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EFFECTS OF ELECTROMAGNETIC FIELDS ON BODY MASS AND FOOD-INTAKE OF AMERICAN KESTRELS[1]

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Abstract. Raptors commonly nest and roost on transmission towers and hydroelectric poles which exposes them to electromagnetic fields (EMFs) from power lines. Our objective was to determine whether EMF exposure affected the body mass of reproducing adult American Kestrels (*Falco sparverius*), and consequently, whether increased body mass was a function of increased dry matter intake related to EMF exposure. Captive kestrels were paired for one (short-term) or two (long-term) breeding seasons to determine EMF effects on body mass of adults. Short- and long-term EMF exposure of males affected overall mean body mass during the reproductive season, with EMF males heavier than controls when molting began. In contrast, the body mass and pectoral muscle scores of females were unaffected by EMF exposure during egg laying, 20 days post-laying, and after 70 days of EMF exposure. There were no significant effects on body mass or food-intake of wintering kestrels related to 10 days of EMF exposure. Our results can be explained by EMFs affecting the birds' response to the photoperiod as indicated by altered melatonin levels in these male kestrels. The onset of molt was advanced in EMF male kestrels.

Key words: American Kestrels, electromagnetic fields, Falco sparverius, *food-intake, mass, molt.*

INTRODUCTION

Transmission towers have proved beneficial to birds, providing alternative sites for perching, nesting, roosting, and hunting (Steenhof et al. 1993). Nest platforms and boxes have been erected on transmission towers and hydroelectric poles for use by raptors (Olendorff et al. 1981). Over 10 years, 133 pairs of raptors and Ravens (*Corvus corax*) established new nests along a 500-kV transmission line in southern Idaho–Oregon, and 82% of pairs repeatedly nested on this line (Steenhof et al. 1993). Overall nest success rates were similar to or higher than pairs nesting on surrounding substrates.

Power lines and structures also have electrocuted many birds, particularly birds of prey (Olendorff et al. 1981). However, it was unknown whether birds spending considerable time in the vicinity of power lines were affected by electromagnetic fields (EMFs). EMF exposure adversely affected hatching success of American Kestrels (*Falco sparverius,* Fernie 1998), and possibly reproductive success of free-ranging Tree Swallows (*Tachycineta bicolor*) although these results could not be directly attributed to EMF exposure (Doherty and Grubb 1996).

Physiological changes from EMF exposure may, or may not, have adverse biological effects on exposed animals. Plasma melatonin was suppressed then elevated in male kestrels exposed to EMFs (Fernie 1998). Kestrel embryos exposed to EMFs were structurally larger than control embryos (Fernie 1998), and female nestlings were larger in terms of bone and body mass development (K. Fernie, unpubl. data). Dry matter intake and body mass of Holstein cows increased under EMF conditions (Burchard et al. 1996; M. Rodriguez, pers. comm.).

EMF exposure affected the kestrels' response to the photoperiod, i.e., they responded as if the photoperiod was longer under EMF conditions than control conditions (Fernie 1998). Manipulations of photoperiods advance the onset or rate of molt in several bird species (Dawson 1991, 1998), and molt is associated with changes in body mass in American Kestrels (Fernie 1998). Here, our objective was to determine whether EMF exposure affected body mass of adult kestrels during reproduction, and consequently, body mass and dry matter intake of nonbreeding adult kestrels during the winter.

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METHODS

REPRODUCTIVE CONDITION

We used 56 pairs of captive American Kestrels from the Avian Science and Conservation Centre of McGill University. In 1995, 28 pairs were randomly assigned to the control room, and 28 pairs to the EMF room. In 1996, new birds were randomly assigned as 13 control pairs and 15 EMF pairs. Another 13 control and 15 EMF pairs, randomly selected from 1995, were assigned for a second season to the control and EMF room, respectively. Kestrels used in the experiment for one breeding season identified effects of "short-term" EMF exposure, whereas those used for two seasons identified "long-term" EMF effects.

Pairs were genetically unrelated within the past seven generations. Each bird had previous breeding experience. Within each sex, adults were similar in age (2–5 years), size (wing chord), body mass, and condition (body mass: wing chord index) at pairing (1-way ANOVAs, all $Ps \geq 0.45$).

