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THE REGIONAL DISTRIBUTION OF EMOTIONAL SWEATING IN MAN

BY JUDITH A. ALLEN, JANET E. ARMSTRONG AND I. C. RODDIE

From the Department of Physiology, The Queen's University of Belfast, Belfast BT9 7BL

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SUMMARY

1. Emotional sweating was induced in normal subjects by mental arithmetic at environmental temperatures of 29 and 26° C and estimated from continuous records of body weight loss.

2. The sweat output from four independent regions of the body – (*a*) the head and neck, (*b*) the arms and legs, (*c*) the trunk, and (*d*) the hands and feet – was studied separately, the remainder of the body being covered in each case by plastic bags. The evaporative water loss from each skin region increased markedly during mental arithmetic.

3. The sweat contribution from each region was a substantial fraction of the total body sweat response and appeared to be roughly proportional to the calculated number of sweat glands in each region.

4. There is no evidence from these experiments to indicate that the sweat glands of the skin of the hands and feet behave differently to those of the skin of the rest of the body in response to emotional stress.

INTRODUCTION

Emotional sweating is thought to be confined largely to the palms of the hands, soles of the feet and the axillae (List & Peet, 1938; Chalmers & Keele, 1952; Kuno, 1956), with perhaps a contribution from the forehead (McGregor, 1952). Recent work has suggested that other areas may also participate in emotional sweating (Abram, 1972), but it was not known whether these responses were generalized or confined to a particular site.

The primary object of this investigation was to study the emotional sweat response of four independent regions of the body (the head and neck, the arms and legs, the trunk and the hands and feet) and to assess, if possible, the relative contribution of each area to the total body response.

In a further series of experiments, emotional responses at two environmental temperatures were compared.

METHODS

Emotional sweating was induced by a 10-min period of moderately difficult mental arithmetic and estimated from continuous records of body weight loss (Allen, Grimley & Roddie, 1971). The mental arithmetic consisted of items such as the multiplication of a two- or three-digit number by a two-digit number.

The subjects were healthy male students in their early twenties. They wore only shorts and lay supine on a bed attached to the pan of a balance. The subject and balance were enclosed in a thermostatically controlled heat chamber in which the relative humidity was in the range of 30–40 %, remaining constant throughout an experiment. To allow comparison of results from subjects of different sizes, the rate of weight loss was expressed in units of g per m^2 total body surface area per 5 min using the formula of Du Bois & Du Bois (1916).

Heart rate was recorded throughout each experiment from a Devices instantaneous ratemeter (Type 2750) triggered by the QRS complex of lead II of the electrocardiogram. Skin temperatures were monitored continuously using thermocouples.

Regional sweat responses

These experiments were carried out on six different groups of five subjects according to the following plan.

Group	Experiment 1	Experiment 2
	Weight loss measured from	
1	Head and neck plus respiratory passages	Whole body plus respiratory passages
2	Arms and legs plus respiratory passages	Whole body plus respiratory passages
3	Trunk plus respiratory passages	Whole body plus respiratory passages
4	Hands and feet plus respiratory passages	Whole body plus respiratory passages
5	Whole body plus respiratory passages	Whole body plus respiratory passages
6	Respiratory passages	

Experiments 1 and 2 were separated by a 4-week interval.

When a particular region was under investigation, the rest of the body was enclosed in plastic bags so that the sweat secreted by it would be retained on the body balance. These bags were attached with 'Sellotape' to the appropriate anatomical landmarks, the clavicles, the suprasternal notch and seventh cervical spine; the acromio-clavicular joints, anterior and posterior axillary folds; the anterior superior iliac spines; the malleoli and styloid processes. A disposable oxygen mask (Bakelite Xylonite Ltd.) was fitted to a hole in the bag when it was necessary to cover the head. Subjects in group 6 were completely covered except for this mask.

Each experiment was carried out at an environmental temperature of 29° C, and observations were made during a 25-min control period, a 10-min period of verbal mental arithmetic and a 15-min recovery period.

Influence of environmental temperature

In this series of experiments, the emotional sweat response from (*a*) the hands and feet and (*b*) the rest of the body was studied in each of eight subjects at environmental temperatures of 26 and 29° C as shown.

