Monitoring heart rate and body temperature in red foxes (*Vulpes vulpes*)

TERRY J. KREEGER
Department of Fisheries and Wildlife, University of Minnesota, St. Paul, MN 55108, U.S.A.
DANIEL MONSON
Alaska Office of Fish and Wildlife Research, U.S. Fish and Wildlife Service, Anchorage, AK 99504, U.S.A.
VALERIAN B. KUECHLE
Department of Ecology and Behavioral Biology, University of Minnesota, Minneapolis, MN 55455, U.S.A.
ULYSSES S. SEAL
Veteran's Administration Medical Center, Minneapolis, MN 55417, U.S.A.
AND
JOHN R. TESTER
Department of Ecology and Behavioral Biology, University of Minnesota, Minneapolis, MN 55455, U.S.A.

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Twenty-four captive-raised red foxes were surgically implanted with radios that transmitted both heart rate and body temperature. Successive fox pairs were placed in a 4.1-ha observation pen for 2 weeks and behavior was video recorded. The radio signal was recorded on the audio portion of the video tape for computer decoding. Heart rate and body temperature were measured for six behavior categories: sleeping, awake, hunting, feeding, running, and being chased. The heart rate for each of these categories was significantly different from any other ($P = 0.0001$). All body temperature categories were different from each other except for running and being chased ($P = 0.0001$). Both heart rate and body temperature increased with level of activity. The only significant difference in heart rate and body temperature between sexes was for the sleeping heart rate category, where females had higher values than males ($P = 0.04$). There was also a significant time of day effect showing that body temperature while awake was highest at night ($P = 0.0005$). Sleeping foxes displayed a pronounced sinus arrhythmia which disappeared when they became active.

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Vingt-quatre Renards roux élevés en captivité ont été opérés afin de les munir d'émetteurs radios permettant d'enregistrer leur rythme cardiaque et leur température interne. Des paires de ces renards ont été placées successivement dans une enceinte d'observation de 4,1 ha pour 2 semaines et leur comportement a été enregistré sur vidéo. Le rythme cardiaque et la température ont été mesurés en relation avec six catégories de comportement : sommeil, éveil, chasse, alimentation, course et fuite. Le rythme respiratoire s'est avéré particulier à chacune de ces catégories ($P = 0{,}0001$). La température interne différait aussi selon chacune des catégories, mais elle était la même lors de la course et lors de la fuite ($P = 0{,}0001$). Les deux variables augmentaient en fonction de l'intensité de l'activité. Le sexe n'entraînait qu'une seule différence significative : le rythme cardiaque durant le sommeil était plus élevé chez les femelles que chez les mâles ($P = 0{,}04$). Le moment de la journée avait aussi une influence significative qui se manifestait par une augmentation de la température du corps la nuit au cours de l'éveil ($P = 0{,}0005$). Durant le sommeil, les renards manifestaient une arhythmie sinusale prononcée qui disparaissait au moment où ils reprenaient leurs activités.

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Introduction

Heart rate (HR) and body temperature (BT) are dynamic physiological indices that can be used to assess relative energy costs as well as the internal milieu of an animal (Kimmich 1980). Monitoring such indices via radio telemetry allows normal response to environmental stimuli uninfluenced by chemical or physical restraint. Heart rate and (or) BT have been telemetrically recorded in several species of wildlife (Amlaner and MacDonald 1980) as well as in domestic dogs (*Canis familiaris*) (Marvin and Reese 1986). No studies, however, appear to have been conducted on wild canids.

The purpose of this study was to develop and test a radio telemetry device capable of transmitting both HR and BT of red foxes (*Vulpes vulpes*), as well as to establish base-line values with which responses to controlled manipulations of the animals' environment could be compared.

Methods

This study was conducted from October 1985 through March 1987 in east-central North Dakota, U.S.A. A total of 24 (12 female, 12 male) animals was used in this study. Dens were located by aerial searching in June, with removal of 8- to 12-week-old pups (Sargeant *et al.* 1981) by excavation. All pups were initially maintained in family units in 3.0 × 6.1 m wire mesh pens equipped with under- and above-ground den boxes. The foxes were fed frozen commercial mink food and provided water ad libitum. All animals were vaccinated for rabies, canine distemper, canine parvovirus, infectious canine hepatitis, leptospirosis, and parainfluenza. All were periodically treated for ecto- and endo-parasites. At 4–5 months of age, each animal was paired with an unrelated mate and the pair was housed separately.

