesion
SC	24	1.80	69.0	T_6
JW	20	1.63	61.5	T_{10}
DF	23	1.86	68.0	L_2

Temperatures were measured by copper-constantan thermocouples recorded automatically, at 24 points on the skin (tip of index finger, forearm, upper arm, anterior shoulder, anterior and posterior chest, cheek, forehead) above and below the level of sensation (abdomen, medial thigh, calf), in the external ear canal (compared frequently to the sublingual temperature with the mouth taped shut) and at multiple sites in the room around the patient. Oxygen consumption was measured automatically by an open circuit method and periodically checked by collected samples analysed with the Scholander apparatus. The insensitive

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portion of the body was placed in a surgical blanket through which was circulated an alcohol mixture at a manually adjusted temperature. The studies were performed in an environmental room with relative humidity at 50% and the temperature controlled in a preselected fashion.

Studies were performed in the following manner:

The internal body temperature (ear, mouth) was kept constant by regulating the heating of the surgical blanket while the sentient skin was cooled either by:

(a) Ramp cooling: cooling the room temperature at varying rates up to 18°C/hr.
(b) Step change cooling: suddenly moving the patient from a room at 30°C to a much cooler room.

In other studies after a period of skin cooling with a constant internal temperature, the internal temperature was caused to fall by cooling the insentient body in the cooling blanket.

RESULTS

RESPONSE TO SKIN COOLING ALONE:

Each patient when exposed to a step change in ambient temperatures of 30°C to 13.5°C or greater or a ramp change of at least 16°C/hr showed an early rise in oxygen consumption that tended to increase with continued cooling even with a constant internal temperature. Figure 1 shows a representative study in patient with level at T_{10}. The ear temperature was kept constant at approximately 37°C by careful heating of the insentient area while the sentient skin was cooled by cooling the room air. Increased oxygen consumption began within a few minutes of starting the room cooling and increased slowly as the cooling continued.

Table 2 shows the average per cent increase in oxygen consumption after forty minutes of skin cooling alone by step change (30° to 6°C) for three patients. The change in oxygen consumption was greater in the patients with the larger areas of sentient skin cooled.

TABLE 2. Effect of cooling on oxygen consumption

Subject	Skin cooling alone	Skin and central cooling
	Oxygen consumption at 40 min of cooling (Per cent increase above resting)	Maximum oxygen consumption (Per cent increase above resting)
SC	30	107
JW	40	142
DF	95	181

RESPONSE TO SKIN AND CENTRAL COOLING:

In each subject after a period of skin cooling alone, central cooling was produced by cooling the lower body, and there was a rapid increase both in the rate of oxygen consumed and in the vigour of shivering (Table 2). A representative study is shown in Fig. 2 where in the patient with an L_2 lesion oxygen consumption had increased to 100% of resting with skin cooling, but when the ear temperature was allowed to fall the metabolism rose to 181% of resting. As seen in Table 2 the maximum oxygen consumption in response to both central and peripheral cooling was much greater than with skin cooling alone and also was greater in the patient with the lower spinal lesion than those with the higher lesions.

