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DYSHIDROSIS PRODUCED BY GENERAL AND REGIONAL ULTRA-VIOLET RADIATION IN MAN

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Diminution or absence of sweating is a feature of many, if not all, cases of heat stroke. At high environmental temperatures, the resulting upset of evaporative heat loss is sufficient to explain the hyperpyrexia, but the cause of the breakdown in sweat production has not yet been found.

Experience as a Naval Medical Officer in Ceylon during the last war suggested that the sweating rate of personnel was reduced after an exposure to the sun sufficient to cause erythema. Elevated temperature, headache and malaise were also noted in certain cases where sunburn appeared to be the only abnormality present. It is at present believed that sunstroke and heat stroke are identical and that the sun only acts by increasing the heat load. The views of authorities on this subject may be summed up in the words of Blum (1945): 'It is possible that there are some direct specific effects of sunlight in heat stroke, but such have not been demonstrated.' However, it appeared possible that where extensive blistering had been caused by solar radiation (such as might readily occur in summer in temperate latitudes) sweating would be impaired at least over the blistered areas. It had been observed that the blister of a second degree thermal burn became noticeably larger after profuse perspiration.

According to Lippman (1942), ultra-violet (U.V.) radiation caused an average of 10% reduction in the insensible perspiration rate of white subjects 2 hr. after exposure. There was almost complete return to normal after 24 hr.

The first series of experiments was carried out to determine whether U.V. radiation, particularly the wave-lengths present in sunlight, affected man's ability to sweat and if so what was the reason for this, and what adverse effects accompanied the alteration in sweating rate. The work was carried out in experimental hot rooms at the National Hospital, London, and at the Department of Experimental Psychology, Cambridge, using human volunteers from the Royal Navy, Army and the Royal Air Force.

METHODS

The subjects were all fit young men who had been acclimatized by resting and working in the heat for at least 2½ hr. per day for 10 days during the fortnight before the trials. Each experiment involved a series of daily trials during which the subjects were exposed to controlled environmental thermal conditions and air movement in the nude for standard times. For the same length of time each day they worked by stepping at a known rate on and off a stool 1 ft. high. In one climatic chamber it was possible to maintain a high degree of uniformity in temperatures and air movement for all trials, and observations to ascertain the effects of radiation were made on the same subjects before and after exposure to the U.V. lamp. In the second climatic chamber, where temperature control was less accurate, one or more subjects were left unradiated as controls. (Air movement was constant throughout each experiment.) The men were weighed immediately before entering and before leaving the hot room, and sometimes at intervals during the trials. Water was allowed *ad lib.* but an effort was made to achieve approximately the same intake every day. Fluid intake and excreta were measured and recorded on charts for each subject. Rectal temperatures and pulse rates (in the standing position) were taken on entering and before leaving the hot room, and after each work period.

For qualitative determination of sweating rate on small areas and to delineate the pattern of the sweat drops Minor's method (1927) and quinizarine were used. In Minor's method a solution containing iodine is painted on to the skin. When this is dry starch powder is applied by dusting. When sweating commences a blue-black colour (starch-iodine reaction) appears. Quinizarine, a purplish powder, when dusted over the skin shows the presence of sweat by turning black.

Quantitative estimations of sweating rate on small areas were made in the first test (Fig. 2) by Weiner's method (1945) suitably modified; in the second test (Fig. 3) by a method devised for the purpose of this investigation. To eliminate variations in sweating rate due to acclimatization and to fluctuations of environmental temperatures, two areas were marked on corresponding positions on either side of the body and the sweating rate was always determined simultaneously on both areas. The normal ratio of the sweating rates of the two areas having been found, one area was kept as a control and the effect of radiating the other was ascertained from variations in this ratio.

The apparatus, designed by the author, is machined from Perspex and consists of a hollow cylindrical cover 1·5 cm. high and 5·0 cm. diameter which is placed, open end downwards, on the skin surface under test. A rod carrying a filter-paper (4·25 cm.) on a disk attached to its lower end passes through the upper surface of the cover and can be manipulated so that the filter-paper is held 0·5 cm. above the skin, or lowered into contact with it. The disk carrying the filter-paper is removable, and with a close-fitting lid, is weighed before and after sweat collection.

Procedure. The sweating surface is blotted dry and the cover with disk and filter-paper attached (but minus the lid) is placed on the surface, with paper out of contact with the skin. After a measured interval, which depends on the rate of sweating, the filter-paper is pressed on to the skin for a few seconds. It is then removed and quickly covered with its lid. The increase in weight of the filter-paper assembly measures the sweat secreted from the time of blotting the skin to the instant when the filter-paper is removed. Because of phasic variations in sweat-gland secretion first noted by Kuno (1934), and investigated by Randall (1946), it has been found advisable to take the average of more than one (usually three) separate determinations as the final estimate of the sweating rate.

