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THE RECEPTORS CONCERNED IN THE THERMAL STIMULUS TO PANTING IN SHEEP

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It is now generally accepted that the maintenance of a stable deep body temperature in mammalian homoeotherms is achieved by means of thermoregulatory responses to both central and peripheral thermal stimuli. However, whether such responses to a change in the thermal gradient between an animal and its environment can result from the stimulation of peripheral receptors alone, or whether a change in the temperature of the blood supply to the temperature-sensitive areas of the hypothalamus must precede these responses, is not yet clear.

This aspect of temperature regulation has been the basis of a number of investigations into the site of thermal stimulation involved in the onset of panting ever since Goldstein (1872) suggested the involvement of a rise in the temperature of the blood supply to the brain, and Sihler (1879, 1880) expressed the contrary view that the normal stimulus to panting must be entirely from the body surface. The majority of subsequent investigators (Richet, 1898; Hammouda, 1933; Vlcek, 1937; Hemingway, 1938; Forster & Ferguson, 1952; Lim & Grodins, 1955), using the cat and dog, have attributed considerable importance to a peripheral thermal stimulus to panting, but have been unable to define clearly the relative importance of peripheral and central thermal stimulation.

One of the difficulties has been to keep the temperature of the hypothalamic centres of temperature regulation, or of their blood supply, under constant observation in the intact conscious animal. The rectal temperature is inadequate as a measure of deep body temperature because of its considerable thermal inertia when the heat content of the body is changing (Ross, 1956; Bligh, 1957*a*), and the introduction of temperature-sensitive instruments directly into the hypothalamic tissue may well produce a variable degree of damage.

To meet this difficulty Bligh (1957*c*) used a polythene-clad thermocouple, chronically implanted within the bicarotid trunk, to keep the temperature of

the blood supply to the brain of the calf under constant observation, and was able to show that in this species the onset of panting in response to a sharp rise in environmental temperature does in fact occur in the absence of any rise in the temperature of the blood supplying the brain. It is thus inferred that the thermal stimulation to panting can be entirely peripheral in origin.

The experiments now presented show that this is also true for the densely fleeced sheep. They also provide evidence about the topography of the thermal receptors involved.

METHODS

Five castrated male Welsh Mountain sheep, 1–2 yr old and weighing 24–28 kg, were used. With aseptic precautions, a polythene-clad copper-constantan thermocouple was inserted into a carotid artery so that the thermojunction lay below the point of bifurcation of the bicarotid trunk into the common carotid arteries. The thermocouple wires were brought to a terminal button sewn

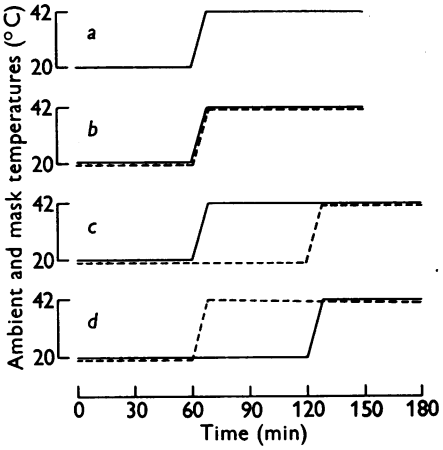

Fig. 1. The four types of experiment: —— ambient chamber temperature; ---- temperature of the independent air supply to the mask covering the nasobuccal area.

to the skin in the neck region. When the animal was taken into the temperature-controlled chamber, the thermocouple was connected to the temperature-measuring system of the chamber, but at other times the animal was able to move about freely in its pen. This technique has already been described (Bligh, 1957*a*, *b*). Respiration rate was recorded by means of a stethograph belt and recording tambour. Skin temperature was measured by means of a fine thermocouple at one position only, beneath the fleece in the dorsal thoracic area.

Experiments were started with each sheep 4 days after the operation, and were continued daily with interruptions at week-ends. The animals were brought from the pen to the climatic chamber in a trolley, so as to cause minimum disturbance to metabolism, and were then required to remain standing within tubular steel stanchions throughout each 2–3 hr experiment, without access to food or water. Respiration rate, skin temperature and bicarotid trunk blood temperature were recorded at intervals of 5 min throughout each experiment. In some experiments a face mask with its own temperature-controlled air supply was placed on the animal, so as to vary the temperature of the air surrounding the nasobuccal area independently from that which surrounded the animal's general body surface.

