



Effects of radiotransmitters on body mass, feed consumption, and energy expenditure of northern bobwhites

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Abstract Radiotelemetry is commonly used in northern bobwhite (*Colinus virginianus*) research. An underlying assumption is that radiomarked individuals provide unbiased estimates of population parameters. Our objectives were to evaluate the effects of radiotransmitters on body mass and feed consumption of radiomarked and banded-only pen-raised bobwhites in a controlled environment and to compare daily energy expenditure (kJ/g/day) between treatments in a simulated field setting. We randomly assigned a treatment (i.e., radiomarked or banded-only) to 40 pen-raised bobwhites and placed them in individual cages (51- × 27- × 28-cm) within an environmental chamber. We conducted 2 separate 21-day experiments to simulate summer (35°C daytime high, 23.9°C nighttime low, 15-hour photoperiod) and winter conditions (18.3°C daytime high, 4.4°C nighttime low, 10-hour photoperiod) typical for south Texas. For the field experiment, we evaluated energy expenditure via doubly labeled water for radiomarked ($n=5$) and banded-only pen-raised bobwhites ($n=5$) in a flight pen (50- × 30- × 4-m). We documented no difference in change in body mass or feed consumption between radiomarked and banded-only bobwhites during either experiment ($P>0.05$). We also found no difference in daily energy expenditure between radiomarked (0.839 ± 0.056 kJ/g/day) and banded-only pen-raised bobwhites (0.804 ± 0.014 kJ/g/day; $P=0.77$).

Key words *Colinus virginianus*, northern bobwhites, radiotelemetry, radiotransmitters, Texas

Northern bobwhites (*Colinus virginianus*) have received considerable research attention during the past 70 years. Extensive research is available on survival (Marsden and Baskett 1958, Pollock et al. 1989, Burger et al. 1995), reproduction (Guthery et al. 1988, Giuliano et al. 1996), foraging ecology (Lehmann and Ward 1941, Curtis et al. 1990, Peoples et al. 1994), and diseases (Kellogg and Calpin 1971, Davidson et al. 1982, Demarais et al. 1987). During recent decades the advent of

radiotelemetry has enabled researchers to study these subjects even more intensively and to estimate population parameters that otherwise would be difficult or impossible to obtain. Previously held beliefs on the life history of bobwhites also have been changed as a result of radiotelemetry, such as the existence of polygamy in bobwhites (Curtis et al. 1993). Despite these advances, researchers often suggest that population parameters estimated from radiotelemetry studies might be inaccurate (Herzog

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1979, Nenko and Healy 1979, Johnson and Berner 1980, Marks and Marks 1987).

An underlying assumption of radiotelemetry studies is that radiomarked individuals provide unbiased estimates of population parameters. This assumption is valid only if the survival, reproduction, and behavior of radiomarked individuals are similar to nonmarked individuals. This assumption has been debated, and research has provided conflicting results (Boag et al. 1973, Erikstad 1979, Paton et al. 1991, Sodhi et al. 1991, Parry et al. 1997).

Most studies of radiotransmitter effects on bobwhites have concentrated on survival and have indicated no negative impacts (Mueller et al. 1988, Osbourne et al. 1997, Parry et al. 1997, Corteville 1998). However, the accuracy of radiotelemetry survival estimates has been questioned (Guthery 1997). Low survival estimates (<0.10) suggest apparent negative effects of radiomarking on bobwhites (Guthery and Lusk 2004). Radiotransmitters might have indirect, sublethal effects on bobwhites such as increased energy expenditure. Few studies have investigated impacts of radiotransmitters on body condition (Osbourne et al. 1997, Corteville 1998), and no study, to our knowledge, has investigated the impacts of radiotransmitters on energy expenditure of bobwhites. The objectives of our study were to compare body mass and feed consumption of radiomarked and banded-only bobwhites under temperature extremes in a controlled environment and to compare energy expenditure of radiomarked and banded-only bobwhites in simulated field conditions.

Methods

Experimental design

Environmental chamber experiments. Our experiment involved a 2×2 factorial completely randomized design. The 2 factors were gender and treatment (i.e., radiomark and banded-only [control]). We randomly assigned 40 adult bobwhites ($n = 20$ males; $n = 20$ females) a treatment by gender. Thus, each gender \times treatment combination had 10 bobwhites. We then used these 40 bobwhites in an experiment simulating summer conditions and subsequently winter conditions.

