

RENAL FUNCTION, RESPIRATION, HEART RATE
AND THERMOREGULATION
IN THE OSTRICH (*STRUTHIO CAMELUS*)

by

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(With 11 figures)

INTRODUCTION

As the ostrich is the largest bird in existence it is of considerable physiological interest. Moreover, in spite of being flightless and of too large a size to escape to a protective micro-climate, it is a successful inhabitant of many desert regions of Africa. This is particularly true of the Namib Desert in South West Africa where they are found in large numbers under very arid conditions. The ostrich has, however, received very little attention from physiologists. Crawford and Schmidt-Nielsen (1967) were the first to undertake serious physiological studies related to possible desert adaptation. They studied the hot-room reaction of an ostrich in terms of temperature regulation and evaporative cooling. This study was followed by a refined investigation of respiration in the ostrich by Schmidt-Nielsen, Kanwisher, Lasiewski and Cohn (1967), again under artificial conditions. More recently Cloudsley-Thompson and Mohamed (1967) have examined the effect of water deprivation on body weight and feed intake of the ostrich.

No attempt has, as yet, been made to examine the nature or efficiency of renal function in the ostrich, which is central to the problem of assessing adaptation to desert survival. Moreover, apart from the body temperature study by Bligh and Hartley (1965), no effort has been made to make a composite study of the main physiological systems involved in water metabolism and thermoregulation under

natural conditions, where the animals are exposed to cycling effects of wind, solar load, light and diurnal variation in ambient temperature. For these reasons, then, the present investigation was initiated to assess the physiology of adaptation of the ostrich to a desert environment under as near natural conditions as possible.

PROCEDURE

The birds used in the investigation were semi-domesticated adult females obtained from the Oudtshoorn District. In all, three ostriches were employed with body weights of 90 kg, 93 kg and 114 kg respectively. Throughout the experimental period they were housed in loose boxes. These were constructed of wood and were specially designed to allow free circulation of air around the animals. The birds were able to move several feet forwards and backwards. They were able to lie down and get up in comfort, but were not able to turn around. The crates provided no shade for the animals and they were exposed to natural climatic conditions at all times. The following treatments and methods were applied.

Water provision

For the first three days of the experimental period the birds were drenched daily by means of a stomach tube. Each bird receiving a total amount

of water equal to 10 per cent of its body weight each day, divided in two separate doses at 10.00 hr. and 17.00 hr. This meant that the birds received between 8 and 11.4 litres of tap water per day, depending upon their body weight. After the third day the animals were entirely deprived of water up to and including day 11 of the experimental period (i.e. for eight days). On day 12 the animals were again drenched with the same amount of water (10 per cent of original body weight) and after urine and blood samples had been collected on the morning of the thirteenth day, the experiment was terminated.

Feed intake

The ration provided for the birds consisted of whole maize grain only. This was fed *ad lib.* and daily feed intake was recorded.

Atmospheric temperature

Ambient temperature was measured by means of a thermistor probe (YSI No. 405) placed in direct sunlight 80 cm above ground level. In addition, the more conventional screen temperature and relative humidity were recorded on a maximum and minimum thermometer and a sensitive thermohygrograph in the standard manner. The former temperature (direct sunlight) was considered of greater biological significance while the latter has been reported for standard comparisons.

Body temperature

During a pilot investigation it was established that forceful restraint of the ostrich and even the presence of humans in the near vicinity of the birds greatly distorted various physiological parameters. This was particularly true for heart rate and respiration rate, which were increased by as much as 100 per cent, and to a lesser extent body temperature. For this reason these parameters were measured remotely using either thermistor probes with long extension leads or radiotelemetric devices. In the case of body temperature a fine thermistor probe (YSI No. 402) was surgically implanted to a depth of 5 cm in a standard position in the left gluteal muscle of each bird. The surgery was performed under aseptic conditions and the implantation site was covered with a thick layer of cotton wool, adhesive plaster and finally ostrich feathers to insulate the probe from heat conduction and radiation. Body temperatures were then recorded remotely, without any disturbance to the birds, at regular intervals throughout the day and night.

Skin and feather space temperatures

In addition to body temperature, the skin temperature and the temperature of the air space

between the skin and feather layer was measured in the case of one ostrich. The skin temperature was recorded by means of a flat thermistor probe (YSI No. 409) which was attached to the skin beneath the feather layer on the rump. This probe was insulated from environmental influences by a covering of 'styrofoam' and adhesive plaster, measuring 7 x 5 cm. A second thermistor probe (YSI No. 401) was attached above this insulation layer to measure the temperature of the air space between the skin and feather layer. The insulation layer above the first probe (an area of 7 x 5cm) protected the second from direct effects of skin temperature. These temperatures were again recorded at regular intervals throughout the day and night.

Respiration rate

Respiration rate was recorded through the use of a pneumographic device which was attached by means of plastic tubing to a remote manometer. Oscillations of the manometric fluid were counted over a 3 minute period against a stop watch. In this way respiration rate could be recorded remotely at regular intervals during the day and night without disturbing the birds.

Heart rate

Heart rate was monitored simultaneously with body temperature and respiration rate using radiotelemetric apparatus. This consisted of a miniature EKG transmitter connected to electrodes implanted subcutaneously in each ostrich and a standard FM receiver. EKG pulses were received as an audible signal and counted against a stop watch.

Urine and faecal collections

Because of the highly viscous nature of ostrich urine and other considerations it was not possible to make complete collections of urine and faeces which would be sufficiently uncontaminated for chemical analysis. However, as the ostrich lies down throughout the night without either defecating or urinating it was possible to collect the first urine and faecal sample voided each morning shortly after they stood up. Moreover, unlike most other birds, defecation and urination in the ostrich are two separate acts; urine collects in the urodaeum but there is no mixing with faecal matter due to an internal rectal sphincter which prevents faeces entering the urodaeum of the cloaca. Each morning, shortly after they had stood up the ostriches voluntarily urinated and this act was immediately followed by extrusion of the internal rectal sphincter and defecation. This first urine sample was collected daily from each ostrich in large plastic containers which had been triple-rinsed in deionised water. The urine was then stirred in a standard

manner before pipetting off a 20 ml sample which was frozen for later analysis. Faecal samples were collected separately and frozen in air-tight containers for later moisture determinations.

