Brain temperatures in the rat during exposure to low environmental temperatures

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Exposure to cold is known to elicit a rise in metabolic rate in various tissues of homeothermic animals. The role of the hypothalamus in this response was investigated by exposing normal and cold-acclimated rats to environmental temperatures of 26 C, 6 C, and -8 C and comparing the temperature changes in the thalamus, hypothalamus, and rectum using chronically implanted thermocouples. At all environmental temperatures the cold-acclimated rats had lower hypothalamic temperatures than did the normal animals. Apart from this, pattern of response was similar in all animals; the hypothalamic temperature tends to increase on exposure of the animal to cold while the adjacent thalamic region shows a marked fall in temperature, the rectal temperature staying fairly constant. This difference in response suggests increased metabolic heat production in the hypothalamus on exposure of the rat to low temperatures.

METHODS

Adult male and female rats of the Long-Evans strain weighing from 300 to 400 g were used. The animals were individually caged and maintained at either 26 (±1) C or 6 (±1) C and used after 50 to 90 days at these temperatures.

The temperatures were measured with thermocouples constructed from no. 30 B & S gauge iron and constantan wire. The iron-constantan leads were arc welded, coated with epoxy resin and dried for 1 hr at 85 C. Readings could be estimated to within 0.05 C using a Speedomax recorder. The probes were tested in a water bath at various temperatures before use. The thermocouples were placed in the brain of each rat using a Krieg-Johnson stereotaxic instrument with the animal under pentobarbital anesthesia, 6 mg/kg body weight. Standard placements were used in all experiments: 1) 3 mm behind the bregma, 0.5 mm to the right of the sagittal sinus, and 4.0 mm below the brain surface (thalamic region); 2) 2 mm behind the bregma, 0.5 mm to the left of the sagittal sinus, and 7.5 mm below the brain surface (hypothalamus).

The thermocouples were fixed in position with NuWeld dental cement. A further probe was inserted approximately 7 cm into the rectum, the leads running under the skin from the back of the neck.

Experiments were started on each animal 24 hr after operation to allow full recovery from the anesthetic.

Temperature recordings were made at environmental temperatures of 26 (±1) C, 6 (±1) C, and -8 (±1) C with the animals unrestrained, sufficient time being allowed for the recordings to stabilize at each of these temperatures.

On completion of each experiment the position of the probes was checked by perfusing the brain with 10 %
RESULTS

Recordings were obtained from 28 experiments on seven normal and nine cold-acclimated animals.

The hypothalamic temperature was consistently higher in the normal group when compared with the cold-acclimated animals at the same environmental temperature (Table 1). Apart from this there was no significant difference between the two groups in either the general pattern or magnitude of the temperature changes in response to exposure to cold.

The mean temperatures for all experiments, in each of the probes and at the three environmental temperatures tested, are seen in Table 2. At all environmental temperatures the highest reading was invariably that of the hypothalamic thermocouple, the mean core temperature, recorded by the rectal probe, being 0.45 ± 0.25°C lower than this.

While the pattern of response to cold is seen in the mean temperatures in Table 2, the changes in the individual animal are more striking. A typical response is seen in Fig. 3. As the environmental temperature is lowered there is a rise in the hypothalamic temperature, the core temperature tends to increase, and there is a progressive fall in the thalamic area. The marked difference in response between the hypothalamic and thalamic probes is abolished if the experiment is conducted with the animal under barbiturate or urethane anesthesia, the temperature difference between the two locations remaining, in this instance, fairly constant (Fig. 4).

DISCUSSION

There will be a temperature gradient from the base to the surface of the brain due to external heat loss so that...
TABLE 2. Mean hypothalamic, thalamic, and rectal temperatures, ± SEM, at environmental temperatures of 26°C, 6°C, and -8°C

<table>
<thead>
<tr>
<th>Environmental Temperature</th>
<th>Hypothalamus</th>
<th>Thalamic region</th>
<th>Rectal</th>
</tr>
</thead>
<tbody>
<tr>
<td>26°C</td>
<td>38.95 ± 0.20</td>
<td>38.35 ± 0.20</td>
<td>38.65 ± 0.30</td>
</tr>
<tr>
<td>6°C</td>
<td>39.00 ± 0.40</td>
<td>37.45 ± 0.20</td>
<td>38.70 ± 0.30</td>
</tr>
<tr>
<td>-8°C</td>
<td>39.2 ± 0.10</td>
<td>37.35 ± 0.20</td>
<td>38.95 ± 0.20</td>
</tr>
</tbody>
</table>

some areas will be cooler than the carotid and vertebral artery blood (11). On exposure of the animal to cold this gradient will increase. Thus the fall in temperature of the thalamic region on exposure to cold will be in part due to an increase in external heat loss.

However, from Fig. 4, the gradient from the base of the brain to the thalamus is quite small (of the order of 0.5°) as is shown by the difference between the respective probes under urethane anesthesia. Hence the decrease in thalamic temperature must also reflect a fall in temperature of the perfusing blood. It follows from this argument that the midhypothalamus is at a higher temperature than the carotid blood and there must therefore be marked metabolic heat production in this area.

The response of the hypothalamus to exposure of the animal to cold is distinct from that of the thalamic region in that the temperature tends to increase rather than decrease. This rise in temperature could be brought about by: a) A decrease in blood flow with diminished convective cooling (since the hypothalamus is at a higher temperature than the perfusing blood); b) the transference of heat to the hypothalamus from thermogenic regions; c) increased metabolic heat production in the hypothalamus.

There does not appear to be any reported study of cerebral blood flow during exposure to cold. It is seen from Fig. 4 that the temperature gradient between the hypothalamus and the thalamic region is decreased under urethane anesthesia. Thus the increased temperature gradient between these regions in the conscious animal cannot be due in any significant degree to increased external heat loss. Since the blood supply to these areas is the same, any changes in blood flow would be expected to produce similar temperature changes in each, i.e., one would also expect the hypothalamic temperature to fall in response to the hemodynamic changes occurring on cold exposure. That this argument is not invalidated by special circumstances pertaining in the thalamic region was checked by placing the control thermocouple in three further animals in the frontal region of the brain, 2.0 mm below the cortex. The temperature changes were essentially the same.

Smith and Roberts (12) have suggested that the brown adipose tissue in the rat has an essentially thermogenic role and that the anatomical arrangement of the emerging veins constitutes a heat exchange mechanism by which the inner vertebral sinus of the thoracic and cervical segments could receive preferential transference of heat. Whether this heat is conveyed further forward is not
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yet known. However since the brown fat has been shown to undergo hypertrophy during cold acclimation (19), one might expect, if such a mechanism were passing heat to the hypothalamus, that the latter would be at a higher temperature in the cold-acclimated than in the normal animal. Since in the present study the hypothalamic temperature was evidently lower in the acclimated animals (Table 1) a forward transfer of heat would thus appear unlikely.

The most likely alternative therefore is that the hypothalamus undergoes increased metabolic activity which at least partially resists any fall in temperature below some threshold level during exposure of the animal to cold. This view is in accordance with the conclusions reached by Donhoffer et al. (2) under different exper-

REFERENCES