Simulated field experiment. This experiment involved a completely randomized design. We obtained 10 pen-reared bobwhites (all adult males) and randomly selected 5 for radiomarking. All 10 bobwhites were placed in a $50 \times 30 \times 4$ -m flight

pen containing natural vegetation and exposed to natural weather conditions. We evaluated only 10 bobwhites in this experiment because of the high costs associated with the doubly labeled water technique (Nagy 1975; see below) used in this experiment.

Data collection and analysis

Environmental chamber experiments. We obtained 40 pen-reared bobwhites (20 males, 20 females) from a Texas game-bird breeder in August 2001. We weighed and leg-banded all bobwhites and placed them individually in $51 \times 27 \times 28$ -cm cages. We provided food (complete ration pellets) and water ad libitum. Cages were contained within an environmental chamber where temperature, humidity, and photoperiod were controlled. We allowed a 2-week acclimatization period (22°C, 70% humidity, 15-hour photoperiod) before we initiated the summer experiment.

After the acclimatization period, we randomly assigned a treatment (radiomarked-banded [hereafter radiomarked] or banded-only) to bobwhites by gender. We radiomarked bobwhites using a 5–6-g neck-loop radiotransmitter (Wildlife Materials, Carbondale, Ill.). We obtained initial body masses and then began a 21-day experiment simulating summer conditions. We chose a 21-day experiment period to encompass the time period (i.e., 7 days) within which radiomarked bobwhites were excluded from analysis if they died (e.g., Burger et al. 1995). This was done to minimize potential bias from radiomarking. The environmental chamber was set to fluctuate between 23.9°C nighttime low and 35°C daytime high with 70% humidity and a 15-hour photoperiod, which was meant to simulate summer conditions in southern Texas. We weighed bobwhites every 3 days and determined food consumption every 2 days. We removed water and feed dishes 1 hour before lights turned on, simulating daylight, to ensure no ingestion of feed or water prior to weighing. We attempted to minimize feed spill by using covered feed dishes with one small (2.54-cm-diameter) circular opening. We used a digital, electronic scale to measure body weights and feed consumption to the nearest 0.1 g. We conducted all data collections at the same time to produce comparable data (Kontogiannis 1967).

Upon completion of the summer experiment, we allowed another 2-week acclimatization period (22°C, 70% humidity, 10-hour photoperiod) before initiating the winter experiment. All bobwhites

remained on the same treatment they were assigned during the summer experiment. After the acclimatization period, we began a 21-day winter experiment and programmed the environmental chamber to fluctuate between 4.4°C nighttime low and 18.3°C daytime high with 70% humidity and a 10-hour photoperiod, which was meant to simulate winter conditions in southern Texas. We obtained initial body weights, and data collection followed the same procedure as for the summer experiment.

Simulated field experiment. We originally attempted to evaluate energy expenditure using wild, free-ranging radiomarked and banded-only bobwhites and doubly labeled water (Nagy 1975). This technique involved an initial capture and a subsequent recapture of individuals 2–3 days later to obtain blood samples. We could not evaluate wild, free-ranging bobwhites because we experienced low success recapturing bobwhites via night netting (i.e., only 1 recapture in 9 attempts). Thus, we opted to evaluate pen-raised bobwhites in a flight pen where recapture probability was assured.

We obtained 10 pen-raised bobwhites (adult males) from a local Texas game-bird breeder in January 2002. We banded all bobwhites and obtained initial body weights. We randomly selected 5 bobwhites for radiomarking using a 5- to 6-g, neck-loop radiotransmitter. We then injected 0.5100 ml of doubly labeled water into the breast muscle of each bobwhite. Two hours after the injection, we obtained an initial blood sample by puncturing the brachial vein and collecting 60 µl in a capillary tube, which was then flame-sealed. We released all 10 bobwhites into a 50- × 30- × 4-m flight pen. The flight pen contained natural vegetation, and birds were exposed to ambient weather conditions. Bobwhites were left in the pen for 2 days and allowed to walk freely. We flushed the bobwhites twice a day to simulate energy expenditure associated with flight of wild bobwhites. At the end of the 2 days, we recaptured all bobwhites and obtained a second blood sample using the same techniques used for the initial sample.

