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EFFECTS OF ELECTROMAGNETIC FIELDS ON THE GROWTH OF NESTLING AMERICAN KESTRELS[1]

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Abstract. We studied nestling American Kestrels (*Falco sparverius*) in a laboratory setting to determine whether exposure to electromagnetic fields (EMFs) affected their growth. Captive nestlings were raised by their parents under control or EMF conditions similar to those occurring near transmission lines in the wild. Nestlings also were exposed to EMFs as embryos when incubated by their parents. Measurements of body mass, and lengths of tarsi, antebrachia, and feathers were taken every three days after hatching. EMF exposure affected the growth of female and male nestlings. EMF nestlings and fledglings were heavier and had longer tarsi. The periods of maximal weight gain and antebrachial growth were delayed in EMF males compared to controls, although EMF males were heavier and had similarly long antebrachia to controls by 21 days of age. Growth of ninth primaries and central rectrices of nestlings were unaffected by EMF exposure. Growth patterns of male and female kestrel

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nestlings were similar to those previously reported for this species, although the periods of maximal weight gain and bone growth did not occur earlier in EMF males than females as it did in controls.

Key words: American Kestrel, electromagnetic fields, Falco sparverius, *growth.*

Intraspecific variations in avian growth are determined by environmental factors (Moss 1979, Donazar and Ceballos 1989), food intake (Ricklefs 1983, O'Connor 1984, Lacombe et al. 1994), prey type (Lavigne et al. 1994b), brood size (Dijkstra et al. 1990, Gard and Bird 1992), and genetic factors (Mignon-Grasteau et al. 1999). Growth of nestlings also may be affected by electromagnetic fields (EMFs) when adult birds nest near electrical transmission lines (Fernie 1998). Raptors commonly nest on transmission towers using nest platforms or constructing their own nests (Gilmer and Stewart 1983, Steenhof et al. 1993). Consequently, young are exposed to EMFs throughout their time in the nest. EMF exposure for one breeding season increased embryonic growth but reduced hatching success of captive American Kestrels (*Falco sparverius*; Fernie et al. 2000a). Under EMF conditions, adult kestrels were more active (Fernie et al. 2000b), and males were heavier when molting although their food intake was unaffected (Fernie and Bird 1999). Circulating melatonin levels of adult male and fledgling kestrels were suppressed, then elevated in adult males by EMFs (Fernie et al. 1999).

Reproductive success is partly determined by nestling survival and fledging success. Survival of young birds has been correlated with body size and growth, with larger birds having better survival in some species (Perrins 1965, Newton et al. 1983). Larger young have more body reserves (Marcström and Kenward 1981) that safeguard against cold temperatures and periods of low food availability and enhance post-fledging survival (Newton et al. 1983). Any effect of EMF exposure on growth of nestling birds could therefore affect reproductive success.

Our objective was to determine whether EMF exposure throughout the breeding season affects the size and growth of nestling American Kestrels. We compared growth patterns in body mass, tarsus and antebrachium length, together with feather emergence and length, between nestlings raised by their parents under EMF or control conditions.

METHODS

The experiment was conducted in 1995 and 1996 at McGill University (Quebec, Canada) with captive reared American Kestrels from the Avian Science and Conservation Centre. Kestrels were housed under control or EMF conditions throughout the reproductive season. Nestlings were incubated and raised by their parents, and were exposed to EMFs throughout their time in the nest as embryos, nestlings, and fledglings. Incubation of kestrel eggs occurs for approximately 28 days; young kestrels fledge at approximately 28 days of age, and remain near the nest box for 7 to 10 days afterwards (Bird 1988).

Pairs were genetically unrelated within the past seven generations. Within each sex, adults were similar in age (2–5 years), condition, body mass, and size (wing chord) at pairing and incubation, although adult EMF males were heavier than control males during brood rearing (Fernie and Bird 1999).

