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THE TIME COURSE OF THE DECLINE IN SWEATING PRODUCED BY WETTING THE SKIN

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Wetting the skin with water or dilute saline solution produces a decline in sweat rate locally. This was shown for the special case of the palmar skin by Randall & Peiss (1957), and for the whole body by Hertig, Riedesel & Belding (1961).

Hertig *et al.* (1961) immersed their subjects in stirred water at constant temperature, removing them every half hour to be weighed. Sweat rate increased during the first hour as the body temperature rose, but declined thereafter while the body temperature remained steady (Hertig, 1960). The decline in sweating was attributed to contact of the skin with water, since preliminary soaking in thermally neutral water was found to depress sweating in a subsequent exposure to hot water. The decline was approximately exponential, tending towards zero, but the precision of the measurements was insufficient to establish the form of the curve or its asymptote with accuracy.

Of the various explanations which have been put forward to account for this phenomenon, blocking of the sweat ducts by swelling of the epidermal cells is the simplest (Randall & Peiss, 1957). If this is the mechanism it is unlikely that the decline would take the form described by Hertig *et al.* (1961). Such a process might be expected either to block all the glands after a finite time or to block only some of them after an infinite time and in neither case would the sweat rate tend towards zero. There is no reason to expect the decline to be steepest at the beginning; indeed one might rather expect a sigmoid curve, relatively few glands being affected in the early stages.

It was therefore thought worth while to examine the time course of the decline more accurately and to extend the observations in both directions on the time scale. Early observations would help to distinguish between an exponential and a sigmoid curve, while establishment of the asymptote requires that the curve be followed until the decline is almost complete.

METHODS

In order to achieve as constant a sweating drive as possible, against which to measure the decline caused by wetting the skin, measurements were made under conditions in which sweat production would normally be nearly maximal. Throughout the experiment the sweat rate was measured from a small area of one forearm, which was ventilated with dry air. This region served as a monitor of the sweating drive, and it was assumed that changes in its output of sweat would reflect changes in the sweating drive. Ferguson, Hertzman, Rampone & Christensen (1956) have shown that at high sweat rates the recruitment of further sweat is predominantly from the upper limbs, so that the forearm sweat rate provides the most sensitive index of changes in general sweat rate under these conditions. In the present experiments the forearm sweat rate did not vary by more than 5 % from its mean level on any occasion. The changes in sweating drive would presumably be somewhat less, but a better estimate of sweating drive can be obtained by assuming it to be strictly proportional to the forearm sweat rate than by neglecting the variations.

Experimental routine. The subject was first immersed up to the neck in a bath of either tap water or 15 % NaCl solution at 41·0 ± 0·1° C, where he remained until his mouth temperature had risen to 38·5° C. On leaving the saline bath he was showered with tap water at 41° C from a watering can. The shower water was spread over all parts of the skin manually. He then moved to an adjacent room and lay down on coarse wire-mesh support in an environment of saturated air at 37·0 ± 0·1° C where he was continuously weighed· Immediately after lying down he was sprayed with water from the watering can. In some experiments he returned to the bath, now at 36·0° C, for a variable time, at the end of which the bath was heated to 41·0° C and the whole procedure repeated.

Subjects were encouraged to drink water between heat exposures.

Mouth temperature. In the water or saline bath, mouth temperature was measured with a clinical thermometer retained in the mouth throughout the heating period. In the environment of saturated air a system of five copper constantan thermocouples in series was used, the reference junctions being held in a thermos flask of water at about 37° C alongside the subject.

Sweat output from dry skin. A stream of 10 l./min dry air was passed through a capsule covering 12 cm^2 of the volar surface of the right forearm. The water-vapour content of the effluent air was measured with an infra-red gas analyser (Infra Red Development Co. Ltd., Type RM). Absolute calibration was not performed, but the instrument was checked for linearity.

Saturated environment and weight loss. The arrangements for producing a saturated environment at controlled temperature and for continuously weighing the subject have been described elsewhere (Brebner, Kerslake & Soper, 1962). In the present experiments the air temperature was steady, not being controlled by the mouth temperature. The balance in its original form was able to follow rates of weight loss up to about 2 kg/hr. A heavier chain was substituted in some experiments, allowing about twice this rate of change to be followed.