We submitted blood samples for analysis to the Laboratory of Biomedical and Environmental Sciences, University of California. Energy expenditure was reported as liters CO₂/kg day. We converted this measure into kcal/kg day using the conversion factor of 5.23 kcal/liter CO₂ (Nagy 1983). We report daily energy expenditure as kJ/g/day.

Statistical analysis

We analyzed each environmental chamber experiment separately. We compared initial body masses between treatment groups (i.e., radiomarked females vs. banded-only females and radiomarked males vs. banded-only males) at the beginning of each experiment using a *t*-test (Ott 1993). We analyzed change in body mass (Δ body mass = ending mass – initial mass) between treatment groups also using a *t*-test (Ott 1993). We used a repeated-measures ANOVA to test for the effect of treatment and gender over time on feed consumption using procedure MIXED (SAS 1998).

For the field experiment, we used randomization tests (Edgington 1995) to compare daily energy expenditure between radiomarked and banded-only bobwhites. The absolute difference between \bar{x} radiomarked and \bar{x} banded-only was the test statistic, and its distribution was estimated by 1,000 random permutations of the sequence of inter-treatment differences. The $|\bar{x}_{\text{radiomarked}(\text{random})} - \bar{x}_{\text{banded-only}(\text{random})}|$ was calculated for each of the possible permutations. The proportion of values of $|\bar{x}_{\text{radiomarked}(\text{random})} - \bar{x}_{\text{banded-only}(\text{random})}|$ that exceeded the observed value gave the *P* value (Edgington 1995). We report all results as $\bar{x} \pm \text{SE}$.

Results

Environmental chamber experiments

Two bobwhites (1 M, 1 F) from the banded-only group died during the summer experiment. This reduced our sample size to 20 radiomarked (10 males, 10 females) and 18 unmarked (9 M, 9 F) bobwhites. The cause of mortality was unknown.

There was no difference in initial body mass between radiomarked and banded-only females (*P* = 0.93; Table 1) or between radiomarked and banded-only males at the beginning of the summer experiment (*P* = 0.18; Table 1). Change in body mass was similar between treatment groups (*P* > 0.05; Table 1). We also documented no difference in feed consumption between radiomarked females (53.0 ± 8.7 g wet mass) and banded-only females (63.0 ± 6.1 g wet mass; *P* = 0.43) or between radiomarked males (60.5 ± 11.2 g wet mass) and banded-only males (58.9 ± 8.3 g wet mass; *P* = 0.90).

For the winter experiment, we documented no difference in initial body weight between radiomarked and banded-only females (*P* = 0.83; Table 1) or between radiomarked and banded-only males (*P* = 0.07; Table 1). Change in body mass was

Table 1. Comparison of mean difference in body mass (g) between radiomarked and banded-only northern bobwhite during a 21-day experiment in an environmental chamber simulating either summer (35°C daytime high; 15-hour photoperiod) or winter (4.4°C nighttime low; 10-hour photoperiod) conditions in southern Texas, Kingsville, Texas, September–October 2002.

Experiment		Beginning wt	Ending wt	Difference		Beginning wt	Ending wt	Difference	
Gender	<i>n</i>	$\bar{x} \pm SE$	$\bar{x} \pm SE$	$\bar{x} \pm SE$	<i>n</i>	$\bar{x} \pm SE$	$\bar{x} \pm SE$	$\bar{x} \pm SE$	<i>P-value</i>
Summer									
Females	10	183.4 ± 2.9	194.9 ± 2.3	11.5 ± 2.6	9	183.9 ± 4.1	195.5 ± 5.0	11.6 ± 2.5	0.97
Males	10	174.4 ± 4.3	181.2 ± 3.6	6.8 ± 1.5	9	182.3 ± 4.9	192.8 ± 5.2	10.5 ± 2.7	0.28
Pooled	20	178.9 ± 2.7	188.1 ± 2.6	9.2 ± 1.6	18	183.1 ± 3.1	194.2 ± 3.5	11.1 ± 1.8	0.43
Winter									
Females	10	196.4 ± 2.8	197.0 ± 1.9	0.6 ± 3.2	9	197.6 ± 4.5	196.3 ± 4.5	-1.3 ± 1.1	0.60
Males	10	183.5 ± 3.6	185.5 ± 4.2	2.0 ± 1.6	9	194.2 ± 5.3	193.9 ± 5.2	-0.3 ± 3.1	0.51
Pooled	20	190.8 ± 2.7	191.3 ± 2.6	1.3 ± 1.8	18	195.9 ± 3.4	195.1 ± 3.4	-0.8 ± 1.6	0.39

similar between treatment groups ($P > 0.05$; Table 1). There also was no difference in feed consumption between radiomarked females (62.4 ± 6.1 g wet mass; $P = 0.55$) and banded-only females (69.1 ± 6.8 g wet mass; $P = 0.35$) or between radiomarked males (75.8 ± 6.4 g wet mass) and banded-only males (64.7 ± 7.0 g wet mass; $P = 0.13$).