Urine analyses

Three weeks after the termination of the experiment the urine samples were thawed and immediately centrifuged for 30 minutes in graduated centrifuge tubes using a clinical centrifuge. The percentage undissolved uric acid, which collected at the bottom of the centrifuge tubes, was recorded and the supernatant removed for sodium, potassium and osmoconcentration determinations. Sodium and potassium concentrations were determined by means of a flame photometer and the osmoconcentration in an osmometer (Advanced Instruments 31LAS).

Blood analyses

A 10 ml blood sample was obtained every second day from each bird by venous puncture of the brachial vein using new, heparinised, disposable syringes. The samples were centrifuged immediately and the plasma frozen for later analyses. Prior to centrifugation a sub-sample was removed by means of heparinised capillary tubes for micro-haematocrit determinations.

Plasma concentrations of sodium and potassium were determined by standard flame photometric methods and osmoconcentration again in an osmometer. In addition, total plasma proteins were determined by the method described by Weichselbaum (1946) and the relative percentages of albumin and globulin in the plasma were assessed by paper electrophoresis using a Beckman Durrum cell and densitometer.

Thermoregulatory behaviour

The experimental animals, as well as an unrestrained group in the near vicinity, were observed at regular intervals for any peculiar behaviour patterns which could be related to thermoregulation.

Nest temperatures of a nearby broody pair were also monitored, together with soil temperatures, over a 24 hour period. Nest temperature was obtained by attaching a flat thermistor probe (YSI No. 409) to the side of an egg which was centrally situated in the nest. The surface temperature of the soil in the immediate vicinity of the nest was measured similarly and both thermistors were connected by long underground extension leads to a remotely situated telethermometer.

The experiment was conducted in the Oudtshoorn District of the Cape Province during March and April, 1968.

RESULTS

Feed intake

On the first day after the birds had been deprived of water the average feed intake was 872 gm per bird. This amount increased to reach a maximum of 1,108 gm per bird on the fourth day after water deprivation. Thereafter, consumption declined steadily to 304 gm on the seventh day and on the eighth day two of the birds refused all their feed, the intake of the third bird being only 76 gm. On the ninth day the birds were again drenched with water and feed intake rose dramatically to an average of 747 gm per bird. It is also of considerable interest to note that, even after drenching with as much as 5 litres of water via a stomach tube on the ninth day, the birds still refused to feed. It was only after they had been allowed to voluntarily drink an additional 200 ml naturally that they began to feed. A neural reflex involving the oesophageal metering of water intake may have been involved. Apparently the administration of water via a stomach tube circumvents this reflex.

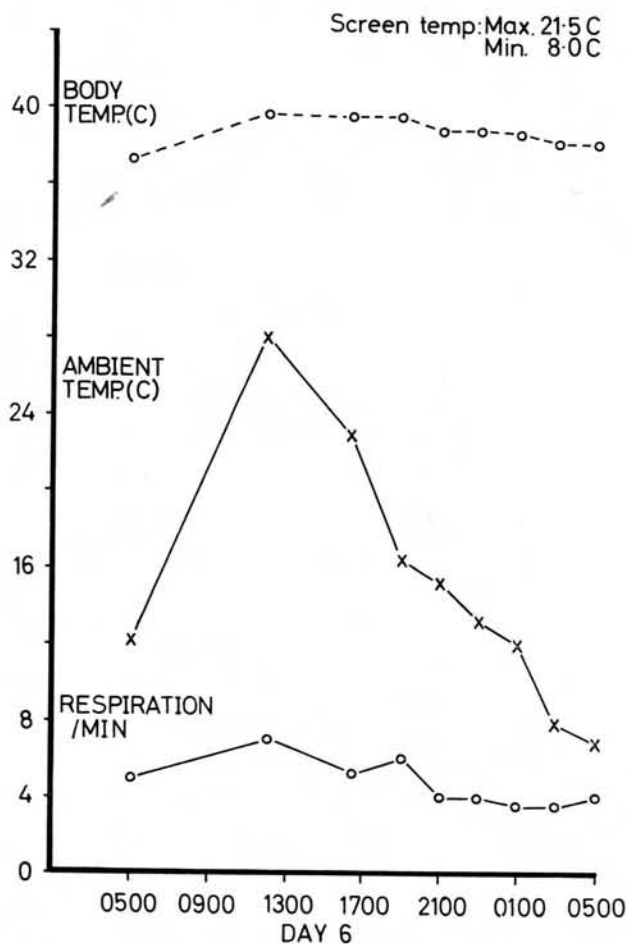


Figure 1: Illustrating body temperature, ambient temperature and respiration rate of an individual ostrich over a 24 hr. period.

Body temperatures

The lowest body temperature recorded over the experimental period was 37.9° C and the highest 40.7° C. By far the greater number of values, however, fell in the range 38.2° to 39.8° C. More important, each bird exhibited a definite diurnal cycle each day. This cycle was approximately in phase with cycling atmospheric temperatures. For example, the lowest temperatures were most frequently recorded at 05.00 hr., the maximum temperatures were recorded between 12.00 and 17.00 hr. and a gradual decline in temperature occurred during the night to reach a minimum again at 05.00 hr. Nevertheless, the magnitude of change in body temperature during the diurnal cycle was similar ($\pm 2.0^\circ$ C) on both cool and hot days which is suggestive of an endogenous rhythm. The diurnal cycle in body temperature is illustrated for one individual on three separate days in Figs. 1, 2 and 3.

