OBSERVATIONS ON MEN EXPOSED TO EXCESSIVE HUMID HEAT*

S. T. LEE†

Physiological Laboratory, Manchuria Medical College, Mukden
(A confiscated Japanese School)

Numerous investigators have described experiments made on men exposed to severe heat which were performed chiefly with the purpose to determine the upper limits of environmental heat in which men can still work effectively. On those experiments a good short review was given by Eichna et al. (1) to which I refer. The physiological reactions of men during exposure to heat were also observed, but most descriptions were limited within the range of heat causing no great disturbances. Available information beyond this range is very limited as experiments are difficult to perform on account of the great suffering of the subject or even for fear of his life. The experiments made by Kuo et al. (2) in which men were exposed to an environment at dry bulb temperature ranging from 41° to 58°C, and wet bulb temperature from 38° to 48°C, for over 40 minutes seem to be one of the most severe experiments ever reported.

There was a hospital in Mukden during the war years where fever therapy was applied to gonorrhoeal conscripts. The patients were placed in a humid heat over 43°C, for 6 hours or longer. As a wet bulb temperature 32°C is generally considered to be the limit under which men can still work without ill effect, the above was an extreme heat, and the patients fell in severe conditions. Observations were made on the patients during the therapy. Although the observations were not accurate enough on account of the inadequate equipment, the results seem, I think, to be worthy reporting.

PROCEDURES

Observations were made on young male Japanese, healthy except for suffering from gonorrhoea. The fever cabinet was semi-cylindrical in shape and about 1½ meters in length, with an internal space of about four times as large as the volume of human body. One end of the cylinder was closed and the other open end was provided with hanging woolen cloths. Hot steam was blown through a few holes into the cabinet at suitable intervals. In this way the temperature...
in the cabinet could be kept at 43° to 50°C. The humidity was not measured, but certainly it was very high.

A nude subject, taking no, or a very light, breakfast, entered the cabinet and laid down on his back, his head being placed outside of the cabinet on an ice-bag. The interstices between the neck and the wall of cabinet were closed by means of the hanging cloths. The investigations were made from early February to the end of March at a room of D.B. 18° to 21°C. and W.B. 10° to 19°C. The subject was injected with 0.2 to 0.3 cc. of one per cent morphine solution before entering the cabinet, and one or two more injections were usually given during the course of therapy. In order to examine if the morphine injections had any influence on the reactions of the subject, salt solution was injected instead of morphine on four subjects, keeping them ignorant of this. It was proved that there was no change in the results.

About 50 observations were performed. But in the majority of cases, the observations had to be interrupted either on account of frenzied actions of subjects, or of their alarmed conditions. Complete observations, most of which lasted for 6 to 7 hours, succeeded only on 11 subjects. On them, the general symptoms, body temperature, sweating, pulse rate, blood pressure, oxygen consumption, respiratory movements and water content of blood were observed. Observations were also made on the properties of blood. But the results being inconclusive, they are omitted from this report.

RESULTS

General Symptoms. There was no marked distress for 10 to 15 minutes after entering the cabinet. In 25 to 30 minutes after entering, oppression in breathing, intrathoracic distress, headache and giddiness began to be felt. Feeling of throbbing in the temporal regions of the head was a common complain. The subjects began to become restless, and some ones fell in fury. Nausea and even vomiting followed. All the symptoms became worse with progress of time so that the subjects sighed, moaned and tossed about, ceaselessly complaining of thirst. Such irritable conditions lasted until about 60 minutes after entering. Then the subjects turned to become quiet, and a semistuporous state seemed to develop. But it did not last longer than 15 to 20 minutes, and the subjects again became more active, much uttering in delirium. They seemed to have hallucinations with dim consciousness. But their talking became again powerless, while they moved the extremities senselessly. Another stuporous state seemed to take place. About this time, 2 to 3 hours after entering, some subjects showed an alarmed condition of the heart so that the treatment had to be discontinued. In the greater part of cases, however, the general condition once more turned for the better in 3 to 4 hours staying in the cabinet and they got able to give fair answers to any questions.

The above symptoms in general are similar to those described by Sutton (3), by Kuo et al. (2) and by others. But special attention shall be drawn to the fact that the conditions of the subjects recovered periodically though they grew weaker with progress of time. After getting out from the cabinet, they seemed
to be very haggard with sunken eyes, not seldom suffering from giddiness, headache and vomiting. But they recovered completely within 2 to 3 hours, or at latest after one night rest.