RESULTS

General form of the decline in sweating. The initial heating of the subject to a mouth temperature of 38·5° C occupied 10–15 min. The output of sweat from the sample area of forearm rose steeply at first, but changed little after the mouth temperature had passed 38·0° C. Transfer to the environment of saturated air at 37·0° C took 2–3 min, and there was often a fall in forearm sweat rate during this period. Within a further 5 min or so the forearm sweat rate rose to its previous level, after which it showed only small changes, irregular in direction. The greatest deviation from the mean level after 10 min in the saturated air was less than 5 %. The mouth temperature rose slowly during the exposure to saturated air.

The rate of weight loss increased for the first 10 min. This increase was considered to represent establishment of the pattern in which the sweat ran off the skin. Subsequently the rate of weight loss decreased, and it was thought that this must reflect a decrease in the rate of production of sweat. Examination of the results will be restricted to those observations made during the period of declining rate of weight loss.

The sweat rate from the sample area of forearm is assumed to be proportional to the rate at which sweat would have been produced from the rest of the skin surface had this not been wet. Changes in the ratio of the rate of weight loss to the forearm sweat rate are then indicative of the effect of wetting the general skin surface with either water or sweat.

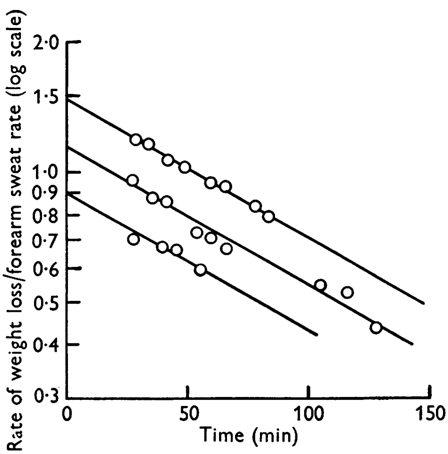

Fig. 1. The decline in sweating produced by immersion in tap water or sweat. Results from three experiments on the same subject. Values of the ordinates have been multiplied by arbitrary factors in order to separate the lines. The observed rate of weight loss from the whole body has been divided by the output of sweat from a small area of skin ventilated with dry air (capsule output) in order to eliminate the effects of small changes in the sweating drive. In all the figures log scales are used on the ordinates.

Figure 1 shows the results of three experiments on the same subject with tap water in the bath. Results on different days have been multiplied by arbitrary factors in order to clarify the diagram. The upper and lower lines refer to experiments consisting merely of a heating period followed by an exposure in saturated air at 37·0° C. The middle line refers to an experiment in which after 70 min the subject was returned to the water-bath (at 36° C) for 20 min, after which the whole procedure was repeated. The results of all three experiments are consistent with an exponential decay of the sweat rate towards zero, but the decay is not followed for long enough to establish the asymptote with accuracy. The first points on the declining curve were obtained about 30 min after the subject entered the bath, and show that the process begins within this time. The time constant is approximately the same on different days.

During the warming period in the bath the skin was immersed in tap water. After transfer to the environment of saturated air the tap water on the skin was slowly replaced by the subject's sweat, and in the later part of this exposure the skin must have been bathed in sweat. Comparison of the results in Fig. 1 suggests that the salinity of the sweat lying on the skin did not measurably affect the progress of the decline in sweating. The observed decline can therefore be regarded as that due to immersion in water or sweat.

Time of onset. It is to be expected that there should be an interval between contact of the surface of the skin with water and the initiation of the decline in sweating. The results described above indicate that this is less than 30 min. Of this period, 12 min was spent in the water-bath heating the subject, and the remainder in transferring him to the balance and establishing the equilibrium between sweat production and drip rate. The total time could be reduced if the subject could be heated without wetting the skin. Hertig *et al.* (1961) found that immersion in 15 % NaCl solution did not cause decline in sweating. If the subject were heated in such a saline bath and then washed down with tap water, it might be assumed that the bath was without effect and that the initiation of the decline in sweating would be related to the time of washing down rather than to the time of entry into the saline bath.