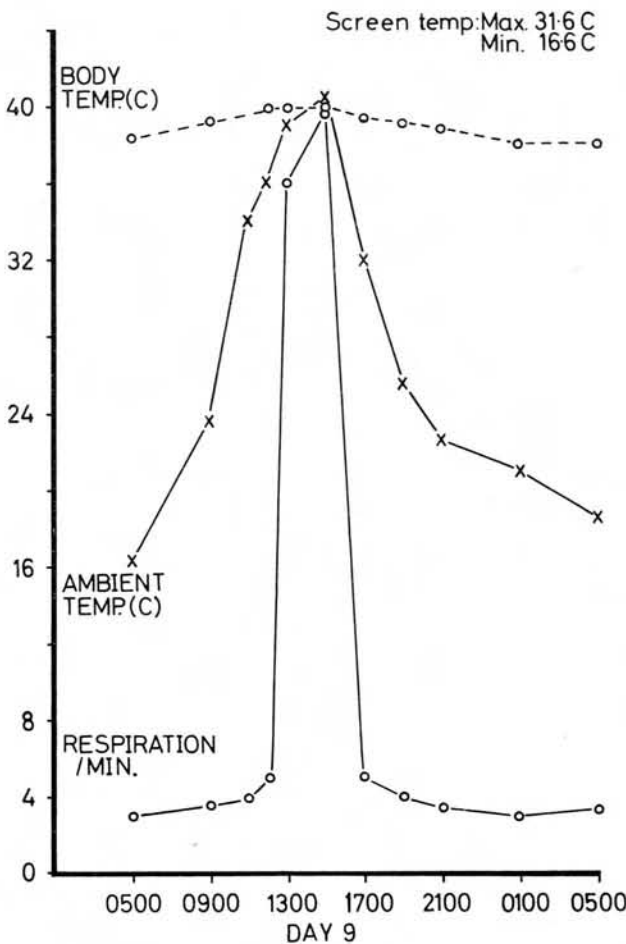


Figure 2: Illustrating body temperature, ambient temperature and respiration rate of the same ostrich as in figure 1. There was no wind on this day.

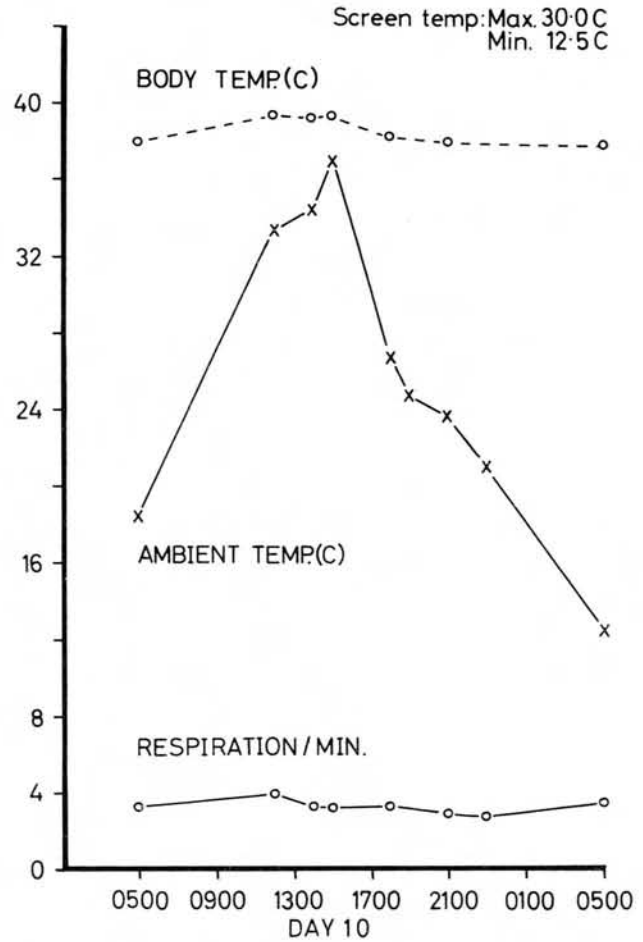


Figure 3: Illustrating body temperature, ambient temperature and respiration rate of the same ostrich as in figures 1 and 2. A steady breeze blew from 13.00 — 15.30 hr.

Skin and feather space temperatures

Cycling body, skin and feather space temperatures for one individual over a 30 hour period are illustrated in Fig. 4. Superficially the data suggest that skin and feather space temperatures are merely a function of cycling body temperatures, but closer examination reveals a far more interesting phenomenon. For example, on the first day between 15.00 hr. and 17.00 hr. the body temperature showed a slight increase while skin and air space temperature showed a slight decline. This decline in skin and air space temperature between 15.00 — 17.00 hr. is then followed by a sharp decrease in body temperature between 17.00 — 19.00 hr. Similarly, the sustained sharp decline in skin and air space temperature between 17.00 — 21.00 hr. is followed by a sustained decrease in body temperature until 01.00 hr. In contrast with the above trend, however, between 21.00 and 01.00 hr., with declining atmospheric and body temperatures, the air space temperature actually rose and the sharp decline in

skin temperature was arrested. This rise in air space temperature was then followed by a sustained rise in body temperature between 01.00 — 05.00 hr. when the atmospheric temperature was actually declining. Also of great interest is the decrease in air space temperature between 12.00 — 14.00 hr. on the next day when atmospheric temperatures were approaching the maximum (34.5°C). This decrease was followed by an arrest of the rising body temperature between 14.00 and 15.00 hr. The subsequent sharp decline in air space temperature between 15.00 — 18.00 hr. was accompanied by a decline in body temperature, but between 18.00 and 19.00 hr., with a continued decline in body and atmospheric temperature, air space and skin temperature rose sharply. It should be noted that at this stage the body temperature was approaching the lower limits of the diurnal cycle.

