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Resting metabolic rate of Golden Eagles, Bald Eagles, and Barred Owls with a tracking transmitter or an equivalent load.—Solar-powered transmitters weighing 160–190 g have been used to track eagles and other larger birds by satellite (Strikwerda et al. 1986). This transmitter load, attached to the back of a bird, may increase the bird's resting metabolism by requiring greater tension in postural and leg muscles to support the additional weight, by increasing heat loss on the bird's dorsal surface in contact with the transmitter, or by increasing the stress level of the bird. Because the Bald Eagle (*Haliaeetus leucocephalus*) uses 90% of its daily energy when perched (i.e., during rest, Stalmaster and Gessaman 1984), even a small increase in the rate of resting metabolism would significantly increase daily energy expenditure and food energy requirements of the bird. We examined the effect of dorsally mounted loads on the resting metabolism of Bald Eagles, Golden Eagles (*Aquila chrysaetos*), and Barred Owls (*Strix varia*) in a series of three experiments over two years. The results from each experiment were used to improve the design of the next experiment; therefore, the methodology differs somewhat among the three experiments.

Methods.—The rate of oxygen consumption ($\dot{V}O_2$) of two Golden Eagles perched outdoors in a small aviary (2.6 × 2.6 × 4.0 m) was measured several nights in December, 1986, with and without a radio transmitter harnessed on their backs. The two eagles (GE1, body mass [M_b] = 4.3 kg; GE2, M_b = 3.9 kg) had been kept outdoors in a large fenced area at the Willow Park Zoo, Logan, Utah, for four years and were transferred to the smaller aviary at the zoo a few days before the metabolic measurements. The birds were fitted with a falconer's hood modified with an outlet tube (see Fig. 16.5 in Gessaman 1987) so $\dot{V}O_2$ could be monitored continuously by withdrawing air from the hood through tygon tubing. The tubing led into a heated building adjacent to the outdoor aviary and conducted the air in series through a H_2O absorber (Drierite), a diaphragm pump, a flowmeter (a rotameter), a CO_2 absorber (Ascarite), a H_2O absorber (Drierite), and an O_2 analyzer (Ametek S-3A) calibrated with atmospheric air. $\dot{V}O_2$ of a bird was computed from Eq. 4b of Withers (1977) and converted to rate of energy metabolism (H_m in W/kg) using the factor 19.8 kJ/L O_2. The eagle wore the hood for a few days before the $\dot{V}O_2$ measurements to habituate it to the hood.

During the $\dot{V}O_2$ measurements the eagle was perched either on the ground or on a log in the aviary. An eagle was harnessed with a transmitter several hours before the start of $\dot{V}O_2$ measurements in the evening. Some nights $\dot{V}O_2$ was monitored from 18:00 to 23:00 h with the transmitter on the bird. On other nights $\dot{V}O_2$ was monitored for two to three h with the transmitter on the bird and for another two to three h without the transmitter. In the second protocol the mean $\dot{V}O_2$ during the last hour of each of these two periods was stable and therefore was used in the subsequent analysis. Air temperature in the aviary was measured with a mercury-in-glass thermometer.

A harness that attached the transmitter to an eagle was worn during all $\dot{V}O_2$ measurements (i.e., with and without a transmitter attached). The harness was constructed of two loops of insulated 14-gauge solid copper wire, one loop fitting around the base of the neck, the other fitting around the body just posterior to the wings. The two loops were connected by similar wires running along the keel. The transmitter was secured to the bird with hooks and swivels attached to the dorsal part of the harness loops. The transmitter, developed by The Johns Hopkins Univ. Applied Physics Laboratory for tracking large birds using satellites (Strikwerda et al. 1986), measured 8.0 × 5.5 × 3.5 cm, weighed 192.5 g, and was solar-powered.

We measured heat flux density between the dorsal surface of the eagle and the overlying transmitter with a heat flux sensor (Thermonetics HA12-18-5-P). Heat flux density was measured with and without a 1 mm thick sheet of Goretex gasket material (manufactured from expanded or foamed P.T.F.E.) glued to the surface area of the transmitter (44 cm^2) in contact with the eagle. We measured heat flux density from the eagle in the absence of a transmitter by gently pressing the transducer against the dorsal surface of the bird.

A second experiment was designed: (1) to increase the number of mean $\dot{V}O_2$ measurements on each bird with and without an attached transmitter (4 to 6 for each condition), (2) to control air temperature, (3) to measure $\dot{V}O_2$ without using a hood, and (4) to obtain measurements of resting metabolism during the day, the bird's normal active period.