Simulated field experiment

We found no difference in daily energy expenditure between radiomarked (0.839 ± 0.056 kJ/g/day) and banded-only pen-raised bobwhites (0.804 ± 0.014 kJ/g/day; $P = 0.77$). We were able to recapture and obtain energy expenditure for one wild, free-ranging radiomarked bobwhite. Daily energy expenditure for the wild, free-ranging radiomarked bobwhite was 0.778 kJ/g/day.

Discussion

Radiomarking did not appear to affect body mass or feed consumption between radiomarked and banded-only bobwhites for either gender under the conditions of our study. Although it appeared that radiomarked males had lower body mass compared to banded-only males at the conclusion of both experiments, it is important to note that radiomarked males also began with lower initial body mass. Because treatments were assigned randomly, these lower initial weights exhibited by radiomarked males were due to random chance. A more appropriate indicator of treatment effect is change in body mass through time. The trend in body mass was positive for all radiomarked bobwhites during both summer and winter experiments. Banded-only bobwhites exhibited a positive trend in body mass during the summer experiment

but a negligible negative trend during the winter experiment.

Our results are similar to Corteville (1998) but are in contrast to Osbourne et al. (1997). Corteville (1998) evaluated the effects of diet (ad libitum and 20% restricted) and radiomarking on captive bobwhites. She documented no significant interaction between diet and treatment and no difference in body weight or lipid levels between radiomarked and banded-only bobwhites. Radiomarked bobwhites consistently maintained higher body weights than banded-only bobwhites (Corteville 1998). Corteville (1998) also compared body mass and lipid levels of wild, free-ranging bobwhites between radiomarked and banded-only groups at 2 sites (Mississippi and Florida). Although body mass varied temporally, bobwhites with and without radiotransmitters exhibited similar temporal trends. The presence of a radiotransmitter did not substantially alter either body mass or lipid mass (Corteville 1998).

In contrast, Osbourne et al. (1997) reported that control bobwhites had higher mean body mass (224.0 g) and lipid mass (18.6 g) at the conclusion of their 12-week study compared to radiomarked bobwhites with either backpack-style (215.5 g and 15.3 g, respectively) or bib-style transmitters (215.5 g and 14.7 g, respectively). Osbourne et al. (1997) proposed that radiomarking affected body composition of captive bobwhites in a negative manner. The estimated mean percentage body fat for their bobwhites was relatively low for the control (8.3%), backpack-style (7.1%), and bib-style transmitter groups (6.8%) compared to the range reported for wild bobwhites (Robel 1969, 1972; Koerth and Guthery 1987; Leif and Smith 1993; Corteville 1998). We note that our study was not directly com-

parable to Osbourne et al (1997) because their holding pens were larger ($4.8 \times 2.4 \times 1.2$ m) than the cages used in this study, and their experiment was of longer duration (12 weeks).

We also documented no difference in energy expenditure between radiomarked and banded-only bobwhites. This might have resulted from low sample size and therefore low power. However, both empirical data and theoretical reasoning provide support for our conclusion that radiomarking under the conditions of our study did not greatly impact energy expenditure of bobwhites. Similar to our findings, Sedinger et al. (1990) reported no difference in energy expenditure between captive radiomarked (467 kJ/kg) and control (594 kJ/kg) black brant (*Branta bernicla nigricans*). Sedinger et al. (1990) did not address the effects of carrying a transmitter during flight, which might be considerable (Gessaman and Nagy 1988). However, bobwhites primarily are ground dwellers that make occasional short-distance flights (Kassinis and Guthery 1996), and carrying radiotransmitters might not represent a considerable energy expenditure for bobwhites. Guthery (1999) estimated, using published studies (Case and Robel 1974, Fedak et al. 1974, Castro and Meyers 1988), that locomotion accounted for a small percentage (<10%) of daily energy expenditure for bobwhites. Thermoregulation accounted for the majority of bobwhite energy expenditure (Guthery 1999). Thus, assuming that radiomarking does not affect thermoregulation, the increase in cost of locomotion associated with radiomarking might be considered negligible relative to the overall energy budget, given a reasonable transmitter weight (e.g., 3–4% of body weight).