**Body Temperature.** The body temperature was measured in the mouth. As can be seen from figures 1 and 2, the temperature rose rapidly after entering the cabinet and reached about 40°C within 40 to 50 minutes, then much more gradually so that a height around 41°C, might be attained during another half an hour. There was no further rise although it underwent more or less occasional fluctuations, and in no case it reached 42°C. Within one hour or two after getting out of the cabinet, the temperature fell to normal, or even to a lower level. But in a few cases, a fever at 38° to 39°C, lasted for several days.

![Figure 1](image1.png)

**Fig. 1.** $T_c$, air temperature in the cabinet. $T_o$, oral temperature. $BW$, water content of blood in volume per cent. $S$, sweating in mg. per 20 sq. cm. of skin per 5 minutes. $P$, pulse rate.

**Sweating.** Sweating was measured on the forehead by Kuno's method, namely water discharged from an area of the skin of 20 sq. cm. per five minutes was determined in succession. This measurement was often disturbed by frenzied actions of subjects, and it was successfully done only in nine cases. The patterns of sweating could be divided into two types.

The first type of sweating is shown in figure 1. Sweating appeared with a latent period of 10 to 15 minutes, rose rapidly and attained the maximum in 30 to 40 minutes. This maximum level was held for a few decades of minutes, but around 60 minutes after entering the cabinet, a sudden sharp fall took place. In figure 1 we see that it fell to about 1/3. This decrease lasted for 10 to 15 minutes, and a new rapid increase occurred. But this time sweating never approached the former maximum level, but remained around a level about a half of the former, with continuous oscillations of more or less extents, such a condition persisted until the end of observation.

Figure 2 represents the second type. The initial rise in sweating was somewhat more gradual and its maximal state lasted longer. The sudden fall occurred somewhat later than in the former, *i.e.* about 90 minutes after entering the cabinet. Sweating, however, recovered soon from the fall, gained the former level and lasted so for another long period, undergoing marked fluctuations. Then a second fall took place, though not so sharp as in the first one. In figure 2, this fall can be seen at about 240 minutes after entering the cabinet. The marked fluctuations of sweating seemed to be characteristic of the second type.
Fig. 2

The first sharp fall in sweating was a phenomenon never failed to find in all cases. It was first thought that this fall and the following fluctuations might reflexly be brought about from occasional changes in cold sensation provoked by the ice-bag. The ice-bag was sometimes taken away, or began to be used in half an hour after entering the cabinet. No influence on sweating could, however, be noticed on such procedures. The fact that cooling the skin has little effect on sweating when it is profuse has already been reported by Kuno and Ikeuchi (4).

Whether the difference in the type of sweating was due to individual characteristics cannot be answered with certainty as the observation could not be repeated on the same subject. At least it had no correlation with the changes in body temperature.

The water content in blood. The amount of water contained in blood was determined by weighing blood drops absorbed in a piece of filter-paper at about one hour's intervals. It increased in early stages of exposure to heat and then decreased (figures 1 and 2), but the exact time relationship of these changes could not be said from the present observation. In one case, shown in figure 1, the water content which had considerably fallen for about three hours, turned to increase again in the last stage of the observation from unknown reason.

In figure 2, a correlation between the changes in sweating and those in the water content in blood can be seen for the first three hours. But such was not the case in all the other experiments. Even in figure 2, sweating increased in the last stage while the water content considerably lowered. The water content of blood seems therefore to play no important role on determining the rate of sweating.

Pulse rate. The behaviour of the changes in pulse rate can be represented by the cases shown in figures 2 and 4. It steeply increased for the first 20 minutes after entering the cabinet so that it sometimes reached 190 per minute. It then remained at the same rate, or at a somewhat decreased rate, varying from 120 to 150 per minute throughout the observations. Minor occasional changes, seemingly coinciding with changes in body temperature, could be seen, but a progressive increase has been found in no case. After getting out from
the cabinet, the pulse rate gradually decreased and came to normal or sub-normal within one hour and a half.

**Fig. 3.** Arterial pressure in 3 subjects. Solid lines, systolic pressure. Dashed lines, diastolic pressure. *H*, exposure to heat.

- ● S.P.
- ◯ D.P.
- ● Age 32 ♀
- △ Age 28 ♀
- × Age 30 ♀
- H⋯⋯hot chamber

**Arterial pressure.** Figure 3 shows the changes in the systolic and diastolic pressures of three subjects on whom the determinations were performed on the brachial artery. Except one case, in which a transitory rise in the systolic pressure occurred, both the systolic and diastolic pressures fell gradually and considerably from the beginning of exposure to heat. The extent of the fall varied in different individuals. Usually in 3 to 4 hours, the sounds became so dim that the determination was difficult. The two enormously low values shown in figure 3 are therefore not certain if they are true or not.