Number of subjects	Experiment 1	Experiment 2
2	(*a*) then (*b*) at 26° C	(*a*) then (*b*) at 29° C
2	(*b*) then (*a*) at 26° C	(*b*) then (*a*) at 29° C
2	(*a*) then (*b*) at 29° C	(*a*) then (*b*) at 26° C
2	(*b*) then (*a*) at 29° C	(*b*) then (*a*) at 26° C

Approximately 10 weeks separated experiments 1 and 2. On each occasion plastic bags were used as previously described to cover the areas not under observation. Measurements were recorded during a 20-min control period, a 10-min period of mental arithmetic and a 15-min recovery period. The coverings were then removed, the skin carefully dried, and the procedure repeated for the other region. The two recording periods were separated by approximately 30 min.

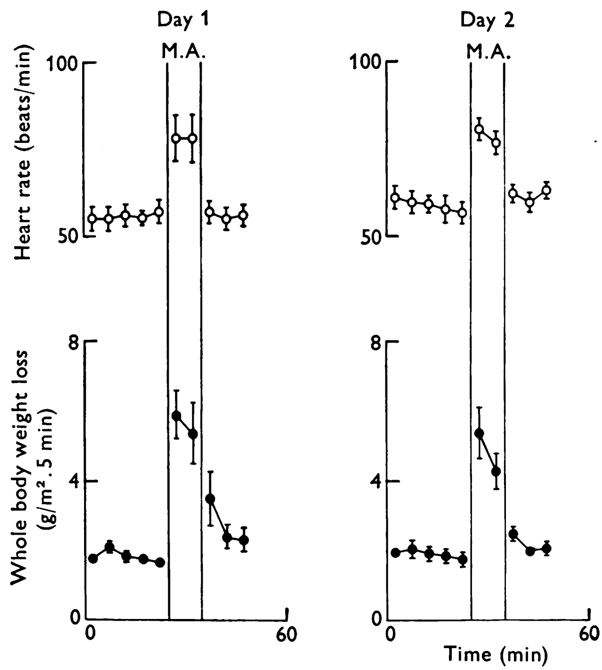

Fig. 1. The effect of 10 min of mental arithmetic on the rate of total body weight loss and heart rate of five subjects. The mental arithmetic (M.A.) was given on two occasions separated by a 4-week interval.
ϕ represents the mean for the group ± 1 s.e. of mean.

RESULTS

Regional sweat responses

Fig. 1 shows the mean results for the five subjects in group 5 whose whole body weight loss was measured on two occasions. In the first experiment, the rate of weight loss increased significantly ($P < 0{\cdot}01$) from a control level of 1·8 (s.e. ± 0·1) g/m^2.5 min to 5·9 (± 0·7) g/m^2 during the first 5 min of mental arithmetic. On the second exposure to the stimulus, the increase from 1·9 (± 0·2) to 5·4 (± 0·7) g/m^2.5 min was also significant ($P < 0{\cdot}01$).

Weight loss responses were calculated for each subject by subtracting the mean control level from that reached during the first 5 min of mental arithmetic. Responses after the 4-week interval were significantly ($P <$ 0·02) lower than those during the first experiment, the values being 65–94% of the original response.

Heart rate rose significantly ($P <$ 0·01) during both experiments from control values of 56 (± 3) and 59 (± 3) to 78 (± 7) and 80 (± 3) respectively during mental arithmetic. However, there was no significant correlation ($r = -0{\cdot}5507$) between the size of corresponding weight loss and heart rate responses (Fig. 2) although both are usually regarded as stress responses.

