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THE SURFACE TEMPERATURE OF THE ELEPHANT, RHINOCEROS AND HIPPOPOTAMUS

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The importance in the animal economy of the loss of heat by radiation, conduction and vaporization of water, justifies a study of the factors governing this loss. Among these factors of no small significance is the surface, i.e., skin temperature, particularly as influenced by the nature of the integument and by the presence or absence of protective covering, such as hair, fur, feathers or, in the case of civilized man, clothing. Observations of the skin temperature of both clothed and nude humans have been in progress in the Nutrition Laboratory for a number of years. With many of the domestic animals numerous data for the skin temperature are recorded in the literature, but these were for the most part taken outside of the fur covering or the attempt was made to secure the observations at the skin well covered with fur. It is obvious that skin temperature measurements obtained under these conditions are not only uncertain but likewise difficult of interpretation, because of the large mass of stagnant warm air contained in the fur. For comparison with the data obtained with nude humans, therefore, the most accurate and most immediate results are secured only with those lower animals that are hairless.

In connection with a series of observations at the New York Zoölogical Park, which has cooperated with the Nutrition Laboratory for a number of years in the study of the metabolism of some of the lower animals, it became possible to obtain skin temperature measurements on several of the large pachyderms. The liberal scientific policy of Dr. W. T. Hornaday, the Director of the New York Zoological Park, and particularly the friendly coöperation of Mr. Raymond L. Ditmars, the Assistant Curator of Mammals and Curator of Reptiles, enabled us to make an intensive study of the skin temperature of two elephants, one rhinoceros and a hippopotamus. These animals are, for the most part,

well used to handling by man, and while obviously in captivity and therefore under artificial conditions, nevertheless have lived under these conditions for a decade or more and hence may be fairly said to have adjusted themselves to their present environment.

A thermo-electric method of taking skin temperature measurements has been carefully tested in the Nutrition Laboratory and a preliminary communication has already been made with regard to certain results obtained upon a human subject, both clothed and nude, after several hours of exposure to cold.[1] Since the animals chosen for the study reported in this second paper were in many instances very restless and only a few seconds could at times be taken to secure the temperature records, this thermo-electric method was ideally adapted for our purpose as it permits extremely rapid and accurate measurements. Fortunately, repeated tests of our apparatus have shown that a 6-second period of application of the thermo-junction suffices to give the true skin temperature.

The apparatus consists of two copper-constantan thermo-junctions, one of which is applied directly to the skin, while the other is placed in a thermos bottle carrying a tenth degree Centigrade thermometer, which can be read to hundredths. The terminal wires lead to a galvanometer which is of such a degree of sensitivity that each millimeter scale deflection corresponds approximately to 0.06°C. The galvanometer was of a fairly low resistance, long leads could easily be used, and this made it possible to go into the farther corners of the several animal compartments without having to carry in delicate electrical apparatus, with the danger of breakage. The constant temperature junction (held at about 30°C.) was read practically every 3 or 4 minutes, and approximately every hour the galvanometer "constant" was verified. In the operation of taking the temperature measurements one of us was at the galvanometer to read and make records of the deflections on the scale, one applied the junction to the skin, and the third determined with a pen point on a series of sketches, outline drawings or picture postcards, the exact location of the measurement, this location being given a number for subsequent reference. With a piece of chalk each point of application was marked on the animal's hide, and subsequent readings could be taken at the same point for a check and control.

The skin temperature of a female Indian elephant and a male African elephant. The first animal studied was a female Indian elephant, *Elephas indicus* (Cuv.). At the time of our measurements she was

[1] Benedict, Miles and Johnson: Proc. Nat. Acad. Sci., 1919, v, 218.

25 years old, her estimated weight was 6300 pounds, and she was 8 feet 5½ inches tall, 10 feet 7¾ inches long, and 4 feet 1 inch broad. This animal, while thoroughly tractable and frequently used in summer to carry children about the Park, was very nervous. The application of the thermo-junction seemed to startle her and it required some training to secure satisfactory readings. The incessant activity of the animal likewise made the measurements difficult. Indeed, it is probably correct to state that at no time during our entire experience, covering several days, was either elephant motionless for two consecutive seconds.