Humidity, temperature, and photoperiod were similar to field conditions during the breeding season, and between EMF and control rooms. Noise levels and light intensities were similar when EMFs were on or off, and between EMF and control rooms (Fernie 1998).

A 60-Hz electrical current in the EMF room created a magnetic field of 30 microtesla (μT) and an electric field of 10 kV m^{-1}. EMFs were equivalent to those experienced by wild kestrels when nesting within 40 m of a 735-kV transmission line running at peak capacity. EMFs were controlled by a computer to provide consistent and uniform fields (Nguyen et al. 1991). The magnetic field of the control room was 2 μT, and the electric field was 0.03 kV m^{-1}.

Kestrels were paired on 11 May 1995 and 13 May 1996. EMF exposure began immediately and lasted for 95 days in 1995 and 91 days in 1996, or one week after the last nestling fledged. Kestrels were exposed to EMFs for approximately 21 hr day^{-1} in 1995 and 23.5 hr day^{-1} in 1996. EMF exposure was comparable to that experienced by wild nestling and fledgling kestrels (Fernie 1998).

Each pair was housed in a visually-isolated breeding pen (0.7 × 0.7 × 1.2 m) with a wooden nest box (0.3 × 0.3 × 0.4 m). Wood shavings were provided as nesting material. Metal materials were minimized to reduce disturbance of the electric field and possible shocks to the birds (F. Renaud, pers. comm.). Magnetic fields penetrated all housing materials (D. Nguyen, pers. comm.).

Newly-hatched nestlings were individually color-marked until old enough to be banded. Body mass (to the nearest 0.1 g) and morphometrics were taken in the morning, prior to feeding of adult pairs. Chicks were measured on their right side (Olendorff 1972). The length of the tarsus, antebrachium, ninth primary, and tail (central rectrix) feathers were measured to the nearest 0.01 mm following Negro et al. (1994). Measurements were taken every three days after hatching until chicks were 36 days old. All measurements were made by KJF to reduce measurement error.

STATISTICAL ANALYSES

Sample sizes consisted of 33 nestlings from 27 nest boxes, with one nestling per sex from each nest box chosen at random. Nestling kestrels are sexually dimorphic in size (Gard and Bird 1992). There were 12 female (6 per treatment) and 15 male nestlings (6 control, 9 EMF exposed). We estimated the asymptotic size (A), growth rate constants (K), and inflection points (I; time of maximum growth rate) for body mass, tarsus and antebrachium lengths of each individual. Data were fitted to a logistic growth model (Ricklefs 1967) using the nonlinear regression function of SigmaPlot (1995). Body mass and bone lengths were compared when birds were 21, 27, and 36 days old.

Lengths of the ninth primary and central rectrix feathers were fitted to a least-squares linear regression. Flight feathers are still growing when kestrels fledge

TABLE 1. Asymptotic values (A), period of maximal growth (I), size at fledging (27 days) and after fledging (36 days) for body mass and length of tarsus of nestling American Kestrels exposed to control or electromagnetic field (EMF) conditions.

	Females		Males	
Treatment	Control	EMF[a]	Control	EMF[a]
Mass				
A (g)	122.3 ± 3.3	133.8 ± 2.4	112.4 ± 2.5	118.7 ± 1.8
I (days)	8.4 ± 0.5	8.2 ± 0.3	7.1 ± 0.4	8.1 ± 0.4
27 days (g)	121.9 ± 4.0	132.5 ± 3.1	109.1 ± 3.3	117.3 ± 2.2
36 days (g)	116.1 ± 1.6	128.8 ± 2.2	107.4 ± 2.6	114.7 ± 1.7
Tarsus				
A (mm)	37.3 ± 0.3	38.8 ± 0.6	37.6 ± 0.3	38.7 ± 0.3
27 days (mm)	36.7 ± 0.4	38.3 ± 0.6	37.1 ± 0.6	38.4 ± 0.3
n	6	6	6	9

[a] For each variable within each sex, EMF values are significantly different from controls at $P \leq 0.05$.