Four types of experiment were employed. In the first, basic, type of experiment, the sheep

spent the first hour in the chamber at an ambient air temperature of about 20° C. At the end of this period, the ambient temperature was raised rapidly to 42° C and maintained at that level for 1 or 1½ hr (Fig. 1*a*). In the other three types of experiment the sheep wore the face mask with the independent air supply. The first of these experiments was similar to the basic experiment. After 1 hr during which both ambient and mask temperatures were kept at 20° C, both temperatures were raised to 42° C and kept at that level for 1½ hr (Fig. 1*b*). In the second type of mask experiment, after the first hour at 20° C ambient temperature was raised to 42° C, while the mask temperature remained low. At the end of the second hour, mask temperature also was raised to 42° C and kept there until the end of the third hour (Fig. 1*c*). The third type of mask experiment was the converse of the second type: at the end of the first hour at 20° C, mask temperature alone was raised to 42° C, and an hour later ambient temperature was also raised to 42° C and kept there until the end of the third hour (Fig. 1*d*). Although given as 20° C, in fact the chamber temperature was uncontrolled during the first hour, and ambient air and mask air temperatures varied between 19 and 23° C, but was usually close to the mean value of 20·4° C.

The basic experiment, without the mask, was made three times on each of two sheep (Nos. WM 2 and 3). In these experiments the ambient temperature was maintained at 42° C for 1 hr only. All four types of experiment were made twice each, in random order, on each of three other sheep (Nos. WM 6, 7 and 8).

Humidity was recorded but not controlled in these experiments. During the first hour, at an ambient temperature of about 20° C, vapour pressure varied between 4·5 and 6 mm Hg (25–32% r.h.). At 42° C vapour pressure remained close to 7·5 mm Hg (12% r.h.).

At the conclusion of the experiments on each animal it was killed, and the position of the bicarotid trunk thermocouple was determined. In each case the temperature-sensitive junction was found to be lying in the mid-stream position, somewhere between the aorta and the point of bifurcation of the bicarotid trunk, and was free from blood clots.

The apparatus for temperature measurement, which was accurate to 0·05° C, was calibrated frequently. Each implanted thermocouple was calibrated before being placed within the bicarotid trunk and usually re-calibrated following its removal postmortem.

RESULTS

The mean values obtained for the respiratory frequency and the blood temperature (bicarotid trunk temperature) of five sheep which were subjected to an ambient temperature rise of 22° C are shown in Fig. 2. In each experiment the animal was kept in the chamber at 20° C for a preliminary period of 1 hr and then for another hour at 42° C. As is shown in Fig. 2, coincident with the rise in chamber temperature there was a rise in skin temperature and respiratory frequency. The blood temperature also increased over the same period but only very slowly and the panting response was well established before a change in blood temperature was detectable. From the rapid onset of panting and from the fact that the blood temperature even at its maximum did not exceed the blood temperature at the beginning of the experiment it appeared that the respiratory response could not have been due solely to the change in deep body temperature.

From the analysis of the individual variations (see Figs. 3, 4) in the response of the five sheep to an increasing ambient temperature it was observed that the rise in respiratory frequency following an abrupt rise in ambient temperature can occur in the absence of any rise in blood temperature (Fig. 4*a*); that

in magnitude this response is independent of any change in blood temperature which may occur (Fig. 4*a*); and that it is also independent of the respiratory frequency during the preliminary period at 20° C ambient temperature (Fig. 4*b*); but that the rate finally attained at the end of 1 hr at 42° C ambient temperature may be dependent upon the respiratory frequency during the preliminary period (Fig. 4*c*).

