Attempts were made by Yen, and more successfully by Takahara (see 5, 6) to observe continuously the discharge of sweat from a single human sweat gland. A capillary glass tube was inserted into a sweat pore and the movement of the sweat column therein accumulated was recorded. This method is very difficult because the sweat duct runs through the epidermis in cork-screw fashion. Furthermore, the application of this method is limited to the palm. Starch paper method introduced by Randall (7) demonstrated a periodic output of sweat. Starch paper, however, must have been attached to the skin for more than 15 sec., which unabled to observe the variation of sweating that might occur during the time. The procedure adopted by Kuno (5) for the estimation of the amount of sweat was as follows: dry air was allowed to pass through the celluloid dish (20 cm.$^2$) adhered to the skin tightly with collodion, was charged thereby with moisture given off from the skin and was led into small U-tubes containing calcium chloride. This method can only observe changes in sweat secretion per unit of 5 min. In the present study, instead of the absorption of water vapor, a sensitive resistance hygrometer was employed enabling a continuous recording of sweating.

The hemihidrotic reflex due to postural changes, first described by Kuno (5) was clearly explained by one of the authors to be a consequence of pressure applied on the skin (8). Recently, Watkins (9) tested the effect of pressure on sweating and obtained completely different results denying the presence of the pressure-sweating reflex. More recently, however, the hemihidrotic reflex has been reconfirmed by Ferres (3). With this state of affairs, the effect of pressure on sweating was again investigated using the new method described in this paper.

METHOD

The arrangement of the apparatus is illustrated in fig. 1. A humidity sensitive element newly devised by Shiba (available as a patent commodity) is made of a slice of plant pith, the electrical resistance of which varies in proportion to the humidity. It reacts in extremely short time and has a negligible hysteresis. The electrical resistance of the elements used in this experi-
ment changed in linear relation to the humidity in the range of 5 to 25%. The relative humidity of the air had, therefore, to be kept at 10% by the adjustment of cock 2 and 3. The compressed air was supplied and the velocity of air stream, being checked by flow-meter, was kept constant. The air volume passed per unit time was measured by gas-meter. Such an air stream was allowed to pass through the celluloid dish (20 cm.²) adhered to the skin tightly with collodion, and was charged thereby with water vapor given off from the skin.

The hygrometer must be placed as near as possible to the dish. Alternative current (1,000 c.p.s.) of a constant low voltage was applied to the humidity sensitive element, and the changes of current produced by the variation of humidity were led to a direct-coupled amplifier of high cut-off and recorded by ink-writing oscillograph. The temperature of the air stream was measured by the thermistor-thermometer. The scale of the velocity of perspiration, if desired can be plotted in advance on the recording paper by calculation which is made from values of the air volume passed in a given time, air temperature and the known relative humidity. Thus, the rate of sweating was presented as the ordinate of the record in the unit of 1 mg/20 cm²/min. Raising the velocity of the air stream increases the temporal fidelity of the recording system but decreases the sensitivity to sweat volume. In the present study, air was passed in the speed of 6-10 l/min.

Slight change of the speed of air stream, air humidity and air temperature may affect the record, but it has been proved that this apparatus is fit for practical use because the base line showed no instability in the blank test. Time delay of this recording system, though can not be estimated accurately, seems to be very small.

RESULTS

The experiments were made in summer and winter at room temperature of 33°-36° C. dry bulb and 28°-32° C. wet bulb. The subjects, five male workers in the laboratory aged from 21 to 31, were sitting at rest.

Under the rate of less than 1 mg/20 cm²/min., changes of the sweating, if any, occurred fairly gradually. In moderate sweating, as illustrated in fig. 2, the rate of sweating varied periodically without any apparent reasons. The
MINUTE PATTERN OF PERSPIRATION

A B

Fig. 2. Pattern of moderate sweating of the chest. Vertical scale is given in the unit of 1 mg/20 cm²/min. Shaded area is referred to in the Discussion of Text. Horizontal line indicates 30 sec. in this and all other records except for fig. 3B.

Periods of this wave-like variation were 6 sec. in most cases, ranging between about 3 to 9 sec. Generally speaking, a tendency was observed that in moderate sweating the period was longer and the amplitude of fluctuation larger, while in profuse sweating the period became shorter and the amplitude was smaller.

These periodical variations were not restricted to one region, but occurred concomitantly on the symmetrical part of the contralateral side (fig. 3A). Furthermore very similar variations were found in the simultaneous recording of the sweating of the chest, forehead (fig. 3B) and thigh regardless of their regional differences of sweat volumes.

Fig. 3. Simultaneous recording of perspiration on the two parts of the body.
A: upper (right chest), lower record (left chest).
B: upper (forehead), lower record (right chest). At signal A, a problem in mental arithmetic (the product of 16 by 25) was given. At B, the subject answered by mistake. Time is given in 2 sec.