From the preceding description, then, it appears as if the temperature of the air space between the

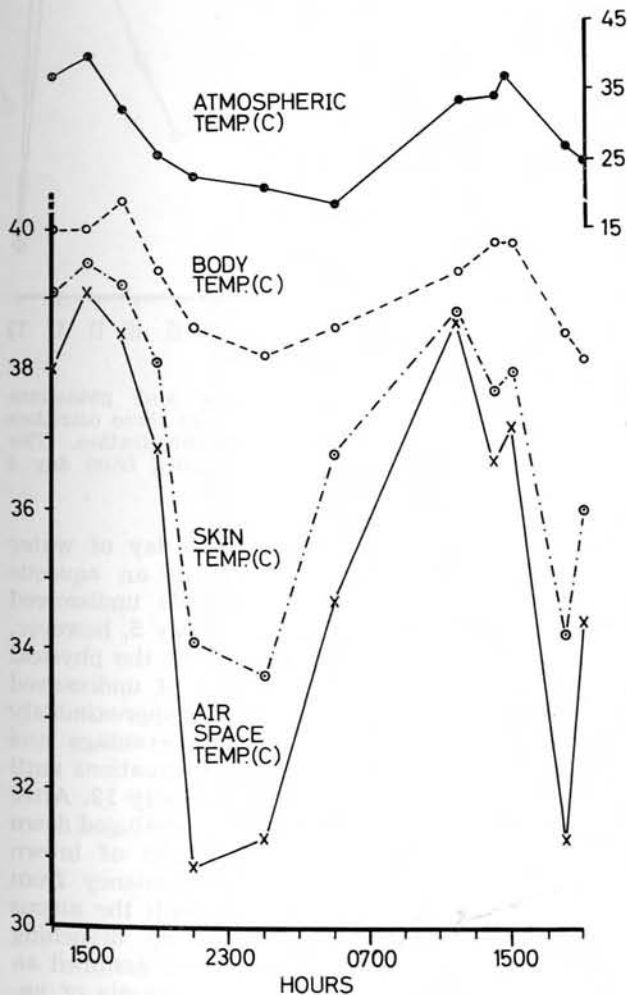


Figure 4: Illustrating body temperature, skin temperature and the temperature of the air space between the skin and feather covering in an individual ostrich over a 30 hr. period.

skin and feather layer plays an extremely important role in the thermoregulation of the bird. For example, when the body temperature approaches the upper limits of the diurnal cycle (40°C) the air space temperature decreases. This decrease is then followed by a subsequent decline in body temperature until the lower limits of the diurnal body temperature cycle (38°C) are reached, whereupon air space temperature rises, which is again followed by a rise in body temperature. The question now arises as to how this control of air space temperature is effected. The most acceptable explanation is to be found in the fact that, when body temperatures approached the higher limits of the diurnal cycle (40°C) under conditions of high ambient temperature, the ostriches were observed to erect their body feathers. In contrast, when body temperatures declined towards the lower limits of the diurnal cycle (38°C) the feathers were flattened tightly over the body. Apparently, then, feather erection allows increased convective cooling at high body temperature and feather flattening conserves body heat through insulation at low ambient temperatures, both mechanisms having a significant effect on body temperature.

Respiration rate

The highest respiration rate recorded during the experimental period was 47 per minute and the lowest 3 per minute. Most values, however, fell into two distinct class intervals namely, a lower range of 3—5 respirations per minute and a higher range of 36—47 respirations per minute. There were very few intermediate values and for most of the experimental period respiration rate remained in the lower range of 3—5 respirations per minute. On two separate days, when the direct sunlight temperature exceeded 34°C and the screen maximum 30°C , the respiration rate increased to the higher range of 36—47 respirations per minute in all three birds. The increase occurred very swiftly, in fact, within seconds a bird would increase respiration rate from the lower to the higher range.

Respiration rates of one individual over a 24 hour period on three separate days are graphically illustrated in Figs. 1, 2 and 3 together with cycling body and ambient temperature. These data illustrate the lower and higher respiration rate ranges and the abrupt increase and decrease between the two ranges is shown in Fig. 2. There was no evidence of a marked diurnal cycle in respiration rate, although lower values were usually obtained at night when the ostriches were lying down than during the day when they were standing.

If the data in Figs. 1, 2 and 3 are examined in an attempt to locate the critical or threshold ambient temperature at which respiration rate is abruptly increased from the lower range to the higher range, it appears from Fig. 2 that the

threshold value lies between 33 — 36° C. However, on the next day (Fig. 3) the ambient temperature reached a maximum of 37° C (screen maximum, 30° C) and the threshold value was not reached. There was, however, an important climatic difference between the two days. On day 9 (Fig. 2) there was no wind, while on day 10 (Fig. 3) a steady breeze blew from 13.00 — 15.30 hr. This result, then, emphasises the importance of convective cooling to the ostrich and confirms the significance of feather erection and flattening as discussed previously in relation to the temperature of the air space between the skin and feather covering.

Heart rate

The heart rate of the ostrich was found to be extremely sensitive to various types of stress. Sudden noise or even the approach of a person caused the heart rate to increase by 30—50 per cent, while forceful restraint of the birds caused an increase of as much as 100 per cent. Under the conditions of the experiment, however, heart rate was only recorded from a remote position by radiotelemetry, when the birds were completely calm, and without any disturbance to them. Under these conditions the lowest value obtained was 23 beats per minute and the highest 46 beats per minute. The greatest number of values were, however, within the range of 28—36 beats per minute. Moreover, the heart rate showed a distinct diurnal rhythm in each bird every day, which was approximately in phase with body and ambient temperature. Similar to body temperature, the lowest values were obtained at night while the birds were lying down and particularly at 05.00 hr. shortly before they stood up. The highest values were usually recorded between 13.00 — 17.00 hr. when body temperature was also in the maximum range.