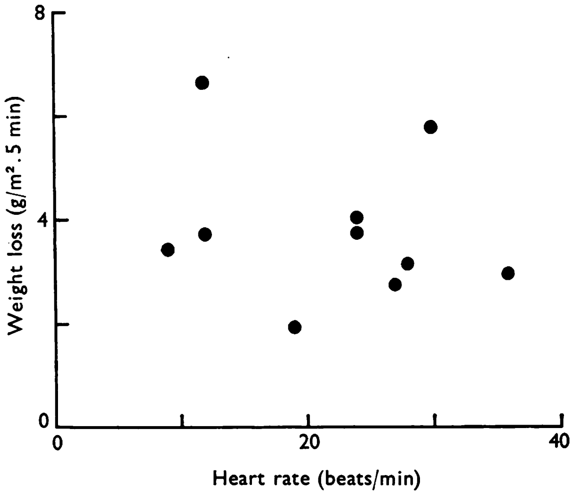

Fig. 2. The absence of correlation between the increase in heart rate and the increase in evaporative water loss during mental arithmetic ($r = -0{\cdot}5507$). The points are taken from experiments 1 and 2 on the subjects in group 5.

In Fig. 3 typical traces of weight loss from the four test regions are shown. The upper weight-loss trace is a direct recording, and small fluctuations due to respiratory and other movements are evident. To eliminate such artifacts, an integration circuit was used to give an average reading every 30 sec of the area under the weight loss slope, as shown in the lower trace. All results were calculated from the latter trace.

The gradient of the weight loss slope is proportional to the rate of weight loss, therefore the steeper slope during each period of mental arithmetic seen in Fig. 3 indicates an increased rate of weight loss. These responses are typical of emotional sweating as described by Kuno (1956), showing an immediate response to the stimulus and a rapid return to control levels afterwards. Since the effect was immediate, statistical analyses were applied to the values reached during the first 5 min of mental arithmetic.

Fig. 4 shows the mean results for the five subjects in each group. The mental arithmetic produced the following significant ($P < 0{\cdot}01$) increases in weight loss:

1·3 ($\pm$0·1) to 2·3 ($\pm$0·2) g/m^2.5 min from the head and neck group
1·4 ($\pm$0·3) to 3·1 ($\pm$0·5) g/m^2.5 min from the arms and legs group
1·1 ($\pm$0·2) to 2·8 ($\pm$0·4) g/m^2.5 min from the trunk group
1·2 ($\pm$0·1) to 2·8 ($\pm$0·3) g/m^2.5 min from the hands and feet group

Heart rate also rose during the mental arithmetic with significance levels of $P < 0{\cdot}05$, $P < 0{\cdot}02$, $P < 0{\cdot}02$ and $P < 0{\cdot}002$ for the four groups respectively.

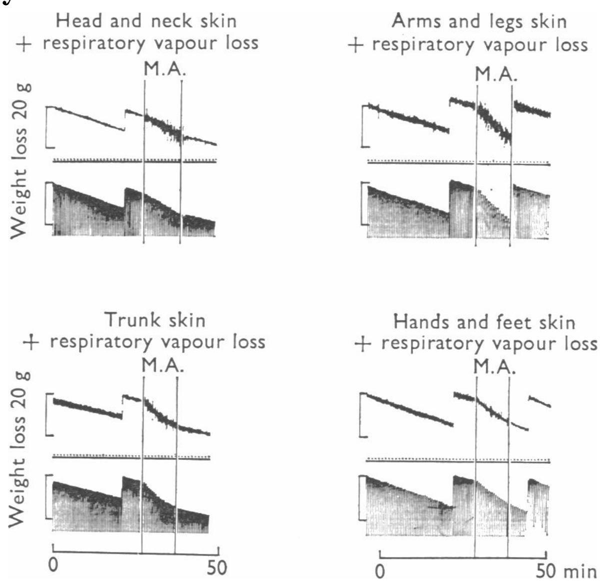

Fig. 3. The effect of 10 min of mental arithmetic (M.A.) on weight loss from four body regions. Each record represents respiratory and cutaneous water loss. Upper trace: direct recording of weight loss; lower trace: 30 sec integration of weight loss.

Hand skin temperature fell significantly ($P < 0{\cdot}05$) from 34·3 ($\pm$0·2) to 33·5 ($\pm$0·2)° C over the stimulus period. Forehead temperature remained constant throughout the experiment. Chest and arm skin temperatures were recorded while covered and uncovered. Only the covered chest temperature showed a significant ($P < 0{\cdot}05$) increase from 34·6 ($\pm$0·3)° C immediately before mental arithmetic to 35·2 ($\pm$0·3)° C immediately afterwards. There appeared to be no tendency for the temperature of covered skin to rise during the control period.