Ultra-violet radiation. General radiation was administered from standard quartz mercury vapour lamps to back and front consecutively so as to produce a uniform third-stage erythema over a large proportion of the body surface. Kromayer contact lamps were used to produce sharply demarcated zones of erythema of diameter 3·75 cm. The degree of erythema obtained was the only measure of the quantity of radiation received. In most cases it was not practicable to give the subject a preliminary test dose, and the quantities administered were therefore arbitrary. Blister burns were not produced throughout these experiments and the resulting erythema was usually less severe than had been desired.

RESULTS

Effect of ultra-violet radiation in a hot wet (jungle) climate

Two subjects (Mc. and An.) remained in the hot room for 75 min. on each of 5 successive days. The daily routine included four spells of work totalling 25 min. (mean metabolic rate, 210 kg. cal./m.^{2}/hr.). The average dry-bulb temperature (D.B.T.), wet-bulb temperature (W.B.T.) and air movement for all trials were 91·6° F., 89·7° F. and 75 ft./min. respectively, corresponding to a basic effective temperature of 88·7° F.

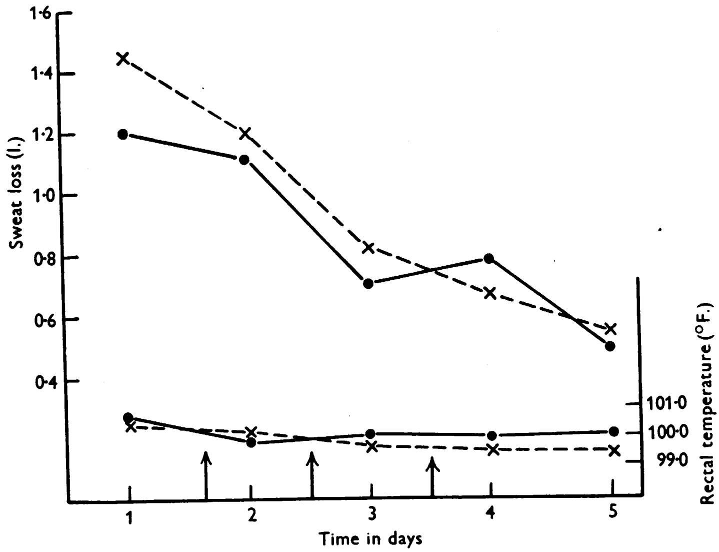

Fig. 1. Sweat losses and rectal temperatures of two subjects before and after general U.V. radiation which was applied at the arrows. Continuous lines, subject Mc.; broken lines, subject An.

Both subjects were brunettes and had pale skins showing no sign of past exposure to U.V. radiation. Neither had been out of Britain nor had done much sun bathing. Three doses of U.V. radiation were given to each subject at the intervals indicated in Fig. 1, the relative strengths of the doses being 1:1:2.

The first and second exposures produced only faint reddening of the upper chest and back. After the last (increased) dose, a third-stage erythema appeared above the waist in both subjects.

The weight loss adjusted for fluid intake and urine voided, which is a recognized measure of sweat loss, had fallen by the fourth day after the commencement of radiation to 40% in the case of Mc., and to 37% in the case of An. of its preradiation value (Fig. 1).

Neither rectal temperature nor pulse rate indicated any adverse effects of the reduction in sweating rate. There was, if anything, a tendency for the final rectal temperature and pulse rate, and for the increment in both these values due to work, to fall throughout the week from the control value (Fig. 1). The subject Mc. complained of nausea during the third trial, but this was probably fortuitous. There was no evidence of alteration in subjective sensations throughout. The trials unfortunately had to be terminated before the minima of the curves, or the time to return to normal, were established.

Effect of ultra-violet radiation in a hot dry (desert) environment

The most pressing question raised by the above trials was: 'Does radiation cause the same reduction of sweating rate in an environment where such a reduction, if it occurred, would be reflected in increased discomfort, poorer performance and hyperthermia?'

In an endeavour to answer this question, three young acclimatized soldiers were exposed for 155 min. in the nude in the hot room at 120° F. D.B.T., 80° F. W.B.T. and 500 ft./min. air movement (basic effective temperature 88·7° F.), for 6 successive days. Four spells of work were carried out lasting in all 70 min., and involving a mean energy expenditure of 109 kg. cal./m.^{2}/hr. U.V. radiation was administered to two of the three subjects. The intervals and lengths of exposure were the same as those of the above experiment.