In every experiment the change in skin temperature at the one point of measurement, when ambient temperature was raised, was similar to that shown in Fig. 2. This measurement is of little assistance in interpreting these experiments, except to indicate the order of temperature change transmitted

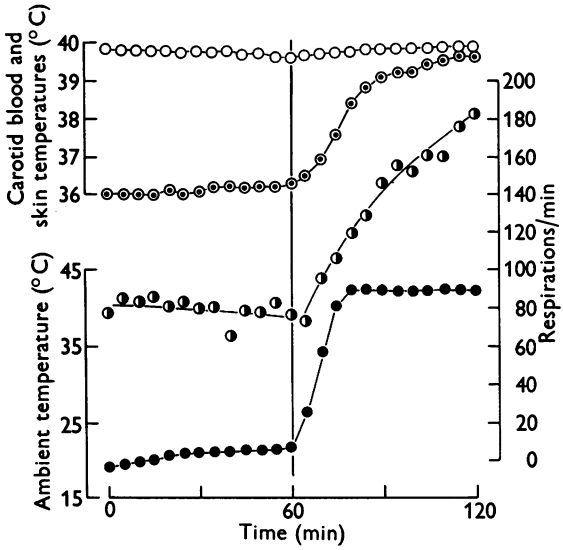

Fig. 2. The effect of raising ambient temperature (●—●) from 20 to 42° C upon bicarotid trunk blood temperature (○—○), skin temperature (⊙—⊙) and respiratory frequency (◑—◑). The mean values obtained from twelve experiments on five sheep. The vertical line indicates the point at which the temperature of the chamber started to rise.

to the skin beneath the fleece. The change may be largely passive, and any component due to an active change in peripheral vasomotor tone cannot be distinguished.

In experiments in which the animals were made to breathe through a mask, raising the temperature of both the ambient air and the inhaled air produced effects similar to those already described, which were due to raising ambient temperature alone. Therefore, the mask itself had no significant effect and experiments in which it was employed may be legitimately used to analyse the separate effects of raising the temperature so as to act on skin receptors and raising the temperature of the inhaled air so as to act on receptors of the respiratory epithelium.

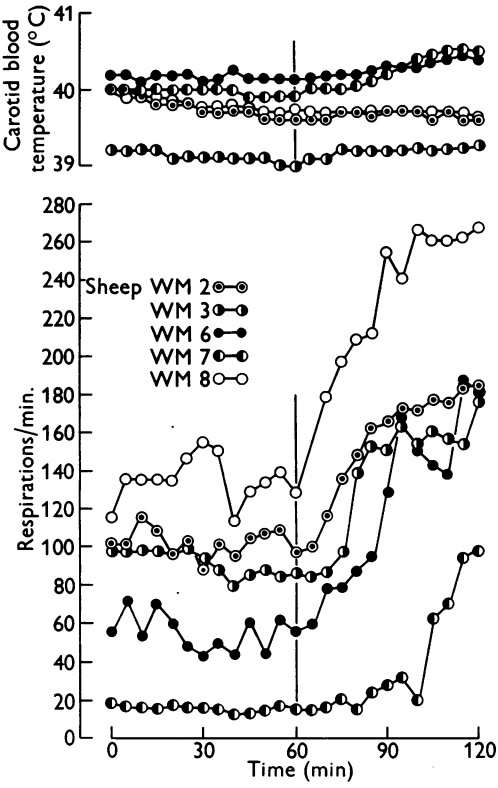

Fig. 3. The effect of raising ambient chamber temperature from 20 to 42° C upon bicarotid trunk blood temperature and respiratory frequency of each of the five sheep studied. Each plot is the mean of two or three experiments on one animal. The vertical line indicates the point at which the temperature of the chamber started to rise.

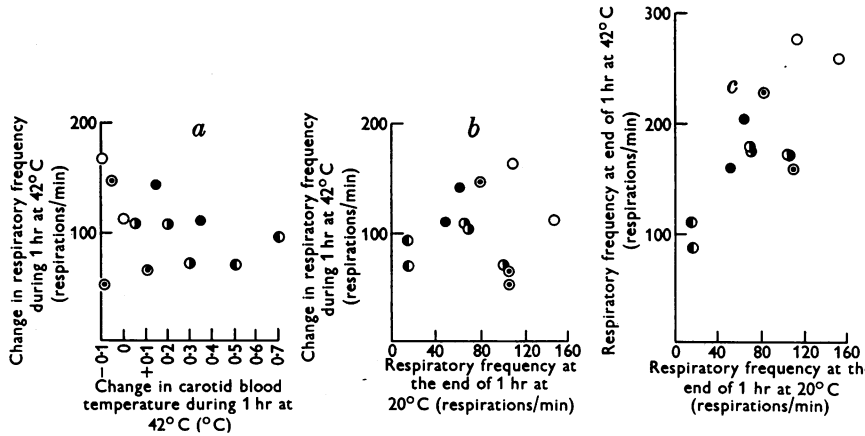

Fig. 4. Analysis of the variation from animal to animal in the effect of a rise in ambient chamber temperature from 20 to 42° C upon bicarotid trunk blood temperature and respiratory frequency. The symbols represent individual sheep and correspond to those used in Fig. 3.