Both skin and respiratory vapour loss contribute to the responses shown in Figs. 3 and 4. The size of the respiratory component was estimated from the results of the subjects in group 6 who were completely covered

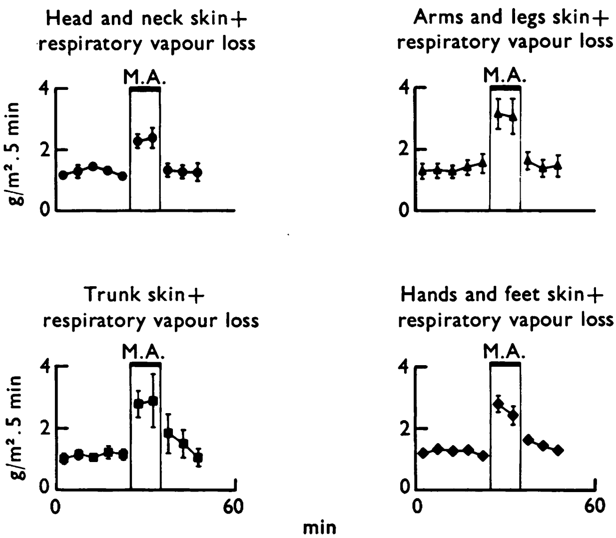

Fig. 4. The effect of 10 min of mental arithmetic (M.A.) on weight loss from four body regions.

The filled symbols represent the mean results ± 1 S.E. of mean for five subjects.

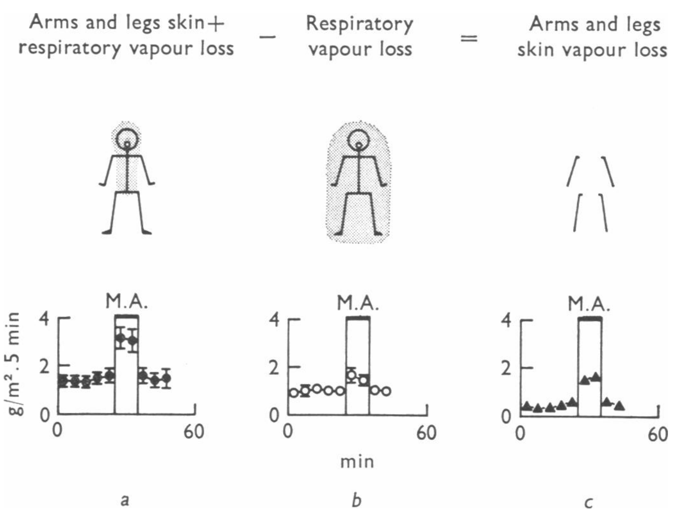

Fig. 5. The calculation of cutaneous vapour loss by subtraction of respiratory vapour loss from cutaneous and respiratory vapour loss.

a, evaporative water loss from the arms, legs and respiratory tract, the rest of the body being covered in plastic bags.

b, evaporative water loss from the respiratory tract, the rest of the body being covered by a plastic bag.

c, calculated values for evaporative water loss from the arms and legs obtained by subtracting values in *b* from values in *a*.

except for the mask. In this group there was a small but significant ($P < 0{\cdot}05$) increase in the rate of weight loss from a control level of 1·0 ($\pm 0{\cdot}1$) to 1·7 ($\pm 0{\cdot}3$) g/m^2.5 min during mental arithmetic. The mean results from this group were subtracted from those in Fig. 4 to give a measure of the rate of sweating from the skin of the four regions. Fig. 5 shows this calculation, using the arms and legs region as an example. By a similar calculation the rate of sweating from the skin of the whole body could be calculated.