In the control and EMF rooms, humidity, temperature, and photoperiod followed natural conditions (45°30′N, 73°26′W) and were similar (*t*-tests, all $Ps \geq 0.34$). Air exchange between the two rooms was similar. Noise levels with EMFs on or off, and average light intensity at birds' head level, were similar between rooms (*t*-tests, all $Ps \geq 0.24$). Noise levels are indicative of mechanical vibrations from the EMF equipment (D. Nguyen, pers. comm.).

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 to which wild kestrels are exposed when nesting under a 735-kV transmission line running at peak capacity. The 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 to pairs began immediately and lasted for 95 days in 1995, and 91 days in 1996. Kestrels were exposed to EMFs for approximately 21 hr day^{-1} in 1995 and 23.5 hr day^{-1} in 1996. These exposure periods are comparable to those potentially experienced by free-ranging kestrels which are incubating eggs and young nestlings, and perch-hunting from distribution lines (Fernie 1998).

Each pair was housed in a visually-isolated breeding pen of the same size ($0.7 \times 0.7 \times 1.2$ m) and made of reinforced corrugated cardboard and roofed with nylon netting. A standard wooden nest box and rope perch were provided. Wood shavings served for bedding and nesting material. Metal materials were minimized to reduce disturbance of the electric field and possible electric shock to the birds (F. Renaud, pers. comm.). Magnetic fields penetrated all housing materials (D. Nguyen, pers. comm.).

Male kestrels were weighed (nearest 0.1 g) every 14 days, between 08:00 and 11:00 prior to morning feeding. Female kestrels were weighed and measured three times, between laying of the third and fourth egg (mid-clutch), 20 days post-laying, and at 70 days after pairing. Females were weighed at 13:00 to avoid disturbing egg laying which generally occurs in the early morning (Liou et al. 1987; I. Ritchie, pers. comm.). Pectoral muscles of the females were scored from 1 (poor) to 4 (excellent; Gosler 1991) to monitor protein reserves throughout the experiment. Initiation or occurrence of molt was recorded at sampling periods. Kestrel pairs were provided daily with ad libitum day-old cockerels and water, and leftover food was removed.

For the reproductive condition study, repeated measures ANOVAs (Sokal and Rohlf 1995) were used to analyze EMF effects on body mass using SAS (1985) software. Analyses were conducted separately by sex within short- and long-term groups. When necessary, data were transformed using the Box-Cox transformation (Sokal and Rolf 1995). Friedman's repeated measures ANOVA on ranks was used to analyze female pectoral muscle scores. Statistical significance was considered at the $P < 0.05$ level, and means $\pm$ SE are reported.

WINTER FOOD TRIAL

The food trial was conducted during the winter to eliminate complications from chicks and/or mates consuming food. A 10-day period of EMF exposure was selected as EMF females laid larger eggs after 11 days of EMF exposure (Fernie 1998). Furthermore, the availability of the EMF room was restricted by other experiments.

A cross-over experimental design using 32 captive kestrels was used for the winter food trial study (4 December 1996 to 11 January 1997).

Sixteen kestrels were housed in each of the control and EMF rooms for trial one, then switched to the opposite room for trial two. In each room, eight males and eight females were housed individually in the breeding pens without nest boxes. Before beginning the EMF trial, the kestrels went through a 6-day acclimation period in the heated rooms (EMF 20 ± 0.5°C, control 21 ± 1°C) because they were previously housed at ambient temperatures (0 ± 5°C). Once food intake was stabilized, EMF exposure began for 10 days, followed by a 4-day elimination period without EMFs to remove any residual effects. Kestrels were then switched from EMF to control rooms, and vice versa, followed by another 4-day acclimation period without measurements taken. Another 10-day trial and 4-day elimination period followed.

The kestrels in which food intake was monitored were exposed to EMFs for 23 hr day^{-1}. EMF levels and daily exposure periods were comparable to the reproductive condition study. In both rooms, photoperiod was natural, and humidity, temperature, noise, and vibration conditions were similar (1-way ANOVA, all $Ps \geq 0.38$).

Kestrels in the winter food trial study were similar in age (3–4 years) to each other and to the reproductive birds. They had been previously exposed to EMFs for one season in the reproductive condition study.

As in the reproductive condition study, kestrels were provided with ad libitum day-old whole cockerel and water between 08:00 and 11:00 each day. Kestrels were weighed daily at this time. To facilitate leftover food collection, pens were lined with wax paper which was changed at each feeding. Leftover food from each bird was immediately frozen at −20°C until thawing for 24 hr prior to drying. Food samples were dried to a constant weight at 177°C for 24 hr, and weighed to the nearest 0.01 g. The average dried mass of a cockerel (n = 20) was used to determine the dry mass of provided food. Dry matter intake was calculated as dry mass fed minus dry mass of leftover food.