While the temperature of the elephant house was kept relatively constant at about 19.5°C., the weather at the time of our observations was extremely cold and not infrequently a perceptibly cold draft from one of the skylights and pronounced wind drafts from the wall could be felt about the elephant's body. We have reason to believe that these drafts at times materially affected the surface temperatures of the animals. Thus, for example, when the series of measurements was repeated on the second day, considerable differences in skin temperature amounting to 3° or 4°C. were noticed in the same spot. Owing to the inquisitiveness and restlessness of the elephant, it was impossible to place a psychrometer within reach of or anywhere near the animal. The psychrometer was, however, placed around the corner in an adjoining compartment, under practically the same atmospheric conditions, and the temperature of the wet bulb was found to be on the average 10.9°C. throughout our observations.

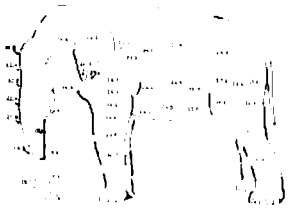

Fig. 1. Surface temperatures of a female Indian elephant (left side). Temperature of environment, 19.5°C.

A topographical survey of the skin temperature of this female Indian elephant is given in figure 1. In this and the following diagrams are given *only* measurements on the unprotected skin areas. Each record represents in most cases the average of a number of measurements, but occasionally a single measurement. The decimal point in each number serves to indicate the exact location of the measurement; in a few instances where this method could not be advantageously adhered to, an arrow points to the location of the measurement. Figure 1 represents the left side of the Indian elephant, since practically all

of the observations were made upon this side. A few temperature measurements were also obtained on the right side of the body, two points on the exterior surface of the ear giving 23.7°C. and 24.1°C., respectively, and two points on the right shoulder giving 26.2°C. and 25.0°C.

The relatively high values found around the lower end of the trunk, particularly on the inside of the trunk, may be explained by the fact that the expired air was constantly being blown against these parts. In the semi-enclosed places, such as the groin and axilla, high values were normally to be expected.

On the ear extraordinarily high temperatures were found. In general, the temperature on the inside of the ear was somewhat warmer than that on the outside, but one would normally expect that the tip end of the ear would be relatively cold, as is the case with humans. As a matter of fact, the warmest spot on this animal's entire surface was on the tip end of the left ear, where two records averaging 32.5°C. were obtained. Although it was impossible to make a very close examination of the ear and the skin was so rough that veins or arteries could not be seen, every effort was made to take a sufficient number of observations to be sure we were not dealing with the temperature taken directly over an artery. The two figures obtained at the tip end of the left ear of 31.6°C. and 33.4°C. may therefore be considered as certainly characteristic of the temperature at this particular point and at the particular moment. Indeed, the temperature at this point was so high that, when called to the attention of the keepers, it was noted by the hand alone.

The right ear of this elephant gave at no point temperatures as high as those found on the left ear, the highest record obtained at any time being 24.1°C. at a point approximately equivalent to where an average of 32.5°C. was found on the left ear. This difference of substantially 8° we are unable to explain. The keepers looked for a possible abscess as a result of the use of an elephant hook, but nothing could be found to account for the high temperature. With the other elephant a similar observation of high temperature on the tip of the ear was made. Furthermore, it should be stated that on the three days during which we studied the elephants, marked differences in the temperature of the two ears and, indeed, very wide and relatively rapid changes in temperature on the periphery of the ear were frequently noted, thus suggesting a large blood supply even to the tip of the ear.

In general, as seen from figure 1, there is a fairly uniform temperature distribution over the skin of this Indian elephant, the average skin temperature being close to 25.5°C.

Skin temperature measurements were likewise secured with a male African elephant, *Elephas oxyti* (*Matschie*), which at the time of our observations was 15 years old, 9 feet $3\frac{1}{4}$ inches tall, 11 feet $1\frac{1}{4}$ inches long, 3 feet 7 inches broad, and had an estimated weight of 6000 pounds. This animal, though not considered so peaceful and tractable as the female Indian elephant, having at times shown a rather unruly disposition, proved to be extraordinarily docile in the hands of his keeper, Mr. Walter Thuman, and, aside from the inevitable inquisitiveness and restlessness, permitted measurements ad libitum.

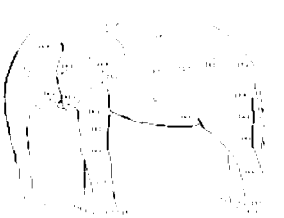

Fig. 2

Fig. 3

Fig. 2. Surface temperatures of a male African elephant (left side). Temperature of environment, 19.5°C.