In addition to the diurnal cycle, maximum heart rate increased slightly (± 11 per cent) when the ambient temperature exceeded 34° C (screen temperature 30° C). At this time the respiration rate of the birds was in the higher range of 36 — 47 respirations per minute. In spite, however, of the above trends and, excluding excitement, the posture of the animal appeared to have the most important effect on the heart rate.

Urine analyses

As total urine collections were not carried out no exact information on urine volumes during the experimental period can be reported. Nevertheless, it was clear from observation that the volume of urine and frequency of micturition decreased dramatically during dehydration. Moreover, and perhaps of equal significance, the physical consistency of the urine underwent a marked change. During the first three days of the experiment, when water

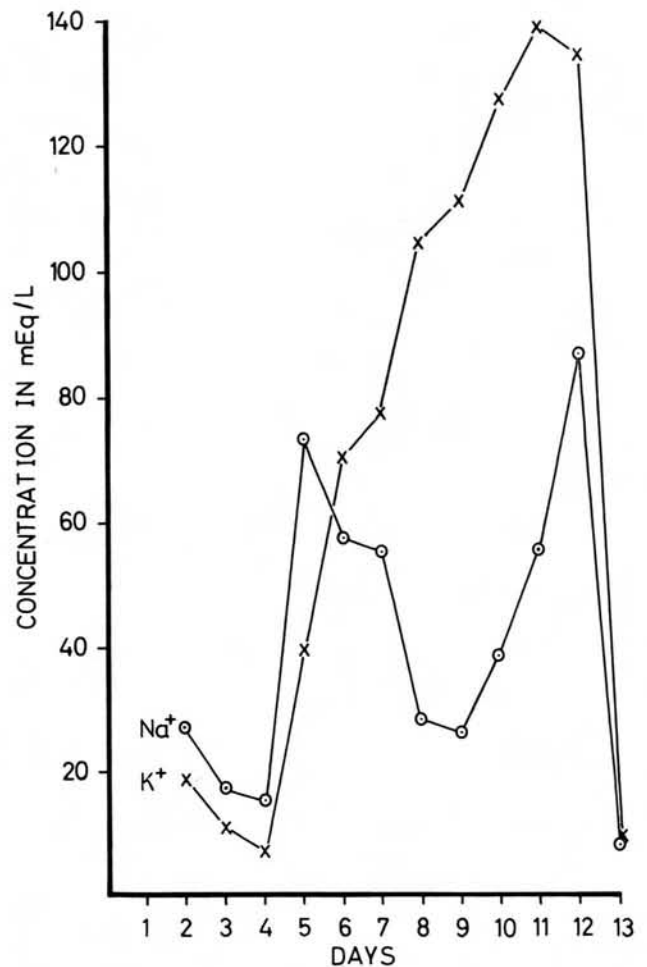


Figure 5: Illustrating mean sodium and potassium concentrations in the urine of three ostriches during dehydration and rehydration. The period of dehydration extended from day 4 to day 12.

was administered, and on the first day of water deprivation the urine was clear, of an aqueous consistency and contained very little undissolved uric acid (0.8 — 1.2 per cent). On day 5, however, the urine became highly viscous with the physical consistency of mucus. The amount of undissolved uric acid in the sample increased by approximately 1,500 per cent over the original percentage and remained at this level with minor fluctuations until the animals were drenched again on day 12. After the undissolved uric acid had been centrifuged down the supernatant was found to consist of brown mucus. The urine retained this consistency from day 5 to the morning of day 12, with the mucus becoming progressively darker. After drenching again on day 12 the urine once more assumed an aqueous consistency with minimal amounts of undissolved uric acid (2.9 per cent) in the sample.

In view of the significance of the above finding, namely, that during dehydration free water is re-

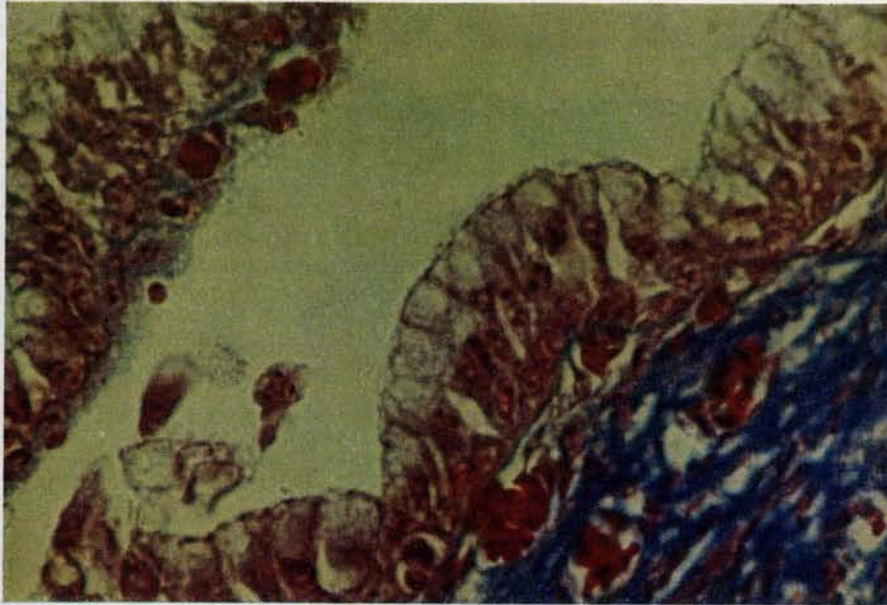


Figure 6: A photomicrograph of a section of the ureter depicting the large amount of goblet cells in the epithelial lining of the lumen. (Mallory Azan stain).