Figure 2 shows the results of such experiments, zero time being the time of washing down with tap water. The decline in sweating begins within 15 min. Confirmation that the saline immersion did not produce decline in sweating was sought by returning the subject to the saline bath at 36° C, later re-heating him in it and repeating the observations of weight loss. The upper curve in Fig. 2 represents an experiment in which the total time in the second saline bath was 20 min. The circles show the observations taken after this immersion and are displaced to the right with respect to the line drawn through the earlier points. If the later observations are displaced 20 min to the left, as shown by the squares, the points fall on the original line. The lower curve shows an experiment in which the saline immersion lasted 40 min. In this case agreement is not so good, but the same tendency is shown. The results suggest that during the saline immersion the decline in sweating is frozen, neither progressing nor regressing.

On subsequent wetting with water or sweat it proceeds from the point it had reached immediately before the saline bath.

The first measurements of sweat loss after heating in saline solution were 20–40 % higher than the corresponding figures after heating in water. This is further suggestive evidence that the saline bath did not produce decline in sweating, but is inconclusive since the saline experiments were done after the water ones and the subjects were probably more acclimatized.

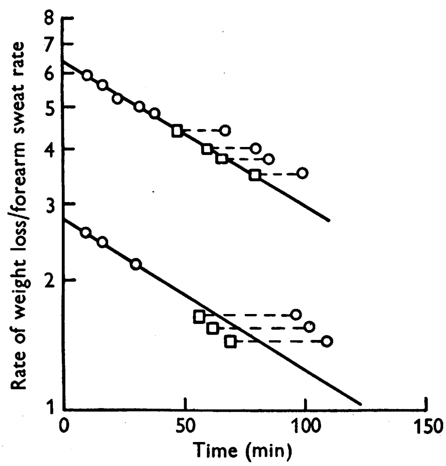

Fig. 2. The decline in sweating after heating in 15 % saline solution and washing down with tap water at time zero. After about 40 min the subject was returned to the saline bath for 20 min (upper curve) or 40 min (lower curve). Open circles, observed points; squares, points obtained after the second saline immersion displaced on the time axis by the duration of this immersion.

Figure 3 shows results obtained on two other subjects. In this figure the ratios have been adjusted on different days to a common value of unity at zero time. There is some evidence of a variation in time constant from day to day, but the results on each subject can be fairly described by a single line. The three subjects showed time constants of 135, 115 and 105 min.

Examination of the asymptote. The estimated rate of evaporation from wet skin at 38·5° C into the test environment was about 70 g/hr, and the actual rate may have been lower, since the skin temperature may not have been so high. It was considered that so long as the rate of weight loss exceeded 100 g/hr it could reasonably be equated with the rate of sweat production, but no attempt was made to follow the decline to lower rates than this. With this limitation the decline could be followed for 5 hr in two subjects, but for only $3\frac{1}{2}$ hr in the third, whose normal sweat rate was much lower. The forearm capsule could not be worn continuously for these long periods and was not used in these experiments. It was also impracticable to keep the face and scalp wet, so, during the measurement of sweat rate, sweat from the head and neck was retained on the balance, being caught in a crash helmet and linen scarf.

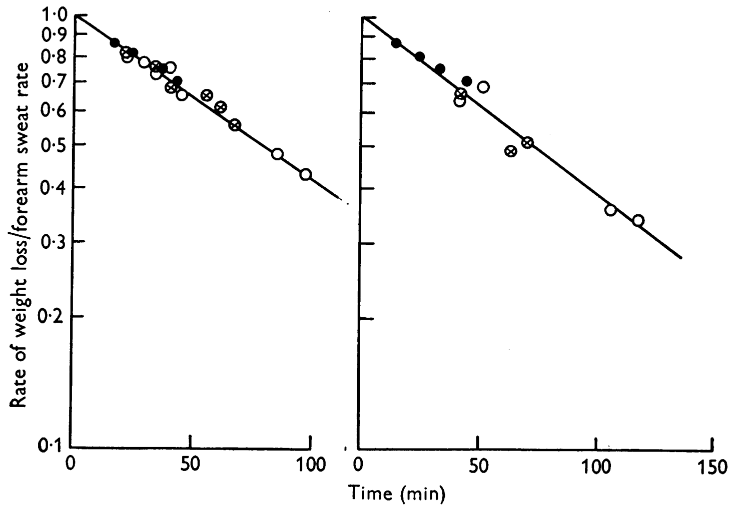

Fig. 3. Results on two other subjects. Filled circles, initial heating in 15% saline solution; crosses, initial heating in water; open circles, initial heating in water with return to water-bath after about 50 min and later re-exposure to heat. Results on different days have been multiplied by factors adjusted to give a common value of 1·0 at zero time.