The resting metabolism of one immature (3.9 kg) and one adult (3.7 kg) Bald Eagle was measured with the birds unhooded inside a metabolic chamber in a temperature-controlled room at Utah State Univ. (USU). One side of the metabolic chamber (91.4 × 45.7 × 58.4 cm) was clear plastic, and the other sides were plywood. A perch covered with artificial turf was positioned 9 cm above the floor of the chamber; the bird's tail feathers just touched the floor. $\dot{V}O_2$ was recorded for 24 h at 0° and 15°C, with and without a transmitter attached to the bird's back. A transmitter was secured to the dorsal surface of an eagle using teflon ribbon (5 mm wide) in an X-attachment design (Snyder et al. 1989), i.e., an anterior neck loop and a loop posterior to the wings were joined over the keel of the bird. The longest axis of the transmitter was aligned with the anterior-posterior axis of the bird. The transmitter extended 3.5 cm above the dorsal surface. The eagles were housed outdoors in a large fenced area at the Willow Park Zoo, Logan, Utah, and were transported to USU for 48 h for the $\dot{V}O_2$ measurements. Lighting in the chamber was controlled on a 12:12 photoperiod, lights turned on at 08:00 h (typical of the outdoor photoperiod at the time of the measurements).

In a third experiment, the equipment used in Exp. 2 also was used at the Raptor Center at the Univ. of Minnesota to measure $\dot{V}O_2$ of two captive Barred Owls. The owls were held at 20°, 0° and −20°C and were harnessed with three different loads: (1) an empty backpack weighing about 2% of the bird's body mass, (2) a backpack and lead weights inside weighing 5% of M_b, and (3) a backpack and lead weights inside weighing 10% of the M_b. A teflon ribbon harness, like that in Exp. 2, was used to hold a nylon sack on the bird's back. The sack was about 9.5 × 6.5 × 3.5 cm, weighed 15 g, and had a velcro flap closure on the top. Lead weights were added through the closure to adjust the load to 5% or 10% of each owl's M_b.

During a $\dot{V}O_2$ measurement, the unhooded owl perched inside a metabolic chamber (the same chamber used in Exp. 2) inside a temperature-controlled room. The rate of air flow through the open circuit system was 14 L/min. Twenty-four mean hourly $\dot{V}O_2$s were computed for each owl from a continuous 24-h recording of its oxygen consumption. These were control values, i.e., recorded without a backpack. $\dot{V}O_2$ of owls harnessed with a backpack was measured for 4–6 h at each of the three loads and was compared with the control rates measured earlier at the same hours. The lighting in the chamber was controlled on a 12:12 photoperiod; lights came on at 08:00 h. The average body mass of the two owls during the measurement periods was 812 and 745 g. They were probably both females.

Results.—In the first experiment mean rate of energy metabolism was not significantly different between the two Golden Eagles ($F = 2.36$; $P = 0.14$). The mean H_m of both eagles was about 17 to 18% greater when harnessed with a transmitter (Table 1). This increase was significant for GE2 ($F = 4.96$, $P = 0.049$, N = 11) but not for GE1 ($F = 1.167$, $P = 0.316$, N = 9). Mean hourly air temperature (T_a) in the outdoor aviary during the control and experimental measurements on GE1 averaged −12.5 and −12.7°C, respectively. T_a averaged −13.5 and −13.8°C during these same measurements on GE2.

In the second experiment mean H_m of two Bald Eagles without a transmitter at 0°C (2.01 W/kg) did not differ from that at 15°C (1.98 W/kg) ($F = 0.28$; $P = 0.598$). Mean H_m of both eagles without a transmitter during the day (2.04 W/kg; 08:00 to 20:00 h) was significantly higher than at night (1.94 W/kg; 20:00 to 08:00 h) ($F = 5.62$; $P = 0.018$). Mean H_m of eagles with a transmitter (2.04 W/kg) was 4.7% higher than without a transmitter (1.95 W/kg) ($F = 4.38$, $P = 0.037$) when all temperature data were combined. The mean H_m of transmitter-equipped birds at 0°C (2.18 W/kg) was 9.5% greater during the day the 12.7% more at night (2.04 W/kg) than controls (1.99 and 1.81 W/kg, respectively) ($F = 5.37$, $P = 0.0210$); however, H_m was not different ($P > 0.05$) between the control and transmitter-equipped birds at 15°C. Each eagle responded differently to transmitters at 15°C; the bird-temperature interaction was significant ($F = 11.23$).

H_ms of the two Barred Owls were analyzed with ANOVA by considering each owl, air temperature, and load as sources of variance. H_m values of the two owls were not significantly different. Mean H_m for both owls increased in the cold; 20°C = 2.64 (N = 77), 0°C = 3.45 (N = 77), and −20°C = 5.29 (N = 90) W/kg, respectively. The differences among temperatures were significant ($F = 110.7$). The H_m of owls wearing any of the three loads was not significantly different from the control rates of energy metabolism, i.e., without a load ($F = 1.0$).