Statistical analyses for the winter food trial study were based on dry matter intake, and involved repeated measures ANOVA. The statistical model controlled for residual effects from the initial acclimation period or the two EMF trials. Data were transformed by standardized transformation prior to analysis due to the large variation within the raw data (Sokal and Rohlf 1995). Means ± SE are presented.

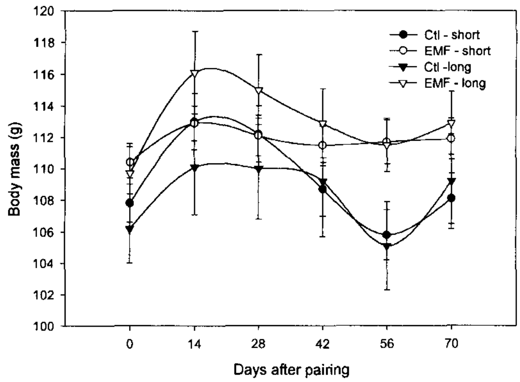

FIGURE 1. Effects of electromagnetic fields on body mass of adult male American Kestrels (*Falco sparverius*) exposed to short-term or long-term EMFs. Ctl = Control; EMF = Electromagnetic fields; short = short-term exposure for one breeding season; long = long-term exposure for two breeding seasons.

RESULTS

REPRODUCTIVE CONDITION

There were no significant differences in body mass of short-term males between years within control or EMF groups, either overall or at specific sampling periods (all $Ps \geq 0.32$). Consequently, data were pooled. Short-term EMF exposure of male kestrels affected body mass ($F_{6,68}$ = 4.8 $P < 0.001$; Fig. 1). EMF males were heavier than controls at 56 days ($F_{1,76}$ = 8.8, $P < 0.01$) and at 70 days ($F_{1,76}$ = 5.7, $P < 0.05$). Time ($F_{5,69}$ = 10.5 $P < 0.001$) and treatment × time interactions were significant ($F_{5,69}$ = 5.4 $P < 0.001$).

Long-term EMF males also were heavier than control males ($F_{6,20}$ = 5.4, $P < 0.01$; Fig. 1). A trend was evident at 56 days, i.e., long-term EMF males were heavier than controls ($F_{1,25}$ = 3.8, P = 0.06). Time ($F_{5,21}$ = 140.3 $P < 0.001$) and treatment × time interactions ($F_{5,21}$ = 4.3 $P < 0.01$) were significant for this group.

Body mass data for short-term females were pooled because there were no differences between years for each treatment, either overall or at individual sampling periods (all $Ps \geq 0.31$). Short- and long-term EMF exposure of female kestrels had no effect on body mass (ANOVA, all $Ps \geq 0.59$). Time effects were significant for short-term females in 1996 only ($F_{3,15}$ = 70.0 $P < 0.001$) and for long-term females ($F_{3,18}$ = 57.0

$P < 0.001$). There were no significant treatment × time interactions (all $Ps \geq 0.35$). Pectoral protein reserves of females were unaffected by EMF exposure or time (Friedman's ANOVA, all $Ps \geq 0.47$).

WINTER FOOD TRIAL

Initially, control and EMF kestrels within each sex were similar in body mass (1-way ANOVAs, all $Ps \geq 0.24$), with males weighing 129.9 ± 4.5 g, and females weighing 142.8 ± 5.5 g. No significant differences were observed in body mass of birds between EMF and control groups throughout any trial period (ANOVAs, all $Ps \geq 0.18$).

There were no differences in dry matter intake for either sex during the winter food trial (ANOVAs, all $Ps \geq 0.17$). Average daily dry matter intake of wintering adult males was 11.8 ± 1.0 g, and for wintering adult females, 13.3 ± 1.1 g. These measurements are equivalent to each bird consuming 43.0 to 48.6 g (wet mass) daily.

DISCUSSION

This study showed that EMF exposure had an overall effect on body mass of reproducing male kestrels, particularly at molting, and effects increased as the season progressed. Molting had begun in the EMF males (93%), but was very limited in the control males (5%), at 56 days of the trial (Fernie 1998). Molting is accompanied by an increase in body mass in kestrels (Dietz et al. 1992, Fernie 1998).

