tivation analysis (11) revealed that liver and sausage contained 0.17 and 0.072 ppm, respectively (the detection limit of the atomic absorption spectrophotometer is 0.3 ppm for a 20-g sample of tissue with a volume reduction of 4.0 to 5.0 ml). The present U.S. Food and Drug Administration tolerance limit for mercury in meat products is 0.5 ppm.

The concentrations of mercury in serum, urine, and cerebrospinal fluid were determined in samples from the human victims. Urine samples obtained from Mr. H., his son (age 13), and his two daughters (ages 8 and 20) on 8 January contained, respectively, 0.16, 0.21, 0.20, and 0.06 ppm of mercury. Concentrations of mercury in the urine samples of the neighbors varied from < 0.05 to 0.18 ppm (33 samples); the content of mercury in the serum samples of the neighbors averaged < 0.2ppm (38 samples). After treatment with British Anti-Lewisite, the concentrations of mercury in the urine samples of Mr. H.'s son and older daughter (age 20) had increased to 0.50 and 0.49 ppm, respectively [the concentration of mercury in the urine of Mr. H.'s younger daughter (age 8) was < 0.03 ppm]. Concentrations of mercury in the serum samples of these children were approximately 16 times those in the urine. The concentrations of mercury in the serum and cerebrospinal fluid of Mr. H.'s son were about the same (3.0 ppm). The urine of Mrs. H., who was pregnant at onset of the children's illness, contained 0.09 ppm of mercury on 8 January and 0.18 ppm on 11 February; her serum contained 2.91 ppm of mercury on 22 January and 0.47 ppm on 11 February. The amniotic fluid contained < 0.02ppm of mercury on 11 February. Concentrations of mercury in the newborn baby's urine ranged from 2.70 ppm at delivery to 1.56 ppm several days later. These concentrations of mercury indicate placental transfer to the fetus.

The mercury, identified by atomic absorption spectrophotometry, was confirmed as organic mercury by mass spectrometry (Fig. 1); these results substantiated the clinical diagnosis of organic mercury poisoning. The dye coating on the waste seed grain was isolated by column chromatography; it absorbed at 5440 Å. This dye was identical to that in commercial samples of Panogen and Ceresan. The extracts from the waste seed grain prepared by the method of Westöö contained, ac-

cording to mass spectral analysis, characteristic Hg+, methyl Hg+, methyl HgCl+ (chloride from the analytical procedure), ethyl Hg+, and probably methoxyethyl Hg+ isotopic ion clusters at m/e (mass-to-charge ratio) 202. 217, 231, 237, 252, 281, and 296. Other mercury-containing organic ions were observed at m/e 329, 344, and 358

These data clearly show that mercury accumulated in animal tissues and human body fluids and confirm that compounds containing organic mercury were, in fact, the causative agents in the poisoning incident. The changes in the mercury concentrations in the serum and urine of the mother after delivery and the content of mercury in the urine of the newborn baby indicate placental transfer.

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- We thank M. E. McLain, Jr., Nuclear Research Center, Georgia Institute of Technology, Atlanta, for neutron activation analyses.
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   Chen Detection and Science and Sci
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- Glass chromatographic columns, 8 mm 14. in diameter, were packed with 4.0 cm of silica gel (Woelm), grade 1, below 2.0 cm of anhy-drous sodium sulfate. The columns were wet benzene before introduction of from the extract was eluted with about 14 ml of benzene and 5 ml of acetone and then an additional 1 ml of acetone. The second acetone fraction containing the dye was was evaporated. The lected and the acetone was evaporated. The red dye was dissolved in methanol, and its absorbance was determined on a Cary model 4 recording spectrophotometer.
- 15. The Micro-Tek model MT 220 gas chromatograph was equipped with tritium electroncapture detectors for chlorinated compounds and dual flame photometric detectors for phosphorus and sulfur. 16. We thank Mrs. E. Gray for her assistance
- with the statistics and receipt of samples. Present address: Yale University Hospital, New Haven, Connecticut.

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## **Roadrunners: Energy Conservation by Hypothermia** and Absorption of Sunlight

Abstract. Roadrunners sunning in artificial sunlight consume oxygen at standard (basal) levels at ambient temperatures as low as 9.0°C. Energy savings of sunning roadrunners averaged 551 calories per hour. In the dark, birds may undergo hypothermia. Hypothermic roadrunners can elevate their body temperatures to normal levels by sunning, at reduced metabolic cost.