**Oxygen consumption.** The oxygen consumption was determined using Douglas bags. Its changes together with the changes in body temperature and pulse rate in one experiment are shown in figure 4, and nine examples of oxygen consumption only in figure 5. The oxygen consumption considerably rose at
the beginning of exposure to heat in 4 out of 5 cases, in which the determination was made in about 25 minutes after entering the cabinet. In seven out of nine cases, a considerable fall followed about one hour staying in the cabinet or later, therefore concomitantly with the marked fall in sweating above described. Subsequent to the fall a second increase in oxygen consumption set in. The extent of increase was similar to the first, or in some cases more considerable. Sooner or later the oxygen consumption began to fall again so that, in 4 to 5 hours after entering the cabinet, its level became about 60 to 85 per cent of that before exposure to heat. The recovery of oxygen consumption after getting out of the cabinet was very slow in most cases.

Respiratory movements. Immediately after entering the cabinet, the respiration began to increase both in depth and frequency. The expiration markedly prolonged and it often took a type of blowing. In about one hour and a half the respiration grew irregular. Cheyne-Stoke respiration often appeared and the apnoetic phase gradually prolonged so that it became sometimes over 10 seconds. But the respiration returned again spontaneously to normal. The respiratory movements were not recorded, but simply observed by swings of a rubber piece attached to a respiratory mask. The exact time relation of the above variation could not be determined.

DISCUSSION

The general symptoms described above well coincide with those reported by Kuo et al. (2). In this experiment, however, the symptoms seemed to have developed somewhat slower than in Kuo's experiment, probably because the head of the subject was placed outside of the cabinet and an ice-bag was used. But the subjects staying very long in the cabinet, their strain became certainly extreme in later stages. This can also be confirmed from their body temperatures that reached around 41°C, while the highest body temperature observed in Kuo's experiments was 40.1° to 40.6°C.
Among the results of these observations, special attention may be called to the periodical syncopic depressions and recoveries which were revealed in the general symptoms, sweating and oxygen consumption. The subjects, being first excited, fell in a stuporous condition in one hour or later after entering the cabinet. About this time, sweating decreased considerably and the rate metabolism was reduced. A rapid recovery soon followed, but after one hour or later another similar depression took place which seemed to be again overcome.

The first depression was especially striking in sweating as shown in figure 1 and 2. Such a sharp fall in sweating was also observed in Kuo's experiments. Kuo et al. considered this to be a dangerous symptom, and took out the subject from the hot chamber. One example of this kind of experiment is illustrated in figure 16 in Kuno's monograph (5). In that case, the suppression of sweating occurred in about 40 minutes after entering the hot chamber, and the general features of the sweating, not only in its increase but also its sudden fall, closely resembled the first part of the tracing of sweating shown in figure 1 in this paper. It seems therefore to be plausible to assume that the sweating in the case of Kuo et al. had to recover from the decrease if they had not interrupted their experiment.

For these periodical recoveries it may be assumed that there is some sort of secondary regulatory mechanism which is brought into action to awake the activity of cortical and subthalamic centres when they have begun to be exhausted.

In the respiratory movements, considerable fluctuations were observed. But it could not be decided if they were periodical in nature. In body temperature, arterial pressure, pulse rate and water content of blood, no such periodical changes could be noticed. This may be so either because their changes are more of peripheral origin, or because their changes are too slow to show transitory influences.

Another point to mention is that the body temperature of the subject, which had risen to 40° to 41°C, during the first an hour or so, remained almost unchanged throughout the later stages in spite of his staying under the extreme heat. The question therefore arises if there was any secondary chemical regulation. The oxygen consumption lowered in later stages of exposure to heat. But this decrease was only the case after three to four hour staying in the cabinet and till then it remained higher than the level before exposure to heat so that the heat production was large while the body temperature was stable. Probably the heat gain of the body in the cabinet was compensated by the heat loss from the head. The surface area of the head and the part of the neck which were exposed out of the cabinet may be assumed to be 8 to 9 per cent of the total body surface and they are the parts where sweating is profuse. A considerable amount of heat should have been derived from the body by vaporization of the sweat. On the other hand, transmission of heat from the skin to the ice-bag was to be augmented by a rise of body temperature from 37° to 41°C.

**SUMMARY**

Observations were made on 11 men exposed to wet heat ranging from 43°
to 50°C. for over 6 hours for fever therapy.

The general symptoms were similar to those reported by previous investigators, but the subjects showed periodical exhaustions and following rapid recoveries, first in one hour or later and once more in 3 to 4 hours after the beginning of exposure to heat.

Sweating was suddenly suppressed after about 1 to 1½ hour exposure, but it was soon restored. Another suppression was found in some cases, seemingly concomitantly with the second stuporous state of the subject.

Similar periodical changes could also be seen in oxygen consumption but not in body temperature, pulse rate, arterial pressure and water content of blood.

REFERENCES