Discussion.—Experiments 2 and 3 are the best tests of the effect of a large solar-powered transmitter and a variable-weighted backpack on the resting metabolic rate of an eagle and Barred Owl, respectively. The number of measurements of mean hourly $\dot{V}O_2$ was large in

TABLE 1

MEAN RATE OF ENERGY METABOLISM (±SD) (H_m IN W/KG) OF TWO GOLDEN EAGLES AND TWO BALD EAGLES WITH AND WITHOUT A 192.5 G SOLAR-POWERED TRANSMITTER HARNESSED ON THEIR BACK[h]

			Energy metabolism			
					Calculated from allometric equations	
Experiment	Body mass (kg)	T_a (°C)	Without a transmitter (control)	With a transmitter	Wasser (1986)	Aschoff and Pohl (1970)
Golden Eagle 1[d]	4.300	−12.6	4.33 ± 0.88	5.23 ± 1.22	1.70	2.34[f]
Golden Eagle 2[e]	3.900	−13.7	4.01 ± 0.66	4.74 ± 0.45	1.76	2.40[f]
Bald Eagles[a]	3.767	0 day[b]	1.99 ± 0.15	2.18 ± 0.21		
		night[c]	1.81 ± 0.22	2.04 ± 0.25		
		15 day[b]	2.04 ± 0.10	1.97 ± 0.09		3.08[g]
		night[c]	1.95 ± 0.13	1.98 ± 0.18	1.79	2.50[f]

[a] Data for 2 eagles are combined.

[b] Day = 08:00 to 20:00 h.

[c] Night = 20:00 to 08:00 hr.

[d] Golden Eagle 1 = GE1.

[e] Golden Eagle 2 = GE2.

[f] Inactive period.

[g] Active period.

[h] Measurements were made at different air temperatures (T_a in °C). The body mass of each bird was used with the allometric equations of Wasser (1986:61) for resting metabolism of falconiformes during the inactive period ($H_m = 34.62\ W^{-0.36}$, H_m in mW/g and W in g); and of Aschoff and Pohl (1970) for non-passerines during the inactive period ($H_m = 3.56\ W^{-0.266}$, H_m in mW/kg and W in kg); and during the active period ($H_m = 4.41\ W^{-0.271}$) to compute predicted rates of energy metabolism for comparison with the measured values.

Exp. 2 (N = 433) and in Exp. 3 (N = 244). The potential contribution of day to night changes in metabolism, on any observed differences between metabolism with or without a transmitter, was minimized or eliminated in both experiments. In Exp. 2, the rate of resting metabolism of two Bald Eagles harnessed with the solar-powered transmitter increased about 10% at 0°C but did not change significantly at 15°C. These results are supported by Exp. 1, where the metabolism of both eagles increased by 17% at −13°C. Therefore, at air temperatures of ≤0°C, the $\dot{V}O_2$ of a resting eagle under the conditions of this study will be higher when harnessed with the solar-powered transmitter.

In Exp. 3 the rate of energy metabolism of two Barred Owls at 20°, 0°, and −20°C was not significantly affected by wearing a backpack weighing 2%, 5%, or 10% of the bird's body mass. The tactile and visual stimulation of the backpack did not appear to stress the owls. The Barred Owls had been handled often as part of the educational program at the Raptor Center at the Univ. of Minnesota. The metabolism of the owls at 20°C (2.64 W/kg) was lower than that predicted by the Aschoff and Pohl (1970) allometric equation for non-passerines during the normal rest period (3.7 W/kg; $H_m = 22.42W^{-0.27}$, H_m in mW/g and W in g) but was similar to the value computed by the Wijnandts (1984:36) allometric equation for Strigiformes (2.61 W/kg) ($BMR = 1.435W^{.759}$, BMR in kJ and W in g).

At air temperatures of 0°C and below, the metabolism of eagles wearing a metal box (i.e., the solar-powered transmitter) was higher than that of controls; in contrast, the metabolism of Barred Owls wearing a cloth backpack was the same as that of controls. These findings initially suggested to us that the increase in heat production of the eagles was a response to an increased heat loss from the dorsal surface covered by the metal transmitter (the transmitter covered only about 2% of the eagles's surface area). However, heat losses through an uninsulated and an insulated transmitter, measured with a heat flux transducer were only about 7% and 2%, respectively, of the increase in heat production due to the transmitter.

The rate of energy metabolism of the two Golden Eagles in Exp. 1 was about two times greater than that of the Bald Eagles in Exp. 2. Two differences between Exps. 1 and 2 could account for part of the difference. The lower air temperatures in Exp. 1 should have elevated thermoregulatory metabolism, i.e., the heat required to maintain a relatively constant body temperature. Secondly, in Exp. 1, the birds wore a modified falconer's hood to collect respired gases. The hood may have imposed a higher rate of metabolism in two ways: (1) at times the tubing attached to the hood appeared to impose a twist on the eagles's head which could have increased tension and metabolism in neck muscles, and (2) the snugly fitting hood could have compressed some head feathers, reducing feather insulation and increasing heat loss from some surfaces of the head). In Exp. 2, the birds were perched in a roomy metabolism chamber, rather than wearing a hood.

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