The advance in molt of EMF kestrels in this study can be explained by EMFs affecting the birds' response to the photoperiod. Suppressed melatonin in EMF reproducing males at 42 days (Fernie 1998), the same birds used in this study, indicated the EMF birds were responding as if the photoperiod was longer than in the control room. Longer photoperiods, or decreases in daylength prior to gonadal regression, advance the onset of molt in many bird species (Meijer 1989, Dawson 1991, 1998). In this study, the photoperiod began to decrease at 39 days. Molt and (likely) gonadal regression began in the EMF males by 56 days of the trial, after the decrease in photoperiod. The birds' perception of a longer photoperiod in the EMF room, and the timing of the decrease in photoperiod, would have advanced the onset of molt in EMF males compared to control males.

The mass of growing new feathers explains why short-term EMF males were heavier at 70 days. In kestrels, feather loss occurs at molt onset with a two-week delay until initial feather regrowth (Fernie 1998). We calculated the potential feather mass of short-term males at 70 days using Turček's (1966) formula, $Fw = 0.09W^{0.95}$, where W is mass in grams. Estimated plumages of EMF males (8.1 ± 0.2 g) were heavier than those of controls (7.5 ± 0.2 g; $F_{1,75} = 7.1$, $P < 0.05$).

EMFs did not affect body mass of females. We offer several explanations for the lack of EMF effects, which are not necessarily mutually exclusive. First, female kestrels begin to molt earlier than males during mid-incubation or in this study after approximately 28 days of EMF exposure. This exposure period is shorter than when EMF effects appeared in males (i.e., ≥42 days). The results indicate EMF effects on adult birds may only occur after continuous, extended exposure. Second, females reabsorb the oviduct when molting, which occurred prior to the decline in daylength in our study. If females are similar to males, the decrease in daylength after the onset of gonadal regression increases the rate of molt, but not its onset (Dawson 1998). Consequently, we would not expect to see an advance in molt onset with associated differences in mass in EMF females. Finally, if female body mass was indeed affected by EMF exposure during molt, any effects may have been masked by the significant weight loss (~40 g) experienced during incubation. This seasonal decline in body mass after clutch production is typical of female kestrels (Bird 1988).

The lack of EMF effects on body mass of captive wintering kestrels is related to their winter body mass being 20–30 g more than their post-clutch reproductive mass. Wintering kestrels experienced consistent warm temperatures, approximately 20°C above ambient temperatures, which would not induce excess eating or fattening for overnight winter survival (Dawson and Marsh 1986). Photoperiod inducement of seasonal fattening was unlikely given that there were no photoperiod differences between groups, and melatonin concentrations were similar between reproducing EMF and control males at 14 days of the trial (Fernie 1998). European Kestrels (*F. tinnunculus*), and likely American Kestrels, experience their lowest periods of daily energy expenditure (DEE) during winter (Masman et al. 1988; I. Ritchie, pers.

comm.). Body mass or food intake was unlikely to increase regardless of EMF exposure as wintering kestrels in our study had reached their maximum seasonal weight gain and were experiencing a relatively low DEE period.

To our knowledge, this study is the first investigation of food intake by birds under EMF conditions. EMF exposure had no effect on food intake of kestrels. Dry matter intake of kestrels is unlikely to be affected by photoperiod (Fernie 1998). Total daily food intake of molting White-crowned Sparrows (*Zonotrichia leucophrys gambelii*) was unaffected by photoperiod length (Murphy and King 1990). Furthermore, an increase in dry matter intake by the kestrels due to increased activity is not expected. The EMF and control reproducing males were similarly active during the nestling phase (Fernie 1998) which was when EMF males were heavier. Consequently, a longer photoperiod experienced by the kestrels would not necessarily increase dry matter intake regardless of reproductive, molting, or overwintering demands.

In summary, short-term and long-term EMF exposure affected body mass of reproducing male but not reproducing female American Kestrels. EMFs affected the birds' response to the photoperiod. EMF birds responded as if the photoperiod was longer in the EMF room than the control room. This perceived longer photoperiod, and its decline prior to molt onset, advanced the onset of molt in EMF males. EMF exposure for 10 days had no effect on body mass or food intake of wintering male and female kestrels. EMF effects on adult birds may only occur after continuous, extended EMF exposure.

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