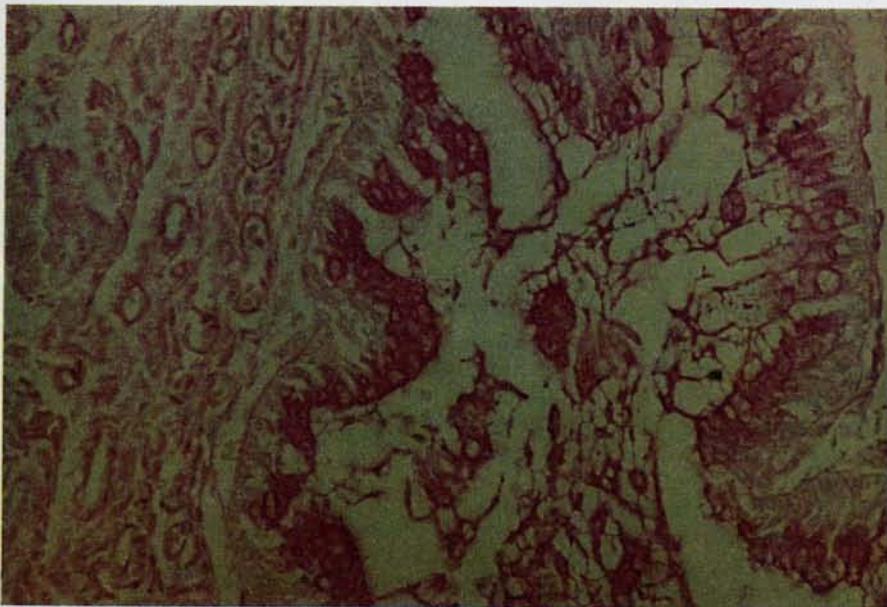


Figure 7: A photomicrograph of a section of the ureter demonstrating the presence of PAS positive mucopolysaccharides in both the epithelial lining and the lumen. (PAS stain).

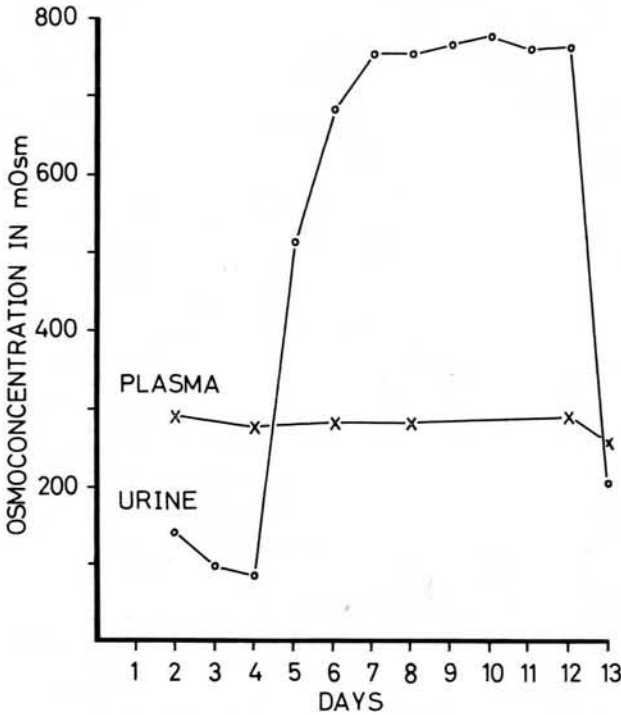


Figure 8: Illustrating the mean plasma and urine osmoconcentration of three ostriches during dehydration and rehydration. The period of dehydration extended from day 4 to day 12.

placed by mucus in the fluid fraction of ostrich urine, histological sections were prepared of the ureter and stained with both Mallory Azan and PAS. Examination of these sections revealed that the epithelial lining of the lumen was extremely rich in goblet cells. PAS staining confirmed the presence of mucopolysaccharides in the goblet cells as well as in the lumen. It appears then that the mucus found in the urine originates, at least in part, from the epithelial lining of the ureter (see photomicrographs, Figs. 6, 7).

The concentrations of sodium and potassium in the urine are graphically presented in Fig. 5 and the osmoconcentration values over the experimental period appear in Fig. 8. The sodium and potassium concentrations declined, as is to be expected, during the period of water administration. On day 5 (second day after water deprivation), however, the concentration of both electrolytes increased sharply and subsequently the concentration of potassium continued to rise steeply to reach a maximum of 139 mEq/L on day 11. In contrast, sodium concentrations fell sharply after the initial rise and remained at this lower level for most of the dehydration period. It was only on days 11 and 12 that sodium concentration increased again, which is not surprising in view of the greatly diminished urine volume at the end of the dehydration period. The above pattern of electrolyte excretion, namely

sharply increasing potassium concentration with declining sodium concentration is highly suggestive of the action of the adrenal cortical hormone aldosterone which, classically, promotes sodium retention and a concomitant increase in potassium excretion. Whereas, the sharp reduction in urine volume was presumably a result of increased anti-diuretic hormone secretion.

The dramatic increase in osmoconcentration of the urine during dehydration contrasts sharply (Fig. 8) with the relatively static osmoconcentration of the plasma over the same period, and highlights the important homeostatic action of the kidney. Nevertheless, it should be noted that the maximum osmoconcentration exhibited by the urine was only 2.7 times that of the plasma.

Faecal moisture

As the dehydration period progressed the faeces became progressively drier and were excreted in the form of hard pellets compared with a moist amorphous consistency during water administration.