Fig. 3. Surface temperatures of a male African elephant (right side). Temperature of environment, 19.5°C.

Two somewhat extensive series of measurements were made upon him on consecutive days. Both the left and the right sides were studied, primarily with a view to noting if there was anything in the nature of a general unilateral temperature distribution, as suggested by the curious changes noted in the ear temperatures. The average values obtained on the left side of this elephant are charted in figure 2 and those on the right side in figure 3. While a careful study of the figures will show that there was not perfect equality in the temperatures at any two corresponding spots on opposite sides of the body, nevertheless if we take into consideration the differences in temperature of the same spot noted at different times of the day and on different days, there is nothing in the data to warrant even a suspicion of a unilateral temperature

distribution. Attention should be called again to the extraordinarily high values found at the tip of the left ear, where one would ordinarily expect low temperatures. The back of the ear, i.e., in a protected area, had on the whole a higher temperature than the front, and very marked differences were observed in relatively small areas. In this connection it should be noted that the ears of the African elephant are considerably larger than those of the Indian elephant.

The semi-enclosed parts, such as the groin and the axilla, and particularly around the ear and the inside of the trunk, were characterized by relatively high temperatures. The highest individual reading noted on this animal was 33.0°C. well up in the groin. On the soles of the feet temperatures were recorded of 24.3°C. on the left hind foot and 25.4°C. on the left front foot.

All the observations taken with this animal seem to indicate a considerably higher temperature down the front leg than down the hind legs. It should be pointed out that this conclusion is based upon only one series of temperature measurements down the front leg from the shoulders to the toes, and it is to be regretted that a second series was not obtained over this same area on the other front leg. As a matter of fact, the computations of the temperature measurements were not made until some time after the actual observations were recorded, and hence this point was not clearly brought out until later. Since this particular elephant was somewhat sensitive to being touched toward the outer end of the trunk, very few observations could be obtained there. The general picture of the data recorded for this male African elephant shows an average skin temperature essentially that observed with the female Indian elephant, i.e., 25.5°C.

The rectal temperature of elephants has not been extensively recorded. Dr. W. R. Blair of the New York Zoölogical Park has furnished us with the following information with regard to rectal temperatures taken by himself to establish normal values. With the Indian elephant he has found rectal temperatures of 97.1°F., 97.2°F. and 98°F. (i.e., 36.2° to 36.7°C.). Our own observations on the rectal temperature of the African elephant gave values of 35.90°C. and 35.85°C. Realizing that the relatively large masses of feces passed by these animals, falling upon a fairly warm concrete floor, would probably lose heat very slowly in the center, a thermometer was thrust into the warm, moist mass of feces as quickly as it was passed, and a record was thus obtained of 36.7°C. for the temperature of the feces of the female elephant and 36.2°C. for those of the male elephant. It is probably true, therefore,

that the rectal temperature of the elephant is not far from that of the human body, possibly slightly lower than the average usually accepted for man, which is 37°C.

The skin temperature of a black African rhinoceros. The rhinoceros in the New York Zoological Park, a female, although reputed to be rather intractable, was, as a matter of fact, a most willing subject. As a rule she remained standing very quietly, and on one occasion actually went to sleep, lying on her side thus affording the best possible opportunity for obtaining the temperatures in the groin and on the soles of the feet. This animal, of the species known as *Rhinoceros bicornis* (*Linn.*), was born in 1905 and accordingly was 15 years old at the time of our measurements. Her estimated weight was 1900 pounds, and she was 4 feet 8 inches tall, 9 feet 6 inches long, and 2 feet 10 inches broad. Her skin, although extraordinarily thick, was much smoother than that of the elephants and thus gave much more satisfactory measurements.

In figure 4 are recorded only those temperatures found on the exposed surface of the skin on the left side of the body. Obviously in the groin and between the folds of skin high temperatures were noted, but these are not given in this diagram. There is a slight tendency for the lower temperatures to be found along the back rather than farther down the sides and belly. The highest temperature recorded on the skin was 27.9°C. on the left flank. Since the temperature of the environment in the rhinoceros compartment was essentially the same as that in the elephant compartment, it is clear that the rhinoceros had a slightly higher skin temperature than the elephant. In addition to the data given in figure 4 a number of records were obtained in the folds of the heavy skin. One record in a fold at the top of the head directly back of the ear showed 29.2°C. In the left axilla, deep in the fold, a temperature of 29.6°C. was found, while well up in the groin two records of 33.4°C. and 33.3°C. were obtained. Two records on the soles of the front feet gave 28.6°C. and 24.8 C., and on the sole of one of the hind feet a temperature of 26.5°C. was noted. The average skin temperature of this rhinoceros was 26.2°C., a value slightly higher than the average found with the elephants, which was 25.5°C.