The mean values obtained in experiments using this method are given in Fig. 5. When the mask air temperature alone was raised to 42° C, so that only the nasobuccal area and respiratory tract were exposed to the higher temperature (Fig. 5*d*), the rise in the respiratory frequency at the end of 1 hr was only 23% of that obtained when both mask and ambient air temperatures were raised simultaneously (Fig. 5*a*). When the ambient air temperature was raised to 42° C while mask temperature remained low (Fig. 5*c*), the increase in respiratory frequency was 63% of the effect of raising both ambient air and mask temperatures (Fig. 5*b*).

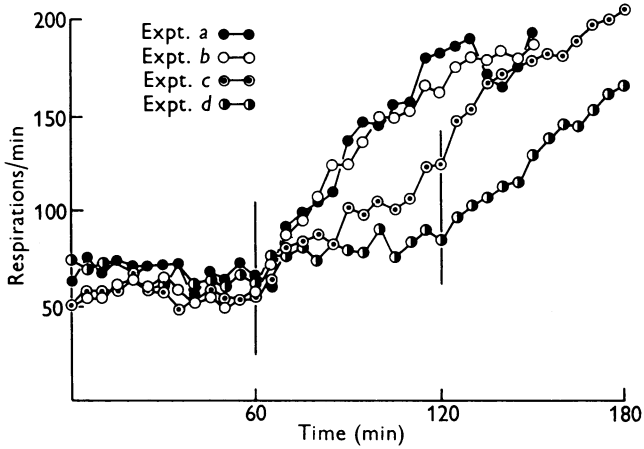

Fig. 5. The mean values of respiratory frequency for experiments of types *a*, *b*, *c* and *d* (Fig. 1). Each plot is the mean of two experiments on each of three sheep. The vertical lines correspond to the changes in chamber and mask temperatures indicated in Fig. 1.

DISCUSSION

It has now been shown that in the sheep, as in the calf (Bligh, 1957*c*), the onset of panting can occur in the absence of any rise in the temperature of the blood supplying the brain. In some experiments there was no change in blood temperature, during the period of high environmental temperature, while respiratory frequency increased considerably. This means that in these instances the animal had exactly balanced the reduced ability to lose heat by radiation and convection, due to a higher ambient temperature, with a rise in the evaporative heat loss from the respiratory tract, and possibly also from the skin, by thermo-regulatory responses to a purely peripheral thermal stimulation. But in other experiments heat loss was not always so finely adjusted. There were instances of both a rise and a fall in bicarotid trunk temperature during this phase of the experiment.

It has been suggested by Bazett (1927) and Burton (1941) that whereas the stimuli to thermoregulatory responses appear to act peripherally, the

magnitude of these responses may be modified by the temperature of the blood supplying the hypothalamic centres. The present experiments, in which the direction and magnitude of change in the temperature of the blood supply to the brain had apparently no effect on the respiratory response to a raised ambient temperature, do not support this view. It would seem that panting is not a finely controlled response to a high environmental temperature, so as to rebalance heat production and heat loss exactly at a fixed level of deep body temperature, but serves only as an approximate means of adjustment, occasionally over-compensating and often under-compensating for the reduction in heat loss by other channels. The final balance between heat production and heat loss involves a fall or rise in the heat content of the body. This interpretation of the experimental results supports the view of Glaser & Newling (1957) that the maintenance of a thermal balance is the fundamental property of temperature control, while deep and superficial temperatures may vary within fairly wide limits.

A possible reason for the failure of those animals in which there was an appreciable increase in deep body temperature to raise their respiratory frequencies further could be that respiratory frequency was already maximal for that animal, and that despite an additional stimulus of central origin, evaporative heat loss from the respiratory tract could not be further increased. This is almost certainly not the case, for in other experiments on these same animals, to be reported later, it was found that if, after respiratory frequency had levelled out following a rise in chamber temperature to 42° C, the humidity was then increased, a further sharp rise in respiratory frequency would occur. The reason for this rise has not yet been fully investigated, but its occurrence suggests that had the rise in deep body temperature in the experiments reported here acted as a direct thermal stimulus upon the hypothalamic centres, the animal was physically capable of responding with a further rise in respiratory frequency.