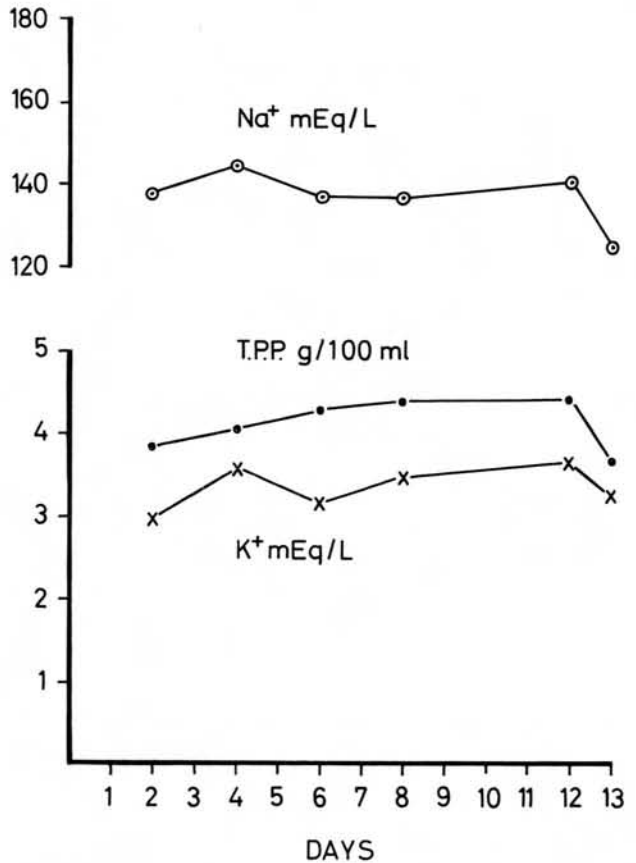


Figure 9: Illustrating the mean plasma values for the sodium, potassium and total plasma protein concentrations of three ostriches during dehydration and rehydration. The period of dehydration extended from day 4 to day 12.



Figure 10: Showing ostriches, in typical desert habitat, engaged in thermoregulation by feather erection and wing drooping. (Photo: Alice Mertens)

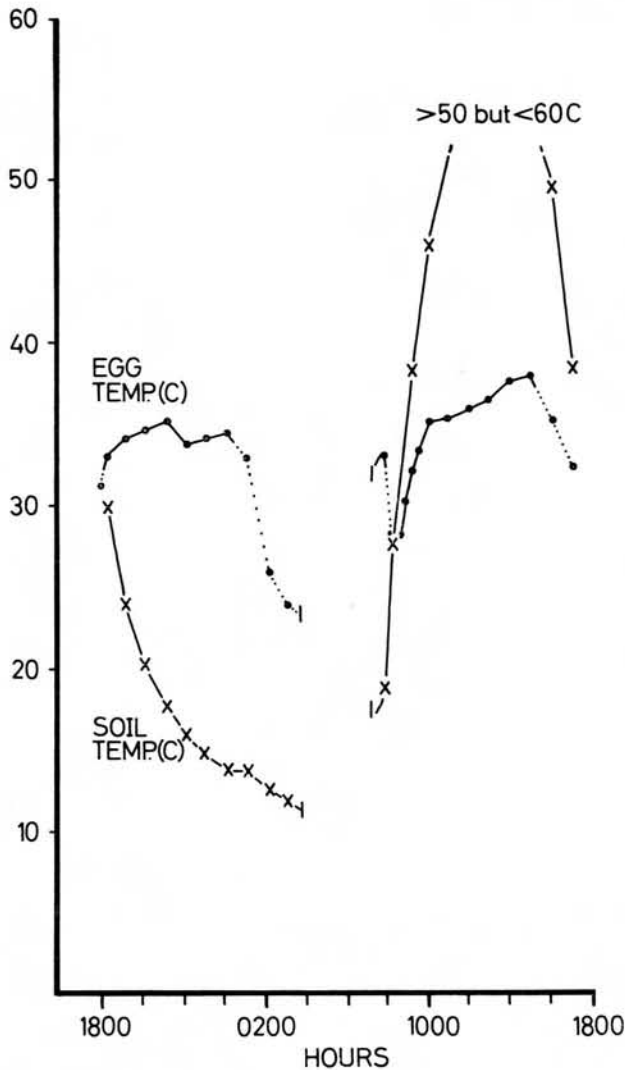


Figure 11: Illustrating the temperature of an ostrich nest, while attended and not attended, in comparison to soil surface temperature immediately adjacent to the nest. The dotted line in the egg temperature curve denotes periods when the nest was unattended.

The mean reduction in moisture content of the faeces during dehydration was ± 18 per cent. This value is, however, not considered very accurate in view of unavoidable but slight contamination of the faecal matter with urine.

Plasma analyses

Plasma levels of sodium, potassium, total plasma proteins and osmoconcentration of the plasma remained remarkably constant during dehydration. It is, however, not surprising that after 8 days of dehydration all these values decreased significantly as a result of the administration of a large amount of water (see Figs. 8 and 9).

Although the above plasma constituents did not vary greatly during dehydration, there was evidence of slight haemoconcentration to be found in the limited but progressive rise in total plasma proteins and a slight increase in haematocrit values. Mean haematocrit values rose during dehydration from 39.2 per cent to a maximum of 41.8 per cent and returned to 38.2 per cent after water had been administered on day 12. In general, however, the plasma analyses illustrate remarkable homeostatic control over the plasma during dehydration.

Electrophoretic analysis of the plasma proteins showed no significant change in the relative percentages of albumin and globulin during dehydration. The overall mean obtained for albumin was 32.8 per cent and 67.2 per cent for globulin.

Thermoregulatory behaviour

Apart from feather erection discussed previously, the birds exhibited an additional behavioral reflex under conditions of high ambient temperature. This consisted of moving the wings forwards and downwards, away from the body (see Fig. 10). This procedure was observed very frequently and exposed the rib cage and thighs bilaterally, which are without any feathers. In this way heat loss by convection and radiation is greatly facilitated. Incidental observations also showed that young chicks utilized the shade created by wings, which had been extended in this manner on hot days.

In contrast to the above behaviour pattern, the birds folded their wings close to the body when low ambient temperatures prevailed. After sunset and shortly before darkness fell, the birds lay down and if undisturbed would remain so until shortly before sunrise. In this way the closely folded wings and flattened feathers provide efficient insulation against low ambient temperatures at night, which are a feature of the desert climate.