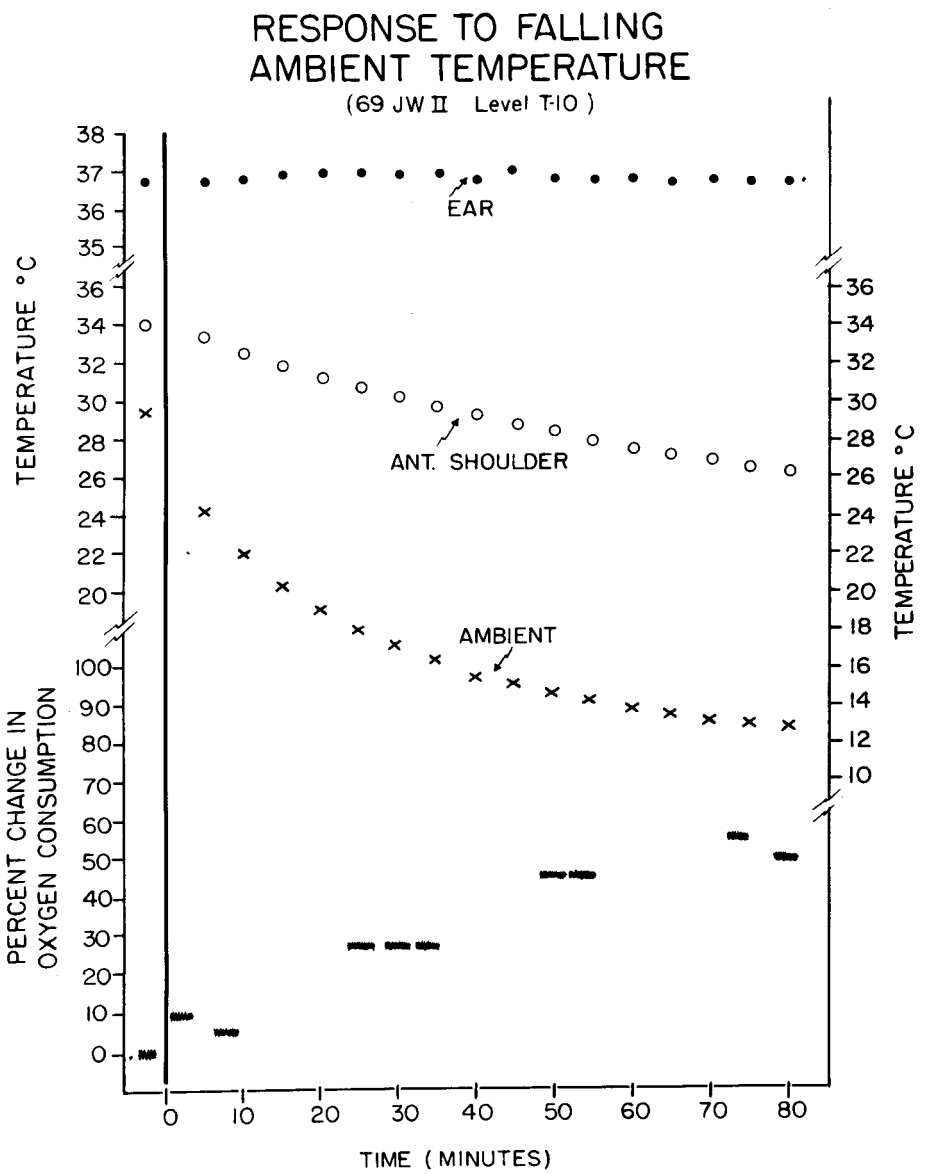

Fig. 1. Response to falling ambient temperature.