(Gard and Bird 1992). We compared the age at which feather growth started (intercept of regression line), growth rate (slope of regression line), and feather length when birds were 27 and 36 days old.

Males and females were analyzed separately. Within each sex and treatment, significant differences between years were determined by one-way ANOVAs (SAS 1985). Data were then pooled because there were no differences between years. Subsequent analyses within each sex involved two-way ANOVAs with treatment and brood size as independent variables. Within each treatment, comparisons between sexes were made using one-way ANOVAs. Means ± SE are presented; significance was considered to be $P < 0.05$.

RESULTS

There were no year or brood size effects on growth of body mass, bones, or feathers of male and female nestlings (F-tests, all $P > 0.25$).

EMF female nestlings were heavier than control females when approximately 21 days old (asymptotic mass; $F_{1,11} = 8.6$, $P < 0.05$), and as fledglings when 27 and 36 days old (both $P < 0.05$; Table 1). EMF male nestlings also were heavier than control males when 21 days old (asymptotic mass; $F_{1,14} = 4.6$, $P < 0.05$) and as fledglings (27 and 36 days: both $P < 0.05$; Table 1). The period of maximal weight gain began 1.1 ± 0.0 days later in EMF males than in controls ($F_{1,14} = 4.5$, $P < 0.05$). Growth rates in body mass were similar for male or female young regardless of EMF exposure.

Asymptotic tarsal lengths were longer in EMF females ($F_{1,11} = 4.8$, $P < 0.05$) and EMF males ($F_{1,14} = 6.7$, $P < 0.05$; Table 1) than respective controls, and when the EMF birds were 27 days old (females, $F_{1,11} = 4.8$, $P < 0.05$; males, $F_{1,14} = 5.2$, $P < 0.05$; Table 1). EMF exposure had no effect on tarsal growth rates or the period of maximal tarsal growth.

Although maximal growth of the antebrachia began 1.1 ± 0.2 days later in EMF males than control males ($F_{1,12} = 5.3$, $P < 0.05$), antebrachial lengths (asymptotes) and growth rates were similar between EMF and control nestlings. There were no EMF effects on the length, emergence, or growth rates of ninth primaries or central rectrices of nestlings.

Regardless of treatment, female nestlings were heavier than males at asymptote (control, $F_{1,11} = 5.9$, $P < 0.05$; EMF, $F_{1,13} = 5.3$, $P < 0.05$) and at fledging (27 days: control, $F_{1,11} = 6.2$, $P < 0.05$; EMF, $F_{1,13} = 16.9$, $P < 0.001$). The periods of maximal weight gain ($F_{1,11} = 5.3$, $P < 0.05$) and growth of tarsi ($F_{1,11} = 7.8$, $P < 0.05$) and antebrachia ($F_{1,11} = 5.3$, $P < 0.05$) began earlier for control males than control females, but not for EMF males compared to EMF females (all $P > 0.18$). There were no other differences in growth of antebrachia, primaries or rectrices, between male and female young (all $P > 0.36$).

DISCUSSION

The growth patterns for body mass, bone growth for controls, and growth rates of the measured parameters, were similar to those previously reported for American Kestrels (Bird and Clark 1983, Gard and Bird 1992, Lacombe et al. 1994). Female nestlings were asymptotically heavier than males, regardless of treatment, and females were heavier than males at fledging (see also Bird and Laguë 1982, Lacombe et al. 1994). Weight gain and bone growth began earlier in control males than females, but did not begin earlier in EMF males than females. Nevertheless, fledging age was similar for control and EMF male nestlings, and fledging success was similar or higher for the EMF pairs than the control pairs (Fernie et al. 2000a).