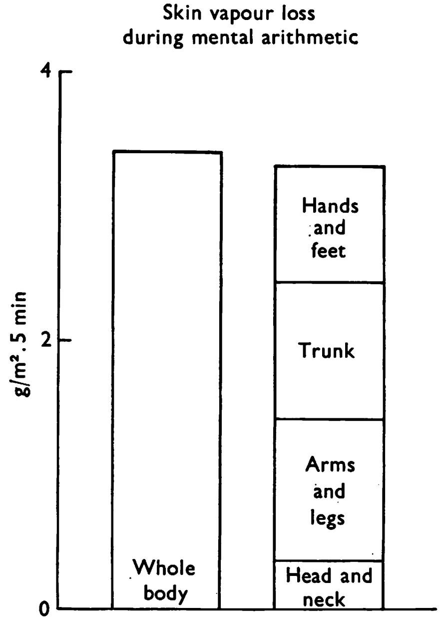

Fig. 6. A comparison of the mean sweat responses from the skin of different body regions to mental arithmetic.

Fig. 6 shows a comparison of the sweat responses to mental arithmetic from the skin of the whole body and the summated responses from the four regions. These results were obtained by subtracting the mean control value for skin vapour loss from that reached during the first 5 min of mental arithmetic. No statistically meaningful error can be calculated for these blocks.

Influence of environmental temperature

Fig. 7 shows the mean results for the eight subjects in this series of experiments. At 26° C, the rates of weight loss from the hands and feet and from the rest of the body during mental arithmetic were 2·2 ($\pm 0{\cdot}2$) and 2·7 ($\pm 0{\cdot}3$) g/m^2.5 min compared with control values of 1·1 ($\pm 0{\cdot}1$)

and 1·3 ($\pm$0·1) g/m².5 min respectively. These increases had significance levels of $P < 0{\cdot}001$ and $P < 0{\cdot}002$. At 29° C, the rates of weight loss during mental arithmetic were 2·5 ($\pm$0·3) and 2·9 ($\pm$0·3) g/m².5 min for the two regions compared with control values of 1·1 ($\pm$0·1) and 1·3 ($\pm$0·1) g/m².5 min. These increases were also significant ($P < 0{\cdot}002$ and $P < 0{\cdot}001$).

The mean weight-loss response of the hands and feet at 26° C was not significantly different from that at 29° C. Neither was the response of the rest of the body at 26 °C significantly different from its response at 29° C.

Heart rate was significantly ($P < 0{\cdot}01$) elevated during mental arithmetic in all parts of this investigation.

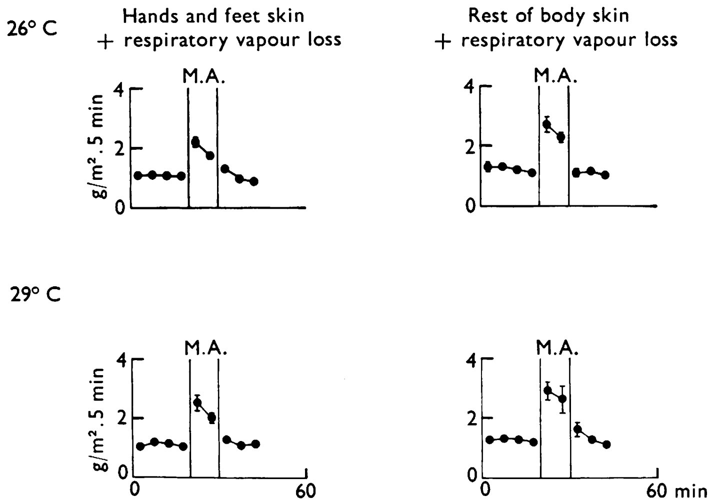

Fig. 7. The effect of 10 min of mental arithmetic (M.A.) on weight loss from the skin of the hands and feet and the rest of the body at environmental temperatures of 26 and 29° C. Each graph contains a respiratory component and is the mean of eight experiments.

DISCUSSION

Mental arithmetic is a convenient and effective emotional stimulus (Kuno, 1956) but subjects readily show adaptation. This is particularly evident if it is given twice during the same experiment (Abram, 1972). It therefore seemed preferable to study responses from the four test regions in different groups of subjects during their first exposure to mental arithmetic, rather than to attempt to counteract the effects of adaptation by a randomized experimental design.