Perhaps because of habituation from previous exposure, neither subject developed the degree of erythema anticipated. One of them, who showed a faint tan prior to radiation, did not desquamate, indicating that only a second-stage erythema had been achieved. No significant changes were obtained as the result of the radiation. The values of sweat loss for radiated and unradiated subjects over the 6 days were remarkably uniform, indicating a high degree of standardization of thermal conditions and work.

Effect of two widely spaced exposures to ultra-violet radiation

It is well known that white-skinned persons acquire a relative immunity as the result of exposure to U.V. rays in sun or lamp. The following trials show that the immunity produced by one exposure does not prevent a second fall in sweating rate after a further dose of U.V. radiation.

Eight acclimatized subjects stayed in the hot room for 2 hr. 25 min. each day, during which period three spells of work of total duration 40 min. were performed (mean metabolic rate, 87 kg. cal./m.^{2}/hr., D.B.T. 92·8–96·3° F., relative humidity 98–100%, air movement 100 ft./min., basic effective temperature 91·0–95·5° F.). After the first trial five of the eight subjects were exposed to an U.V. lamp. On the fourth day thermal conditions were purposely made more severe by increasing the effective temperature by approximately 4·5° F. After the eighth trial a second stronger dose of U.V. radiation was administered to the five subjects who had already been irradiated.

To eliminate the effect of variations in room temperature from day to day the sweat losses of the radiated group have been adjusted (Table 1) to a common mean value of the control group (Snedecor, 1946). The mean adjusted sweating rate fell from 1256 to 991 c.c. on the second day and to 956 c.c. on the third day (2 days after radiation). The fall on the second day was contributed to by all five subjects. The rise in temperature on the fourth day increased the thermal stress appreciably, and in some subjects the limit of tolerance was reached. As a result the adjusted mean sweat loss rose to the same value as on the first day (before radiation). This value was approximately maintained on the seventh and eighth days after a week-end break of 2 days.

TABLE 1. Effect of a second exposure to ultra-violet radiation after the sweating rate had returned to normal

Sweat loss (c.c. per day)

	Day	Basic effective temp.* (° F.)	Radiated subjects Cr.	Da.	Mu.	Gr.	Br.	Control subjects We.	Jr.	Bl.	Average radiated	Average control	Adjusted mean radiated
	1	91·0	970	890	940	1130	980	590	500	490	982	527	1256·1
U.V. radiation													
	2	92·0	820	820	1060	870	990	710	590	590	912	630	991·4
	3	91·5	740	660	890	650	1000	760	550	440	788	583	956·2
Increased temperature	4	95·5	1720	1490	1650	1700	1690	1000	830	810	1650	880	1256·9
	7	91·0	1190	690	910	1100	1090	710	490	430	996	543	1239·8
	8	93·0	1470	1130	1060	1690	1670	750	750	680	1404	727	1300·0
U.V. radiation													
	9	94·5	1040	1090	1080	1360	1690	880	910	680	1252	823	966·6
	10	92·5	1000	960	770	1310	1500	740	755	490	1108	662	1126·9

Exposure to U.V. radiation between days 1 and 2 and between days 8 and 9. Increased temperature on day 4. The adjusted mean sweat losses are corrected for changes in the control group caused by environmental temperature variations from day to day.

* Effective temperature strictly applies to men wearing shorts (basic), and not to nude men. Air movement throughout 100 ft./min.

Exposure to radiation on the eighth day again caused a fall in the adjusted mean sweat loss on the ninth day of the same order as on the second and third days. As before, the fall was shown by all five radiated subjects.

As in previous experiments, no adverse effects were attributed to radiation. Pulse rates and rectal temperatures were higher on the fourth day due to the more severe thermal conditions, but the increase was of equal magnitude in both radiated and unradiated groups. One of the radiated subjects (Gr.) was unable to finish his last work period on the high temperature day; this subject may have had a low tolerance to heat. After the second exposure to U.V. radiation sudamina occurred in four out of five radiated subjects on chest and back where erythema had been most severe.

Statistical note. The mean of the adjusted sweat losses of the post-radiation days 2, 3, 9 and 10 is 1010 c.c. and that of the remaining days 1, 4, 7 and 8 is 1263 c.c. The difference between these means (253 c.c.) is 5·56 times its standard error (45·5 c.c.). The difference is therefore significant ($P<0{\cdot}01$). It has also been noted that after exposure to radiation on both occasions, a fall in sweating rate was shown by all five persons. This would only occur as the result of chance once in 2^5 or 32 times ($P<0{\cdot}03$).