Fig. 4 demonstrates the effect of unilateral skin-pressure upon the sweating of the chest. Light pressure was applied by a finger to the sub-axillar region which was proved to be most sensitive (4). With application of pressure, the rate of sweating of the same side decreased and that on the opposite side increased, after a short latency. Usually, the ipsilateral inhibition was more prominent than the contralateral acceleration of sweating. To compare the patterns of sweating on both sides more clearly, the sensitivity of the apparatus for recording the sweating on the side pressed was greatly increased (fig. 5). Irrespective of their conspicuous differences of sweat volumes, an agreement of periodical rhythm was still verified on both sides. In none of the experiments performed, increase of sweating on the side pressed and decrease on the opposite side were observed. The decrease of the sweating on both sides, however, was sometimes resulted by an unilateral pressure stimulation.

Bilateral pressure stimulation caused a marked decrease of sweating on both sides (fig. 6). As stated above, the periodical fluctuations of the rate were not so distinguishable in profuse perspiration. In this figure, the periodical wave is obviously observed during the inhibition of sweating.
DISCUSSION

In his ingenious monographs of human perspiration, Kuno (5, 6) showed the simultaneous outbreak and concomitant changes of the sweating on all over the body surface with only exception of the palms and soles. Furthermore he stated that “changes in the rate of sweating are essentially due to changes in number of participating glands”. The results obtained by Randall (7) with starch paper method at intervals of 15 sec. indicated that sweating occurred in two steps, the first stage is the increase of the number of active glands, and the second is characterized by the increased secretion of individual glands.

In the present study, it has been shown that the rate of sweating varied periodically with a cycle of a few seconds. Concomitant changes were verified on the chest, thigh and forehead by the simultaneous recording. Recently Dole and Thaysen (1), using an improved print method suitable for quantitative treatment, observed the fact that “large dots remained large and the small dots continued to be small” so that “the relative activity of the glands remained constant”. Such being the case, it can be sure that the wave-like variation of the sweating is not resulted from the random increase or decrease in the number of active glands, but that sweat is actually protruded by individual gland in such a rhythmical manner. These variations of the sweating are supposed in all probabilities to be of central origin because of their generalized appearance. The question then arises what are peripheral effectors which respond to periodical efferent impulses or bursts from the center. As pointed out by Ebbecke (2), sweat flow is roughly regulated by the activity of the secretory cell and is finely modified by the myoepithelial contraction. It is highly probable, that the variations in the amount of sweat are brought about by the summation of these two mechanisms, although at present it cannot
be decided how the individual variation of the records is controlled by the respective mechanism.

According to Takahara (see 5, 6) the sweat column of the capillary tube, which was inserted into a sweat pore of the finger tip, rose gradually and then fell slowly to the previous level while the subject was at rest, and this occurred periodically at intervals of a few minutes. Each increase of sweat column was calculated thereby to vary from 0.003 to 0.005 mm. This value is consistent with the volume of the sweat tube (6), so it was concluded that the periodic discharges were due to periodic contraction of myoepithelium of the sweat gland.

The number of active sweat glands in an area of 1 cm. on the chest was about 100 (6), so that the total volume of the sweat tubes subjected in the present study was 6 mm. The area shaded in fig. 2 corresponds to sweat volume of 0.05 mg. This figure, therefore, may suggest the possibility that the wave of a short duration might be caused chiefly by periodical contractions of the myoepithelium. This is rather acceptable than an assumption that the secretory activity of the cell varies periodically within a few seconds. The period observed by Takahara was 80 sec. at rest and 25 sec. at muscular exercise, while in the present study was only a few seconds. Small and rapid changes of the volume of liquid might not be followed by the use of capillary tube method.

Ebbecke (2) has postulated that the secretion of the cell and the contraction of the myoepithelium were caused by different sympathetic efferents. Pressure to one side of the body, as stated above, affected the secretion, but had nothing to do with the rhythm of contraction. The two mechanisms seem therefore to be controlled by different parts of the central nervous system.

In the figure presented by Watkins (9) as a control experiment, sweat rates of right and left sides changed in opposite direction without any apparent reasons. This can not be the case in human perspiration and the parallelism of the sweating on both sides is now verified more precisely to be not a matter of chance. In the experiment of Watkins, an accompany of large error cannot be avoided because small pieces of filter paper (8 cm.) were employed for measurement.

**SUMMARY**

Human perspiration on a skin area of 20 cm. was recorded continuously by the use of a sensitive resistance hygrometer and it was found that the rate of sweating changed periodically with a cycle of a few seconds. Furthermore, evidence was presented that these variations occurred coincidently not only on the symmetrical parts of the chest, but also on the forehead and the thigh independently of the regional differences in sweat volume. A phenomenon of hemihidrotic sweating induced reflexly by the skin-pressure was reconfirmed. Under this reflex state, the same periodic variations were still found on the side pressed and the opposite side, although the sweating was facilitated on the latter and inhibited on the former. The cyclic variation of sweating may be due to periodical contractions of myoepithelium, and the innervations of which must differ from those of secretory sweat cells.
REFERENCES