A further example of the efficient thermoregulation exhibited by the ostrich is found in a comparison of soil surface temperature and nest temperature illustrated in Fig. 11. These data clearly illustrate how thermoregulation in the nesting bird effectively insulates the eggs from marked change in soil temperature, in contrast to the fluctuating temperatures recorded in the unattended nest.

Body weights

The birds were weighed at the beginning of the experimental period and at the end after they had been rehydrated with an amount of water equal to 10 percent of their original body weight. The mean loss in weight over this period was 5.7 kg which in all probability was largely due to the low feed intake and nature of the ration. Nevertheless, it should be noted that great difficulty was experienced in weighing the ostriches accurately because of their excitable nature, and no great significance can be attached to the above result.

DISCUSSION AND CONCLUSIONS

Renal function

A feature of renal function was the marked decline in urine volume and concomitant increase in osmoconcentration during dehydration, indicating efficient antidiuretic hormone control in the ostrich. Moreover, the pattern of electrolyte excretion points to increased release of aldosterone during the same period. The maximum osmoconcentration exhibited by the urine (2.7 times that of the plasma) is, however, not excessively high, particularly when compared with various desert mammals (Chew, 1965). Of greater interest was the disappearance of free water from the fluid fraction of the urine which was replaced by viscous mucus during dehydration. Moreover, the abundance of PAS-positive goblet cells found in the epithelial lining of the ureter would seem to indicate that this mucus originates, at least in part, from this source. It appears, then, that under conditions of dehydration the obligatory nitrogen excretion, in the form of undissolved uric acid, is facilitated by the lubricating effect of this mucus. The fact that nitrogen is excreted as uric acid represents a significant saving of water *per se*, and the use of mucus and not free water as lubricant for the expulsion of the uric acid may represent a further important water saving mechanism. It is not known whether this copious mucus secretion occurs in other birds.

It has been suggested (Crawford and Schmidt-Nielsen, 1967; Cloudsley-Thompson and Mohamed, 1967) that the nasal glands of the ostrich may contribute to the water economy of the bird during water deprivation. No experimental evidence has, as yet, been advanced in support of this hypothesis. Moreover, in spite of efficient renal function, outlined above, it appears that the ostrich cannot exist indefinitely on dry feed without additional water. In the present investigation feed intake declined sharply during the latter part of the dehydration period and on day 11 two of the three birds refused to feed. Cloudsley-Thompson and Mohamed (1967) came to a similar conclusion when studying the effect of water deprivation on feed intake and body weight. Under natural conditions, however, the ostrich can frequently find sufficient succulent plant material to be independent of free water. Alternatively, under dry feeding conditions the speed and mobility of the bird ensures that it can travel long distances between grazing areas and a suitable water supply. Moreover, as shown by Cloudsley-Thompson and Mohamed (1967), the ostrich is able to maintain its body weight while drinking saline water (20 per cent sea water or 0.2M NaCl) and can easily withstand a loss of 25 per cent of its body weight during dehydration, which is remarkably high.

Heart rate

The most interesting feature of the heart rate data was the relatively slow heart rate exhibited by the ostrich, particularly during the night. As heart rate is closely associated with metabolic rate, it would appear, then, that metabolic rate at night proceeds at a relatively slow rate. The insulating effect of the tightly folded wings and huddled posture of the ostrich during the night facilitates thermoregulation and makes it unnecessary for the metabolic rate to be raised to meet the demands of low ambient temperatures, which are typical of the desert night. A low metabolic rate, in turn, would be of considerable advantage to any desert animal for purposes of nutrient conservation on the highly variable nutritional plane encountered in the desert. It was therefore not surprising to find that ostriches, which had been on a high nutritional plan for a relatively short period, deposited large amounts of subcutaneous fat over the sternum. The importance of the above argument in terms of desert survival is, however, still highly speculative.

Thermoregulation

Under the conditions of this experiment, during which the maximum ambient temperature did not exceed 40° C and the relative humidity cycled daily between ± 40 per cent at noon and ± 90 per cent at 05.00 hr., the ostrich was found to be an excellent thermoregulator. The range of body temperatures in which most values fell (38.2 — 39.8° C) is in agreement with the mean body temperature (39° C) established by Crawford and Schmidt-Nielsen (1967) and the diurnal cycle which was established is very similar to that found by Blight and Hartley (1965) when using radiotelemetric methods on an unrestrained wild ostrich. The range in body temperature which was recorded is, however, considerably lower than in most other birds. The ostrich therefore does not enjoy the advantage of a high temperature which would minimise the temperature gradient between the body and the atmosphere when the latter exceeds the former.

Of greater significance, however, is the fact that the birds made maximum use of convective and radiant cooling through feather erection and wing drooping. Feather erection for cooling purposes may be unique for the species. Only as a last resort, when the ambient temperature approaches 34° C (screen temperature 31° C) and when there is no wind will the birds resort to evaporative cooling by increasing the respiration rate abruptly from a normally slow rate to a rapid oscillating type of respiration. Crawford and Schmidt-Nielsen (1967) estimated that the critical threshold for the above change in respiration rate was 25° C. Their investigation was, however, carried out in an artificially heated room where apparently opportunity for

convective cooling was minimal. The threshold of $\pm 31^{\circ}$ C established in the present investigation seems more realistic as temperatures of 25° C are very frequently encountered under desert conditions. Moreover, as the results indicated, the threshold of 31° C may well be increased considerably under windy conditions. It should also be noted that Schmidt-Nielsen *et al.* (1967) have shown that high respiratory rates in the ostrich, even if sustained for 8 hours, did not induce respiratory alkalosis in the birds. They concluded that under these conditions "a functional shunt system permits a regulated by-pass of the lungs" while increasing air circulation through the air sacs.

In final summary, then, the ostrich appears to be physiologically well adapted to desert survival. Moreover, certain behavioral reflexes are important in enhancing this physiological adaptation.

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