Local radiation

Fig. 2 shows the ratio of the sweating rates of control and radiated areas in two subjects (Cu. and Bo.) exposed to a hot wet atmosphere (D.B.T. 91·6° F., W.B.T. 89·7° F., air movement 75 ft./min., basic effective temperature 88·7° F.) before and after U.V. radiation (½ min.). Before radiation the ratio of the sweating rates of *A* to *B* test areas on the chest was for subject Cu., 1·24 and Bo., 1·09. The marked areas *A* of both subjects were radiated and the ratio of radiated to control areas (*A*/*B*) fell on succeeding days, reaching 0·35 in the case of Bo., and 0·22 in the case of Cu., on the fourth and fifth day respectively.

As a further check, two other areas *C* and *D* were marked out above areas *A* and *B* on the third day of the experiment. The ratio of the sweating rates of *C* to *D* agreed (within 15 %) with that previously found for *A* to *B* in both cases.

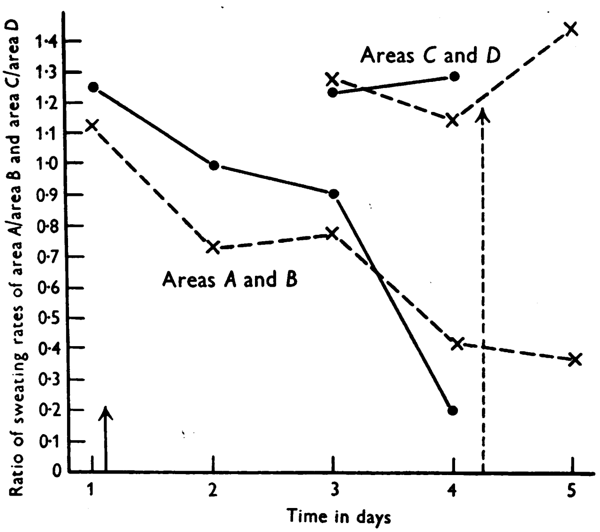

Fig. 2. The graphs show the ratios (*A*/*B* and *C*/*D*) of the weights of sweat produced simultaneously on two pairs of equal areas (*A*, *B*, and *C*, *D*) in each of two subjects (Cu. and Bo.). At the solid arrow U.V. radiation (Kromayer) was applied for ½ min. to area *A* of each subject, at the dotted arrow to area *D* of subject Bo. Continuous lines, subject Cu.; broken lines, subject Bo.

Radiation of similar intensity was then applied to area *D* of subject Bo. The ratio *C*/*D* was found to be increased on the following day, showing again depression of the sweating rate on the area *D*. Each point on these graphs is an average of at least four consecutive estimations.

The data given in Fig. 3 from another subject provides evidence that the wave-lengths of the radiation which cause the diminished sweating are in the region of the long U.V. and are therefore probably present in sunlight. Environmental temperatures were sufficiently high to cause brisk sweating; they were otherwise not controlled. Observations were continued for a longer period

(18 days) to find if, and when, the sweating rate became normal again. In this case, Chance's glass filter (OXI) transmitting mainly the long U.V. between 3000 and 4000 A. and having a fairly sharp cut-off at 3000 A., was interposed between the Kromayer lamp and the skin, and the time of exposure (15 min.) was increased so as to give the usual degree of erythema. The visible changes were third-stage erythema which began to appear after about 3 hr. This was succeeded by pigmentation which appeared to predominate over the erythema about the fifth day. Sudaminous vesicles were noted at the seventh day accompanied by peripheral desquamation which gradually extended and was complete at the eleventh day. The sweating rate on the radiated area reached