The assumption that radiomarking does not affect thermoregulation is plausible. Bakken et al. (1996) documented that heat production, net heat production, and short-term body mass loss did not differ significantly between radiomarked and control 1-day-old mallard (*Anas platyrhynchos*) ducklings. They concluded that their metabolic data did not indicate that ducklings equipped with external transmitters had

biologically significant increases in thermoregulatory metabolism compared to control ducklings.

It is worthy to compare our estimate of daily energy expenditure obtained using doubly labeled water to that obtained by Guthery (1999). Using the equations provided by Guthery (1999), a 180-g bobwhite subjected to an average ambient temperature of 20°C and 10-hour photoperiod, foraging for 5 hours at a velocity of 0.5 km/hour, would have a daily energy expenditure of about 140.1 kJ. We chose 20°C and a 10-hour photoperiod because it represented the mean monthly temperature and approximate photoperiod during our simulated field experiment (January 2002). Our estimate of daily energy expenditure for the wild, free-ranging radiomarked bobwhite was 0.778 kJ/g. Extrapolating to a 180-g bobwhite, our predicted estimate (140.0 kJ/day) closely approximated that of Guthery (1999). Our extrapolated estimates of daily energy expenditure for radiomarked and banded-only bobwhites also compared reasonably well (151.0 kJ and 144.7 kJ, respectively).

The biological significance of the additional 6.3 kJ/day expended by radiomarked bobwhites compared to banded-only bobwhites depends on whether radiomarked birds can meet this additional energy demand. Using previous studies (Robel et al. 1974, Lehmann 1984, Guthery 1999), we calculated that bobwhites can obtain about 166.4 kJ/day during winter (Table 2). Our estimated daily energy intake of 166.4 kJ is in excess of the 151.0 kJ and 144.7 kJ required by radiomarked and banded-only bobwhites, respectively. To the extent that Robel et al. (1974), Lehmann (1984), Guthery (1999), and this study are accurate reflections of reality and our interpretations of the research are correct, the additional energy demand placed on bobwhites by

Table 2. Estimated energy intake (kJ/day) of northern bobwhite during winter based on diet composition of Texas bobwhites. Lehmann (1984) provided data on winter diet composition, Robel et al. (1974) provided estimate of daily feed intake (g/day) for winter bobwhites, and Guthery (1999) provided arbitrary approximations for proportion of water and metabolizable energy (kJ/g) of food items.

Food item	Proportion of winter diet	Wet mass intake ^a (g/day)	Proportion water	Dry matter intake (g/day)	ME (kJ/g)	Energy intake (kJ/day)
Seeds	0.51	8.7	0.03	8.41	13.4	112.7
Invertebrates	0.23	3.9	0.70	1.17	18.8	22.1
Greens	0.10	1.7	0.95	0.09	10.5	0.9
Other	0.16	2.7	0.10	2.45	10.5	25.7
Totals	1.00	17.0		12.12		161.4

^a Wet mass intake = proportion of food item \times 17 g.

radiomarking does not appear to have biological significance.

Conclusions

Radiomarking might affect energy budgets by altering factors such as behavior (e.g., foraging), costs of locomotion, or thermoregulation. Our data do not indicate that radiomarking affected body mass, feed consumption, or energy expenditure of captive bobwhites. Most research does not suggest that radiomarking affects the energetics of ground-dwelling avian species that exhibit minimal flight or during life stages when time spent in flight is minimal (Sedinger et al. 1990, Bakken et al. 1996, Corteville, 1998; but see Gessaman and Nagy 1988 and Osbourne et al. 1997). However, we acknowledge that energy expenditure may not be similar between radiomarked and nonradioed bobwhites in field conditions with extreme weather (e.g., several days with subfreezing temperatures and extended snow cover). Further research should investigate possible effects of radiomarking on bobwhite behavior (e.g., flight characteristics, propensity to flush, predator avoidance, etc.).

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