When evaporative water loss from the whole body during emotional stress was measured in the same subjects on two occasions separated by a

4-week interval, adaptation was evident (Fig. 1). The second responses were significantly ($P < 0{\cdot}02$) lower than the first. It can also be seen that the effect of mental arithmetic was less sustained on the second occasion. These findings suggested that any direct comparison of a regional response with its respective whole-body response would be meaningless. An analysis of variance, based on the whole-body responses of the subjects in groups 1–5, measured during the second exposure to mental arithmetic, showed that all were from the same population ($F = 0{\cdot}9668$). Therefore it was considered valid to compare the regional response of each of the test groups with the first whole body response of group 5.

Most of the experiments were carried out in an environmental temperature of 29° C. Under these experimental conditions, the resting rate of evaporative water loss is constant for at least 2 hr and consists of passive diffusion of water across the skin and respiratory water loss (Allen, Jenkinson & Roddie, 1973). An increase in the rate of evaporative water loss therefore suggests activation of the sweat glands or increased respiratory water loss.

A small increase in evaporative water loss during mental arithmetic was detected in the group who were completely covered except for the breathing mask. Though this would suggest that respiratory water loss increases during mental arithmetic, the increased loss may have occurred from skin near the mouth as the mask enclosed a small area of skin around the mouth and nose. Thus, sweating from this area may have contributed to the measured response of this group and may account for the significant increase in weight loss observed during mental arithmetic.

The apocrine sweat glands of the axilla and groin were covered during these experiments. Thus it appears that eccrine sweat glands in all four body regions were activated by the mental arithmetic stimulus. Visible sweating was actually observed in four subjects, and their results are therefore an underestimation due to incomplete evaporation. Three of these subjects sweated visibly on the forehead, upper lip and around the nose. In the fourth, visible sweating occurred on the trunk and was confined to a central triangular area over the sternum and upper abdomen.

When evaporative water losses from (*a*) the head and neck, (*b*) the arms and legs, (*c*) the trunk and (*d*) the hands and feet, were calculated, significant increases were found to occur from each region during mental arithmetic. The mean responses from these areas of skin are compared with that from the total body surface in Fig. 6. Taking into consideration values for surface area (Weiner, 1945) and sweat-gland density (Randall, 1946; Thomson, 1954; Szabo, 1967), three regions – the arms and legs, the trunk and the hands and feet – appear to have similar numbers of sweat glands, but the head and neck has a much smaller number (approximately one third). This could account for the similarity in the size of the responses of the first three regions and for the smaller contribution from the head and neck.

Although the results of Kuno (1956) and Kennard (1963) indicated that emotional sweating is confined to the palms and soles under normal environmental conditions, they suggested that it may be induced in other areas in the presence of thermal stimulation. In the present investigation, regional responses were studied at an environmental temperature of 29° C which is known to be below the thermal sweating threshold for the experimental conditions (Allen *et al.* 1973) and within the 'comfort zone' (heat loss equals heat production) for lightly clad individuals (Hardy & Du Bois, 1940). Nevertheless, it seemed important to study emotional responses at an even lower environmental temperature. A temperature of 26° C, at which heat loss is greater than heat production, was chosen, and in fact several of the subjects spontaneously complained of feeling cold during these experiments.

It was desirable to carry out all the parts of this investigation on the same subjects and therefore a cross-over design was adopted so that adaptation to the stimulus would not influence the mean results. If the theory of Kuno (1956) and Kennard (1963) is correct, the emotional sweat response of areas other than the hands and feet at 26° C might be expected to be much less than that at 29° C. However, highly significant responses were observed from the hands and feet and from the rest of the body at both temperatures. There was no significant difference between the responses of either region at 26° C and their response at 29° C. It therefore seems unlikely that the skin of the rest of the body can respond to emotional stimuli only when close to or above the thermal sweating threshold.

The local methods of sweat estimation employed by McGregor (1952), Kuno (1956) and Kennard (1963) may have contributed to their failure to detect emotional sweat responses from the limbs and trunk of subjects below the thermal threshold since these areas have comparatively low sweat-gland densities. Differences in environmental conditions and strength of emotional stimuli employed may also help to account for apparent discrepancies between their results and the present observations.

We conclude from these results that the sweat response to emotional stimuli is a generalized phenomenon. There is no evidence that the skin of the hands and feet behaves differently to the skin of the rest of the body.

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