One of the most dependable sources of energy in the desert is solar radiation. Small birds exposed to artificial sunlight have been shown to reduce energy expenditures (1, 2). Although the hypothesis (1) that sunlight directly affects avian heat budgets has

broad implications, the actual ecological role of this phenomenon has yet to be evaluated for any bird. We examined this hypothesis for the roadrunner (Geococcyx californianus) because these desert residents frequently sun themselves in the field and in captivity



Fig. 1. General appearance of the desertdwelling roadrunner (*Geococcyx californianus*) in the normal posture (above) and during sunning behavior (below).

during the early morning hours and intermittently on cool clear days. We have never observed roadrunners exhibiting this particular sunning behavior (Fig. 1) when the ambient temperature  $(T_a)$  was in or above their zone of thermoneutrality. Their sunning behavior, combined with an unusual pattern of cutaneous pigmentation, suggests that absorption of sunlight is important to this species.

When a roadrunner assumes the sunning posture (Fig. 1), the back is oriented perpendicularly to the incoming sunlight, the wings are slightly drooped and held away from the body, and the cervical plumage is erected in a manner that exposes the black skin of the interscapular apterium and the soft black plumage of the dorsal spinal tract. The black skin and soft black plumage is covered by the scapular feathers and wings when the birds are not sunning. Unlike that of most desert birds, the skin of the featherless nestling is deep black, except for a pink interramal region. Adult skin is pink ventrally but varying shades of gray to black dorsally, except for the pink feather tracts (Fig. 2).

Six adult hand-reared roadrunners (average weight and standard deviation, 294.6  $\pm$  33.5 g) were maintained in an outdoor aviary and given free access to a diet of white mice. Oxygen consumption ( $\dot{V}_{O_2}$ ) was measured by open flow respirometry (3) in birds fasted overnight, with experimental techniques

similar to those of Hamilton and Heppner (1). A Lucite chamber (26 by 26 by 70 cm) with a removable window (Corning CS 9-54 Glass, 8 by 9 cm) which transmitted ultraviolet light, was immersed in a 50-gallon, temperaturecontrolled water bath. Artificial sunlight, approximating early morning intensities in the desert  $(0.80 \pm 0.15 \text{ cal})$  $cm^{-2}$  min<sup>-1</sup>), was directed into the chamber from paired Sylvania DWY Sun-Gun lamps positioned above the window (4). Radiation intensity was determined under experimental conditions before and after each sunning measurement (5). Dry air free of CO<sub>2</sub> and flowing at

2500 cm<sup>3</sup>/min was introduced at one end of the chamber and removed from the opposite end by a series of concentrically placed small openings to minimize response times. A sample of the effluent air was directed through  $H_2O$  and  $CO_2$  absorbants before oxygen analysis (3). Oxygen consumption was calculated from the rate of air inflow and the difference in oxygen concentrations of the inflowing and outflowing air (both dried and free of  $CO_2$ ). Gas volumes are corrected to standard temperature and pressure. Temperatures of the bird, bath, and several locations in the metabolic chamber were monitored continually (6). Body temperatures  $(T_{\rm b})$  were recorded by a thermocouple inserted 2 to 3 cm into the cloaca, the lead of which was secured to the rectrices.

A roadrunner was positioned in the darkened metabolic chamber below the glass window, and resting metabolism was determined when  $\dot{V}_{O_2}$  had stabilized. Artificial sunlight was then directed through the glass window, and  $\dot{V}_{O_2}$  was measured for posturing birds.

At ambient temperatures  $(T_a)$  above 10°C, mean  $T_{\rm b}$  of normothermic birds resting in the darkened chamber was  $38.4^{\circ} \pm 0.4^{\circ}$ C (N = 8). However, below 10°C the roadrunners significantly reduced their  $T_{\rm h}$  to hypothermic levels of  $34.3^{\circ} \pm 1.3^{\circ}$ C (N = 6). During sunning behavior, the  $T_{\rm b}$  of hypothermic birds rose to normothermic levels, whereas the  $T_{\rm b}$  of normothermic birds did not increase. Further support for the existence of hypothermia in well-fed roadrunners was obtained from measurements on three birds which were maintained in outdoor cages and were not handled for 2 weeks (7).

The  $\dot{V}_{O_2}$  of normothermic roadrunners in the dark (Fig. 3, closed triangles) closely approximated values reported earlier (8; Fig. 3, dashed line). Our mean value for standard metabolism (9) of  $0.77 \pm 0.15$  cm<sup>3</sup> g<sup>-1</sup> hr<sup>-1</sup> (N = 5) was lower than, but did not differ significantly from, the mean value of  $0.92 \pm 0.09$  cm<sup>3</sup> g<sup>-1</sup> hr<sup>-1</sup> reported by Calder and Schmidt-Nielsen (8). When normothermic roadrunners sunned in artificial sunlight at  $T_a$  between 9.0° and 22.0°C, their  $\dot{V}_{0_2}$  was reduced to standard metabolic levels (six lowest closed circles in Fig. 3).