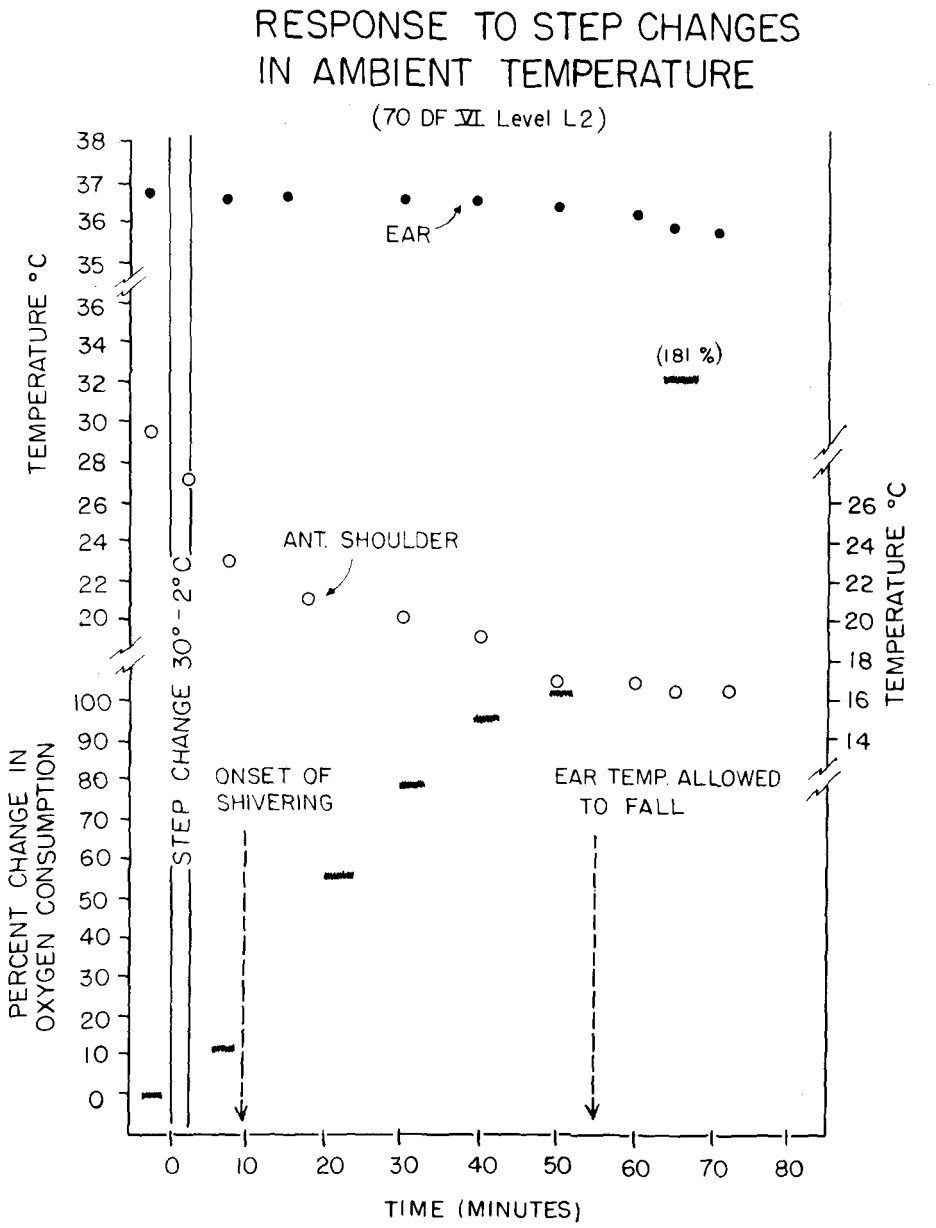

Fig. 2. Response to step changes in ambient temperature.

DISCUSSION

Sherrington (1924) studied spinal dogs in which he placed the insentient portion of the body in ice water while exposing the sentient body to an ambient temperature of 60°C, and when the deep body temperature fell, shivering occurred in the forelimbs. Using a similar technique in our laboratory we found that spinal patients increased their oxygen consumption and shivered in the innervated muscle even when the sentient skin was kept hot (above 34°C) when the deep body temperature (ear) fell to approximately 35.6°C (Downey, Chiodi and Darling, 1967). In paraplegic subjects when the sentient skin was cool, shivering began at higher ear temperatures (Downey, Miller and Darling, 1969). In the present study it has been demonstrated that skin cooling alone, if it be of sufficient degree, can cause a definite and continuous rise in oxygen consumption and shivering even when the central temperature is constant at or above 37°C. There also appears to be a greater response to cooling when the area of sentient skin cooled is greater (the patient with an L_2 lesion as compared to the T_6 lesion) and in all the patients the response was greater the longer the cooling stimulus was continued. The interrelationship between the rate of cooling, the area cooled and the duration of cooling remains to be worked out, but it is apparent that any model of thermoregulation must include these dynamic responses.

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