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CUTANEOUS EVAPORATION IN HEAT-STRESSED SPOTTED SANDGROUSE[1]

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Many species of desert birds are relatively small (<500 g), diurnally active ground dwellers that are naturally exposed to high ambient temperatures (T_a) and low relative humidities (*RH*). Sandgrouse (Pteroclididae), being small birds (weighing between 200 and 400 g) having a relatively high standard metabolic rate (*SMR*), would have to possess an effective mechanism for dissipating heat.

Spotted Sandgrouse (*Pterocles senegallus*), like other species of the Pteroclididae, are successful desert birds (Thomas 1983, Maclean 1984). Thomas and Robin (1977) reported that in incubating female sandgrouse (*P. senegallus, P. coronatus, P. alchata*) neither gular-fluttering nor gaping were observed in birds exposed in the open to 40 to 50°C T_a. This strongly suggested that body and egg cooling could be achieved only if a very efficient cutaneous evaporative water loss (*CEWL*) mechanism existed in incubating sandgrouse.

Certain birds evaporate considerable amounts of water via the skin (Bernstein 1969, 1971a, b; Smith and Suthers 1969; Marder and Ben-Asher 1983), a mechanism that appears to be important for survival under extremely hot ($T_a > 45$°C) environmental conditions (Marder 1983). Since the Spotted Sandgrouse is active during hot summer days (Thomas and Robin 1977), one can hypothesize that this bird has special thermoregulatory capabilities. To test this, we studied *CEWL* in this bird exposed to high T_a.

MATERIAL AND METHODS

Six adult Spotted Sandgrouse, three females and three males, were trapped during the winter in the southern Negev Desert of Israel, about 80 km south of Beer Sheba. Mean body mass was 260 g (±17 SD). The birds were kept in a 1 m³ cage inside a temperature-controlled room (16L:8D) where food and water were freely available. The front wall of the cage was covered with black cloth, enabling the investigator to move freely outside the cage. In order not to disturb the birds, especially at high T_a, all activities inside the cage were carried out in darkness.

Under these conditions we exposed the birds daily to a series of temperatures between 27 and 51°C. On a few occasions T_a was elevated to 60°C for two hours. For five weeks, birds were exposed on six days per week to 8 hr of elevated air temperatures. Skin temperatures (T_s) were determined with a calibrated YSI 24-gauge hypodermic probe (No. 524), the edge of which was lightly pressed to the skin so that about half the needle shaft was in contact with the skin. The probe was attached to the skin for several seconds until stable readings were reached. We measured skin temperatures during or immediately after skin resistance measurements were completed. Body temperature (T_b) measurements were taken last in this series. They were carried out by quick insertion of the hypodermic probe parallel to the vent through the lower intestinal tissue to a depth of 3 to 5 cm. The use of the needle probe enabled rapid and accurate measurements. Our preliminary experiments have shown that the procedure used for T_b measures core tissue temperature and avoids puncturing the abdominal air sacs. We determined cutaneous evaporation by measuring skin resistance to vapor diffusion using Lambda Instrument Li-Cor Model Li-700 Transient porometer (diffusive resistance meter). Measurements were done by gently pressing the sensor head on about 6 cm² of breast skin (feathers from this spot had been plucked two weeks earlier). The instrument, equipped with a quick response Vaisala humidity sensor, makes possible rapid (15 to 20 sec each) and accurate readings; in addition it enables high resolution (±0.05 sec cm^{-1}) within a diffusive resistance range of 0.5 to 20.5 cm^{-1}. Instantaneous temperature readings of both the humidity sensor and evaporating surface were taken using built-in thermister probes. Calibration and measurements were done under isothermal conditions. The calibration plate temperatures were regulated to those measured by the porometer humidity sensor. During measurements the porometer temperature was adjusted close to T_a (±1°C). Cutaneous evaporation can be calculated when the following values are known: (1) the resistance to diffusion of vapor through the skin, r_s, (2) feather coat resistance, r_f, (3) air resistance, r_a, (4) skin surface vapor density, (5) T_s, and (6) T_a (Monteith 1973, Cena and Monteith 1975, Campbell 1977).

Most measurements were done on six birds. The results are presented as means ±SD. Further details of measuring procedures and calculations have been reported elsewhere (Marder and Ben-Asher 1983).