The delayed weight gain and antebrachial growth observed in young EMF males, may compromise nestling survival during periods of low food availability or poor weather (Schifferli 1973). Under captive conditions, EMF males were able to overcome growth delays, becoming heavier and having antebrachia similar in size to those of control males by 21 days of age. Alternatively, the heavier EMF young may experience better survival than control nestlings during adverse food conditions. Heavier young of some raptors (Marcström and Kenward 1981, Newton et al. 1983) and passerine species (Perrins 1965, Howe 1976) are better able to survive when food is scarce. The heavier, larger EMF nestlings may also explain the greater fledging success in 1995 and overall reproductive success in 1996 of captive EMF pairs compared with control pairs (Fernie 1998, Fernie et al. 2000a). Furthermore, EMF females fledged two days earlier than control females although this was not statistically significant.

The heavier body mass of EMF fledglings compared to respective controls may also enhance their post-fledging survival. Body mass was positively correlated with protein and/or fat reserves in fledgling Goshawks (*Accipiter gentilis,* Marcström and Kenward 1981) and American Kestrels (Lavigne et al. 1994a). Larger reserves allow a heavier individual to better survive periods of food deprivation and cold temperatures (Haramis et al. 1986), particularly when fledgling raptors are inefficient hunters (Marcström and Kenward 1981, Newton et al. 1983). Male Sparrowhawks (*Accipiter nisus*) starved more often than females in the first few months after fledging, presumably because they were lighter and smaller, and less able to tolerate periods of temporary food shortage (Newton et al. 1983).

EMF-exposed young had longer tarsi than controls. EMF exposure stimulates osteogenesis in mammals (Grace et al. 1998, Otter et al. 1998, Ryaby 1998). Although bone length is strongly determined by genetic factors (Gard and Bird 1992), environmental factors such as EMFs can also affect bone length. EMF and control parents were similar in body size at pairing (Fernie and Bird 1999), so the longer tarsi of nestlings were unlikely due to parental differences in size.

The larger size of EMF young is consistent with earlier findings of EMF kestrel embryos being larger than controls (Fernie et al. 2000a). EMFs had no effect on growth of rats and mice (Sikov et al. 1984, Margonato et al. 1995). We are aware of no prior studies evaluating EMF effects on the growth of birds.

The larger size of the EMF nestlings is not due to the position in the laying sequence or to differential access to food. Control and EMF nestlings hatched at the same time, and were fed the same diet. Additionally, the number of feeding trips to the nest box by adults was similar between EMF and control pairs (Fernie et al. 2000b). Furthermore, brood size had no effect on the growth of kestrels, which is consistent with previous research involving wild and captive kestrels (Gard and Bird 1992).

In summary, EMF exposure affected the growth of captive nestlings, including changing the growth patterns of female nestlings compared to male nestlings. EMF young were heavier and had longer tarsi than controls. The larger size of EMF exposed young may explain the better fledging and reproductive success of this group in captivity, and may actually contribute to better survival for free-ranging nestlings and/or fledglings.

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THE ROLE OF GASTROLITES ON FEEDING BEHAVIOR AND DIGESTIVE EFFICIENCY IN THE RUFOUS-COLLARED SPARROW[1]

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Abstract. We examined grit consumption in the facultative granivorous Rufous-collared Sparrow (*Zonotrichia capensis*). Grit consumption fluctuated seasonally and was significantly correlated with morphological changes in the digestive tract, and with seed size. The highest values of grit consumption and digestive tract mass were observed during winter. Laboratory experiments suggested that grit consumption was a voluntary behavior rather than the result of accidental ingestion, and favored digestibility. Grit consumption varied considerably when *Z. capensis* fed on different types of food, but remained constant when food availability varied. We suggest that grit consumption together with morphological changes in the digestive tract allow *Z. capensis* to increase energy acquisition in response to higher energy demands during wintertime.

Key words: assimilation efficiency, digestive tract morphology, grit consumption, Rufous-collared Sparrow, Zonotrichia capensis.

In granivorous birds, variables such as seed size and

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