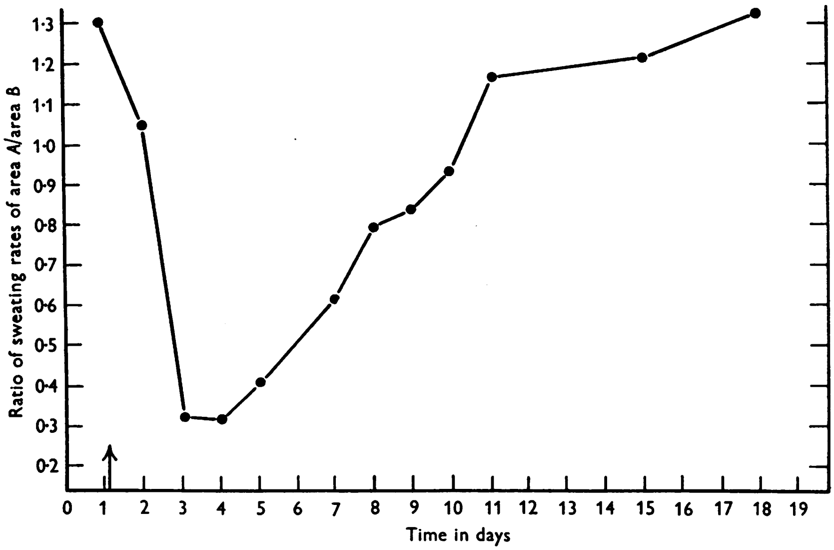

Fig. 3. Ratios (A/B) of the weights of sweat produced simultaneously on two adjoining areas (A and B) of equal size. At the arrow area A was radiated for 15 min. through a Chance's filter OXI.

a minimum (23 % of the pre-radiation value) between the second and third day after radiation and then slowly returned to normal after the tenth day. Using Minor's method or quinizarine, a qualitative reduction in sweating after radiation was demonstrated in at least six other cases.

DISCUSSION

In a hot wet (jungle) environment where more sweat is produced than is required for evaporative heat loss, U.V. radiation caused a reduction in the sweating rate. In a hot dry (desert) environment with high air movement such as that of the second experiment where the exposed skin was dry in spite of a high rate of sweating, indicating that the evaporation of large quantities of sweat was necessary for heat dissipation, no reduction of sweating occurred as the result of radiation.

Since there were no adverse effects on the ability to tolerate heat in any of the above trials, it might be concluded that any reduction caused by radiation was at the expense of the wasted sweat only. Radiation would then be beneficial since it would minimize losses of water and, presumably, of salt. It might also be expected to reduce the incidence of prickly heat which is said to be favoured by unevaporated sweat in clothing. Another explanation must however be considered. In an extensive study, O'Brien (1947) has shown that a high proportion of the total sweat glands must be out of action before symptoms of undue heat retention appear, presumably because the unaffected glands have a marked capacity to compensate by hyper-secretion. The maintenance of normal sweating rate in the hot dry environment may have been due to overactivity of glands which remained unaffected either in the radiated areas, or in zones which received no direct radiation. Support for this theory is offered by the studies on small radiated areas where the reduction of sweating was found to be independent of temperature, and within the limits examined, of the humidity of the environment. The curve of sweating ratios (Fig. 3) is uniform in spite of wide variations in the subject's sweating rate.

The results obtained with local radiation confirm those obtained with general radiation. After a single exposure to radiation the sweating rate falls to a minimum on the second or third day, then rises more slowly to normal. The extent of the reduction, and the time taken to return to normal, are probably proportional to the severity of the radiation.

It has not yet been proved directly that natural sunlight can cause reduced sweating. It has been shown above, that the wave-lengths of the radiation causing the reduced sweating are probably greater than 2950 A., and are therefore present in sunlight. Further evidence that sunburn and U.V. erythema are alike in this respect was provided by the occurrence of a widespread eruption of sudaminous vesicles in a subject in the hot room after a 3 or 4 hr. exposure to the summer sun.

The belief implicit in the name 'sunstroke', that the sun's radiation caused hyperpyrexia by penetrating to the brain or spinal cord has rightly been discarded. It is hoped to explore later the possibility that exposure to the sun, followed by defective sweating, may be a factor in the causation of some cases of heat stroke.

SUMMARY

1. In a hot wet environment general ultra-violet radiation in moderate erythemal doses produced, in seven persons acclimatized to heat but not to radiation, up to 60% diminution in sweating rate on the second or third day after exposure.

2. In two subjects similarly irradiated and exposed to a hot dry environment and high air movement there was no change in overall sweating rate as the result of radiation.

3. With the quantities of radiation administered and at the temperatures of the trials there were no significant changes in the subjects' pulse rates or rectal temperatures.

4. After recovering from the dyshidrosis caused by one exposure to radiation, a second exposure produced a further fall in sweating rate in the same persons.

5. A technique is described for assessing the effect of drugs and other treatments on the sweating rate of small areas of skin.

6. The reduction of sweating rate which occurs after general ultra-violet radiation has been confirmed using methods for the estimation of sweating rates over small areas of irradiated skin. The wave-lengths causing the reduction in sweating rate are probably present in natural sunlight.

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