We were able to secure one measurement of the rectal temperature of this rhinoceros, namely, 37.4°C. (99.3°F.), which compares very well with Doctor Blair's records for the Indian rhinoceros of 100°, 99.7° and 99.7°F.

The skin temperature of a male hippopotamus. A specimen of the *Hippopotamus amphibius* (*Linn.*), a male, was also studied. This animal was 18 years old, had an estimated weight of 4600 pounds, and was 4 feet 10 inches tall, 11 feet 6 inches long, and 4 feet 3 inches broad. He was accustomed to spend much of his time in the water in a large tank adjoining his compartment, the temperature of which was approximately 15°C., but several hours prior to the taking of the temperature measurements the tank was drained and the animal was kept in a dry space along with his food. At the time of our measure-

Fig. 4

Fig. 5

Fig. 6

Fig. 4. Surface temperatures of a female black African rhinoceros (left side). Temperature of environment, 19.5 C.

Fig. 5. Surface temperatures of a male hippopotamus (left side). Temperature of environment, 19.5 C.

Fig. 6. Surface temperatures of a male hippopotamus (right side). Temperature of environment, 19.5°C.

ments, therefore, the animal's body was reasonably dry, and while it felt slightly moist to the hand, no drops of water could be seen anywhere. The animal was extremely irritable and nervous, especially during the second series of observations; it was only with difficulty that we could secure the records here given, and we had to content ourselves with temperatures of the exposed skin, as it was impossible to measure the temperature in the groin, on the soles of the feet, or in any of the semi-enclosed cavities. The temperature topography of the hippopotamus is shown in figures 5 and 6 herewith, for the left and right sides, respectively.

From an inspection of the data in figures 5 and 6 it is clear that the skin temperatures are distinctly low as the back bone is approached, with a tendency for higher values down the side and under the belly. Even here the picture is not perfectly clear, since one extremely low value of 21.2°C. is noted near two high values of 30.6° and 30.9°C. The evidence is sufficient, however, to show that the lower half of the side of this animal has a relatively high temperature. It is not impossible that the lower temperatures on the upper part of the side are due to the vaporization of moisture from the skin and likewise to the possible downward drafts of cold air from the skylight and the ventilators in the chamber. These drafts of air were not sufficient, however, to affect the temperature of the wet and dry bulb thermometer which remained essentially constant throughout the entire 3-day test.

From the relatively few measurements here recorded in figures 5 and 6 it is somewhat hazardous to estimate an average skin temperature for this animal. But if we follow the practice carried out with the elephants and rhinoceros and assume the legitimacy of averaging these results, we find the average for this animal is not far from 25.0°C. The hippopotamus, therefore, has an average skin temperature essentially that of the other three animals studied, although very much greater differences were observed between the temperatures of the back and belly than were found with either of the two elephants or the rhinoceros.

The irritability and viciousness of this particular animal finally resulted in the complete demolition of certain parts of our apparatus, which prevented further reading. No rectal temperatures could be secured with the animal, and the feces were not of sufficient volume and consistency to make it possible to secure the temperature of the feces immediately after their passage. It is probably true, however, that the rectal temperature of the hippopotamus is not far from that of the other large animals we studied, i.e., essentially that of man.

Suggestions for further study. All of the diagrams show that an attempt was made to measure the temperature at a spot corresponding approximately to the forehead of man, which always has a temperature much higher than other exposed parts of the body. With all of these animals relatively low rather than high forehead temperatures were recorded. This brings up the interesting question as to the influence upon the forehead temperature of the supply of blood to the brain, this factor undoubtedly being complicated by the extraordinarily thick skull and very thick skin of these pachyderms. Almost nothing

is known with regard to the blood supply and arterial distribution of blood in these large animals and the importance and significance of a thick skin as protection against heat loss, nor indeed is anything yet known with regard to their total metabolism and heat production per unit of weight or per unit of surface area. Measurements of this type involve very large and elaborate apparatus and partake of the nature of an engineering rather than a physiological problem. Aside from expense, however, no technical difficulties stand in the way of actual measurements of this type, although undoubtedly indirect calorimetric determinations of the carbon-dioxide production and oxygen consumption will have to be made rather than direct calorimetric measurements. But whatever the heat production, undoubtedly the extremely thick skin of these animals plays an important rôle in the protection against heat loss.