RESULTS AND DISCUSSION

During long term experiments (6 to 8 hr each), T_b varied between 41.4 ± 0.6 and 42.6 ± 0.5°C at T_a of 27, 42, 45, and 51°C, respectively (Table 1). In these experiments, birds were exposed for 2 to 3 hr to each T_a. Stable T_s of 42.0 ± 0.8°C was measured in five birds after 240-min exposure to 51°C and low *RH* (<10%). Skin temperatures were always lower than T_b, by between 1.1 and 0.5°C at T_as between 27 and 51°C T_a, respectively. Similar phenomena have been observed in Rock Pigeons (*Columba livia*) exposed to moderate and high T_a 30 to 50°C (Marder and Ben-Asher 1983, Webster et al. 1985).

High frequency panting and gular-fluttering (>300 min^{-1}) were observed at T_a of 40 to 60°C. In two survival tests, birds were exposed for 240 min to 51°C and for 120 min to 60°C (*RH* < 10%). In each case, the sandgrouse stood quietly during the entire test, and showed no behavior suggesting the onset of a critical situation.

The rate of skin evaporation of the sandgrouse at 27°C was 1.6 mg H_2O cm^{-2} hr^{-1}, and the corresponding resistance value was 103.0 sec cm^{-1} (Table 1). During heat stress, resistance decreased to 20.5, 13.5, and 15.0 sec cm^{-1} and water evaporation increased to 11.1, 14.3, and 13.6 mg H_2O cm^{-2} hr^{-1} at T_a of 41, 45, and 51°C, respectively. The values for *CEWL* were calculated from measurements of skin resistance to vapor diffusion determined on unfeathered skin of the pectoral region. However, the actual evaporation may be lower by about 30% if the resistance

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TABLE 1. Body temperature (T_b, °C), skin temperature (T_s, °C), skin resistance to vapor diffusion (r_s, sec cm^{-1}), and skin evaporation (E_s, mg H_2O cm hr^{-1}) of six* Spotted Sandgrouse exposed to high ambient temperatures (T_a). Measurements were made after five weeks of acclimation.

T_a	T_b	T_s	$T_b - T_s$	r_s	CEWL
27	41.4 ± 0.6	40.3 ± 0.2	1.1 ± 0.3	103.0 ± 26.0	1.6 ± 0.4
42	42.0 ± 0.2 (4)	41.3 ± 0.6 (4)	0.7 ± 0.5 (4)	20.5 ± 12.3 (4)	11.1 ± 6.5 (4)
45	42.4 ± 0.3	41.6 ± 0.4	0.8 ± 0.2	13.5 ± 4.3	14.3 ± 5.2
51	42.6 ± 0.5	42.1 ± 0.6 (10)	0.5 ± 0.3	15.0 ± 5.7 (10)	13.6 ± 5.1 (10)

* Number of data obtained on less or more than six exposures are given in parentheses.

of the feathers and the air boundary layer are taken into account.

Of six birds exposed to heat stress, only one evaporated water at a stable rate. In four heat-stress trials at 42, 45, and 51°C T_a, the resistance and evaporation values for bared skin were $r_s = 8.6 \pm 0.7$ sec cm^{-1} and $CEWL = 19.8 \pm 1.9$ mg H_2O cm^{-2} hr^{-1}. For feather-coated skin the corresponding values were 10.6 sec cm^{-1} and 15.9 mg H_2O cm^{-2} hr^{-1}. These data are close to those measured in pigeons exposed to 52°C (Marder and Ben-Asher 1983). We anticipate that, with improved experimental conditions, a better evaluation of the cutaneous cooling mechanism of the sandgrouse would be achieved.

Hyperthermia appears routinely to accompany sustained vigorous activity in birds (Bernstein 1982). Hyperthermia in resting birds is widely believed (see Dawson 1984) to represent an efficient mechanism for dissipating dry heat. Our observations (carried out at T_a 45 to 50°C) on a variety of small birds suggest an alternative interpretation of hyperthermia. Under conditions of extreme heat stress, when T_b cannot be stabilized, it appears equally likely that hyperthermia may develop as a consequence of the insufficient capacity of the evaporative cooling system to dissipate both metabolic and external heat. This view is further supported by previous (Thomas and Maclean 1981) and present investigations where T_b between 40 and 42.5°C have been observed in desert sandgrouse even after prolonged exposure to $T_a > 50$°C. The absence of marked hyperthermia (41.2 to 42.4°C T_b), at T_as of 45 to 50°C, was also observed in acclimated pigeons (Marder and Gavrieli-Levin, unpubl.).

The present findings and previous studies (Marder 1983) support the view that cutaneous water evaporation in desert sandgrouse and pigeons is an important mechanism for surviving hot environmental conditions.

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