The subject spent most of the time in a bath of tap water at 36° C, but at the start and subsequently at intervals of about 90 min he was heated to a mouth temperature of 38·5° C and then transferred for about 30 min to the environment of saturated air at 37·0° C in which he was continuously weighed. The rates of weight loss during the second halves of these exposures, which are considered to represent the rates of sweat production from the trunk and limbs, are shown in Fig. 4.

The results are consistent with a decline towards zero, but there is some indication that subtraction of 10 or 20 g/hr from all values would give a better fit to the exponential equation. This means that the rate of weight loss may tend towards 10 or 20 g/hr rather than towards zero. The rate of evaporation from the respiratory tract and the metabolic weight loss amount to some 7 g/hr, assuming a minute volume of 10 l. and a metabolic rate of 50 kcal/m^2.hr. However, respiration increases at high body temperatures, increasing the loss of both water vapour and carbon dioxide. If the sweat rate in these experiments were tending towards zero, the weight loss would therefore tend to a value somewhat in excess of 7 g/hr, and the results are in close agreement with this. The time constants of 130, 130 and 125 min do not differ greatly from those previously determined on these subjects (135, 115 and 105 min respectively) and the differences are probably insignificant.

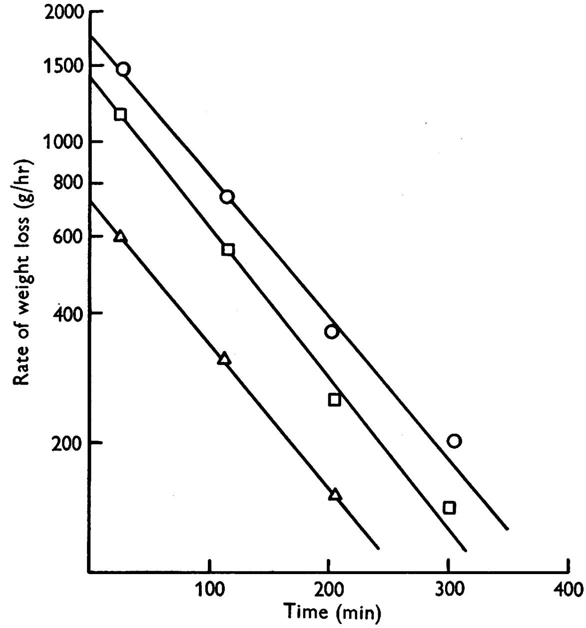

Fig. 4. The decline in sweating resulting from prolonged immersion in water. Sweat from the head and neck was retained on the balance. Weight loss through the respiratory tract has not been subtracted from the observed values. Results for three subjects.

DISCUSSION

The results confirm the description of the decline in sweating given by Hertig *et al.* (1961) and extend the period over which it has been followed. The decline is exponential with time, beginning within 15 min of wetting the skin with water and tending towards a sweat rate of zero after infinite time. It proceeds during water immersion whether the subject is sweating profusely or not, and does not occur in 15 % salt solution. This description has been found to apply to all three subjects, and it seems necessary to seek an explanation which will predict a decline necessarily having all these characteristics. The authors are unable to put forward an adequate hypothesis.

SUMMARY

1. Three subjects were kept wet with water, sweat or 15 % saline solution for periods up to 5 hr, and sweat loss was measured during inter-

mittent exposures to saturated air at 37·0° C after preliminary heating to a mouth temperature of 38·5° C.

2. Immersion in water or sweat caused a decline in sweat rate in a subsequent heat exposure whether or not the subject was sweating profusely during the immersion.

3. The decline began within 15 min of immersion and proceeded exponentially for at least 5 hr (at least 200 min in one subject), tending towards zero sweat rate after infinite time.

4. The decline did not occur with immersion in 15 % saline solution.

5. The results confirm and extend the description given by Hertig *et al.* (1961).

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