It is to be hoped that at some time a series of temperature measurements may be made with hairless animals of the types here studied, when the environmental temperature is measurably higher and lower than 19.5°C. The higher environmental temperatures could readily be obtained in certain seasons of the year, but the practicability of subjecting these tropical animals to a temperature much lower than 19.5°C. without danger is a matter of much uncertainty.

SUMMARY

Measurements were made of the skin temperatures of a group of large captive, hairless animals, namely, two elephants, a rhinoceros and a hippopotamus. For a number of years these animals had been subjected to the same routine of life in a well-ordered animal house at the New York Zoological Park and had become thoroughly acclimated to the conditions. For several weeks, if not months, prior to this investigation they had been living in an environmental temperature essentially constant, i.e., 19.5°C., and with no great changes in the degree of humidity.

With the two elephants the average temperature of the skin was 25.5°C. Local conditions of environmental temperature and drafts affected the skin temperature. Very pronounced temperature gradients were observed on various parts of the ears and extraordinary temperature differences were found at the tips of the right and left ears, both on the front and back of the ears and on different days. Of the three types of animals studied the elephants were by far the most restless and

much more active, for example, than the rhinoceros, who remained standing still or lying down practically the entire time, while the elephants were standing up and continually in motion. It is well known that with humans during severe muscular work there is an increase in skin temperature. On the basis of increased activity resulting in increased metabolism, one would, therefore, normally have expected to find a slightly higher skin temperature with the elephants than with the rhinoceros, but the actual records show exactly the opposite. With the rhinoceros the average skin temperature, 26.2°C., is somewhat higher than with the male elephant. In the semi-enclosed places, such as the groin and axilla and, especially with the rhinoceros, between the folds of skin, very much higher temperatures are observed, a value as high as 33.4°C. being found with the rhinoceros well up in the groin. The hippopotamus, by reason of its moist skin and amphibious nature, has a very widely varying skin temperature. Its skin is considerably cooler on the back than on the belly. The temperament of this animal made it difficult to secure a sufficient number of measurements, but a rough average gives a value for the skin temperature of 25°C., which is not far from that found with the elephants.

All these animals, therefore, may be said in general to have essentially the same skin temperature, averaging about 25.5°C., or about 6°C. above the environmental temperature of 19.5°C. The rectal temperature is essentially that of man. The fact that all four animals show approximately the same average skin temperature is of special significance and leads to the interesting query as to what would be the skin temperature of a man who remained nude and in an environmental temperature of 19.5°C. for a considerable length of time.

STUDIES ON THE RESPONSES OF THE CIRCULATION TO LOW OXYGEN TENSION

V. Stages in the Loss of Function of the Rhythm Producing and the Conducting Tissue of the Human Heart During Anoxemia

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That systemic asphyxiation is a factor in producing slowing of the heart rhythm and in decreasing conductivity has long been known,—Klug (1), Konow and Stenbeck (2) and numerous later investigators. Our present views as to the anatomical differentiations within the heart have resulted from a series of papers presenting the morphological and physiological facts of the conducting and nodal system,—Kent (3), His (4), Keith and Flack (5), DeWitt (6), Mall (7), Lhamon (8), Eyster and Meek (9) and many others. The facts of the functional control of the heart rhythm and sequence from dominant centers as understood at the present time have been developed especially by Erlanger (10), Keith and Flack (5), Adam (11), Flack (12), Lewis (13), Gantz and Zahn (14), Meek and Eyster (15) and Lewis (16). The influence of temperature, of asphyxia, of drugs, and especially of the extrinsic nerves on the sino-auricular and auriculo-ventricular rhythms and on conduction have been discussed in several of the preceding references and also by McWilliam (17), Lewis and Mathison (18), Mathison (19), Meek and Eyster (20), Eyster and Meek (21), Schlomovitz, Eyster and Meek (22), and by Lewis, White and Meakins (23). The reference list is not exhaustive but the literature is fully reviewed in several of the references given. We have also briefly reviewed the literature on asphyxia in article III of this series (24).

The electrocardiographic method has been applied to the study of the changes in the mammalian heart in numerous studies from the laboratories of the University of Wisconsin by Eyster and Meek,