The conclusion drawn from these experiments on sheep, that the magnitude of the rise in deep body temperature had no influence upon the respiratory response to a raised ambient temperature, does not deny the possibility that in the absence of a powerful peripheral stimulus a rise in deep body temperature of the order of those which occurred in some of these experiments would not then have an effect upon respiratory frequency; although there is no evidence to suggest that a rise in blood temperature of 1° C or less can produce panting by a direct effect upon the hypothalamic centres. A rise in respiratory frequency was produced in the anaesthetized cat (Magoun, Harrison, Brobeck & Ranson, 1938) and the anaesthetized dog (Moorhouse, 1911; Hammouda, 1933) by the direct application of heat to the hypothalamic areas concerned in temperature regulation, or by warming the arterial blood supplying these areas. However, in each case it was necessary to raise the

hypothalamic temperature by 3 or 4° C before panting occurred. Hemingway, Rasmussen, Wikoff & Rasmussen (1940) and Ström (1950*a*, *b*) were unable to obtain panting by similar techniques.

The demonstration that in certain circumstances the thermal stimulus to panting can be entirely peripheral in origin inevitably leads to renewed speculation upon the distribution of the temperature receptors involved. This was first considered by Sihler (1880), who investigated the importance of temperature receptors in the lungs of dogs. He reported that breathing warm air did not cause dogs to pant, and that when panting had been established by generalized heating, section of the vagi did not stop it. Richet (1898) confirmed that the vagi play no part in the response, and concluded that the receptors were probably cutaneous, including those supplied by the trigeminal nerve. The more recent suggestion that in bovines there may be temperature receptors in the respiratory tract (Beakley & Findlay, 1955), and the demonstration by Nisbet (1955) of many sensory nerve endings in the bovine muzzle, led to an extension of the studies on the calf to see if the onset of panting depended specifically upon the thermal stimulation of receptors in the nasobuccal area. These experiments, which have only been reported briefly (Bligh, 1957*d*) showed that this is not the case. Warming of the nasobuccal area was a feeble stimulus to panting compared with warming the external surface excluding the nasobuccal area. Similar experiments with the sheep have yielded similar results. It is clear that the nasobuccal area of the Ayrshire calf and the Welsh Mountain sheep contains some temperature receptors, the stimulation of which can result in a small but appreciable increase in respiratory frequency, and that the thermal stimulation of the receptors in this area, together with those somewhere on the body surface generally, is necessary for the maximum respiratory response to a given change in environmental temperature. These results confirm the view of Richet (1898) that reflex thermal polypnoea probably results from the stimulation of cutaneous nerves, including the 5th cranial nerves, which supply the skin of the face and the ectodermal portion of the mucous membrane of the mouth and the nasal cavity (Larsell, 1951), but do not wholly support the suggestion of Beakley & Findlay (1955) that the thermal receptors in the respiratory tract may play a prominent role in the initiation of panting.

The question remains whether the peripheral receptors are more or less uniformly distributed over the body surface, large areas of which, in the case of the sheep, are heavily insulated from the environment by the dense fleece, or whether the receptors are concentrated at some relatively lightly insulated area such as the ears. This will be the subject of further experiments.

SUMMARY

1. It has been shown that in the Welsh Mountain sheep the onset of panting in response to an abrupt rise in environmental temperature need not be preceded by any change in deep body temperature, and that, by inference, this thermoregulatory response must result from the stimulation of peripheral thermal receptors.

2. Such changes as have been observed in deep body temperature coincident with the onset of panting appear to be passive, and do not modify the respiratory response to a high environmental temperature.

3. A face mask with an independent temperature-controlled air supply was used to separate the role of temperature receptors in the nasobuccal area from those on the general body surface. Stimulation of temperature receptors in both the nasobuccal area and elsewhere on the general body surface is necessary for the normal respiratory response to a raised environmental temperature. The receptors on the general body surface are the more effective of the two components.

My thanks are due to Mr Paul Gibbs for his invaluable technical assistance.

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