Hypothermic roadrunners in the dark reduced their  $\dot{V}_{O_2}$  below values predicted for normothermic birds at the respective  $T_a$  (8) by an average of  $0.39 \pm 0.12$  cm<sup>3</sup> g<sup>-1</sup> hr<sup>-1</sup> (Fig. 3, open triangles). When hypothermic roadrunners sunned in artificial sunlight, their  $T_b$  rose to normothermic levels, while their  $\dot{V}_{O_2}$  remained at levels characteristic of hypothermic birds in the dark (six highest closed circles in Fig. 3).

A variety of birds exhibit spread-wing postures (10), often described as sunning. The potential thermoregulatory advantages of the sunning behavior have been recognized, although direct experimental support has been lacking. Heath (11) proposed that early morning sunning by turkey vultures (*Cathartes aura*) may facilitate increasing  $T_{\rm b}$ , as our data indicate for roadrunners. Hypothermia has been re-



Fig. 2. Schematic illustration of the dorsum of adult roadrunners to show the degrees of cutaneous melanization (dark-ened areas) and the feather tracts (stippled areas).



Fig. 3. Relation between oxygen consumption and ambient temperature in adult roadrunners. The dashed line is from data of Calder and Schmidt-Nielsen (8). Symbols:  $\blacktriangle$ , in dark;  $\triangle$ , in dark, hypothermic; •, posturing in "sun."

ported for a number of desert-dwelling birds (12), although the roadrunner is one of the largest species in which this phenomenon has been adequately demonstrated.

Our results confirm the hypothesis of Hamilton and Heppner (1) that birds may utilize sunlight to reduce their energy expenditures because substantial energy savings were observed in sunning roadrunners. Under the conditions of our study, the average energy saving was 551 cal  $hr^{-1}$  (13), an amount equivalent to 41 percent of the standard metabolism predicted for a 294.6-g bird (14).

Heppner (15) suggested that in zebra finches (Poephila castanotis) dyed black and exposed to artificial radiation "warming of the outer feathers . . . reduces the temperature gradient from the skin of the bird to the surface feather, and thus slows the loss of metabolic heat to cold surroundings." This mechanism may operate in the exposed soft black plumage of sunning roadrunners. However, sunning roadrunners also expose the naked black skin of the interscapular region, and this area appears to absorb solar radiation directly. In birds that are not sunning, the naked skin is insulated by the plumage of the cervical and scapular tracts.

Previous studies of thermoregulation, evaporative water loss, and metabolism of roadrunners have been interpreted as indicating that the species is no better adapted to desert conditions in these functions than pigeons and doves (8, 16). Recent data indicate that roadrunners possess a number of physiological specializations which are advantageous for a desert existence; these include a salt-secreting nasal gland (17), a capacity for water conservation when water is limited (18), and adaptations for energy conservation through hypothermia and solar absorption.

The fact that selective forces have produced such specialized behavior and morphology for absorption of sunlight by roadrunners indicates that this phenomenon has ecological significance. Sunning behavior could effectively substitute calories from solar input for those derived from biochemical processes. The inability of roadrunners to make sustained flights to gather food combined with the reduction of insect numbers in the winter months must exert considerable selective pressure for energy conservation. Bryant (19) reported that vegetable materials in the diet of roadrunners increased from 3 to 10 percent during the winter months. Thus, even though sunning occurs throughout the year, it is probably most important during the winter when the productivity of the desert is low.

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## Structure of the Hinge Region of the Mu Heavy Chain of Human IgM Immunoglobulins

Abstract. The amino acid sequence around the central disulfide bridge linking the mu heavy chains of the human immunoglobulin M monomer is unlike that in immunoglobulin G. This hinge area contains one of the five oligosaccharides of the mu chain, is low in proline, and is the site of tryptic cleavage to yield Fabµ and Fcµ fragments.

Immunoglobulins of the three major classes (IgG, IgA, and IgM) have a common tetrachain structure composed of a pair of heavy chains ( $\gamma$ ,  $\alpha$ , and  $\mu$ , respectively) and a pair of light chains ( $\kappa$  or  $\lambda$ ), but IgG, IgA, and IgM differ from each other in many properties because each heavy chain has a characteristic sequence in its constant region (1). For example, owing to an intersubunit disulfide bridge on the  $\mu$  chain, IgM exists predominantly as a 19S pentamer of the tetrachain subunit, while IgG, which lacks such a bridge, is a 7S monomer. Whereas human IgG is very susceptible to limited cleavage by papain at 37°C to vield two well-defined pieces (Fab and Fc) (2), human IgM is rapidly degraded to heterogeneous fragments and peptides (3). This difference is attributable to the nature of the primary and tertiary structure of the two proteins especially in that portion of the heavy chain (the hinge region) that couples the Fd and Fc segments of each of the two classes of heavy chains ( $\mu$  in IgM and  $\gamma$  in IgG). The hinge region has been operationally defined as a section near the middle of the heavy