At 7–10 months of age, a pair was selected for surgical implantation of an HR–BT radio transmitter (Cedar Creek Bioelectronics Laboratory, East Bethel, MN 55011). The animals were anesthetized

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175

and placed in dorsal recumbency and an area just distal to the xyphoid along the ventral midline was clipped and surgically scrubbed. The area clipped was minimized to prevent heat loss after recovery. Aseptic techniques were employed throughout the procedure. An 8-cm incision was made 2 cm distal to the xyphoid. Two sterile, 2-0 braided, stainless steel suture wires were preplaced through holes drilled perpendicular to the long axis of the transmitter at both ends. The sterilized transmitter was then inserted into the abdomen with the two HR electrodes emerging from the cranial aspect of the incision. The ends of the preplaced wire were drawn through the abdominal wall and under the skin 2 cm lateral to each side of the incision. After the linea alba was closed, the cranial and caudal suture wires were tied over the incision. Placement of the electrodes was accomplished by tunnelling subdermally in an anteriodorsal direction, starting from where the electrodes exited the incision. Subcutaneous tissue and skin were then closed with absorbable sutures.

The radio transmitter measured approximately 85 × 38 × 25 mm and weighed 105 g, representing approximately 2.0% of body weight. Transmitter life was about 40 days at an average HR of 200 beats per min (bpm). A radio frequency pulse was transmitted for each detected QRS complex. Temperature was transmitted as a pulse which was delayed after the HR pulse for a time dependent on temperature. Its pulse width (10 ms) was about half the width of the pulse transmitted for the QRS complex.

Electrocardiograph (ECG) signals were buffered by DC-coupled unity gain input amplifiers with an input impedance of approximately 1.0 MΩ. This results in a two-lead balanced system without dependency on lead impedance. Ground paths for bias currents were provided internally. A common mode rejection of greater than 100 dB was achieved using a charge transfer switching scheme. Signals were amplified 200 times by an AC-coupled amplifier with high and low frequency roll-off used to enhance valid signal detection and eliminate amplifier offset. The output of the amplifier was sent to a level detector which was set to trigger on signals at the input leads greater than 0.5 mV. All input signal processing was done using a single quad operational amplifier and a switching circuit.

Output of the comparator was sent to digital circuitry for temperature measurement and transmitter output control. A 175-ms blanking time was provided after comparator triggering to eliminate triggering on P-waves and to allow insertion of the temperature pulse. It also provided time for the ECG detection circuit to settle after transmission of the radio frequency pulses because these pulses could not be prevented from appearing at the comparator input. The 175-ms period was chosen to allow detection of heart rates to 340 bpm. Heart rates >340 bpm were transmitted at half the actual rate which was then corrected upon data analysis. The time delay to indicate temperature was controlled by a thermistor. This delay was a linear function of temperature with a slope of 18 ms/°C.

Data were recorded using a standard telemetry receiver (Cedar Creek Bioelectronics Laboratory, East Bethel, MN 55011) whose audio output was recorded on the audio channel of video recording tape. Recorded data were analyzed using a custom circuit to separate the wide heart rate pulses from the narrower temperature pulses. These pulses were then sent to a computer for measurement and recording. Using interrupts from an internal clock, assembly language routines measured times between heart pulses and between the heart and temperature pulses. Programming in BASIC called the assembly language routines and displayed or recorded the data.

The accuracy of the HR component of the transmitter was determined in two ways. The first was by electrocardiograms performed 2 weeks postsurgery, the transmitted HR being compared with ECG results. This comparison was performed on only the first pair of foxes equipped with transmitters at the start of the field season (October). Secondly, the HRs of all foxes were auscultated at the end of surgery and the counted rate was compared with the transmitted rate. Accuracy testing of the BT component was performed before surgery by placing the transmitter in a calibrated water bath. Transmitted BT could not be verified after surgery because core body temperature is not the same as rectal temperature; however, rectal temperature was taken at the time of surgery.

After a 2-week recovery period, the transmitter-equipped pair of foxes was anesthetized, transferred to a 4.1-ha observation pen, and placed in an underground den to recover. An elevated all-weather observation booth provided a view of the entire enclosure. Activity was video recorded from the booth (Panasonic Model Ag 6010 and WV1850, Panasonic Industrial Company, Secaucus, NJ 07094). A light-intensifying lens (Javelin Electronics, Los Angeles, CA 90502) enabled night observations to be made.

Analyses of HR and BT were conducted on six behavior categories. (1) Sleeping: the animal was either visibly asleep, or if in its den, it showed a pattern and rate similar to known data from sleeping foxes. (2) Resting: the animal was visibly awake, but not moving. Usually, this meant that the animal was lying down with its head up. (3) Hunting: the animal was moving in an exploratory fashion, i.e., it would walk, stop, and investigate an area, then continue walking. (4) Feeding: the animal was eating either provided food or naturally caught prey. (5) Running: the animal was running. It would sometimes appear to run spontaneously, but often it would be interacting with its mate. (6) Chased: six foxes were chased by a dog for approximately 5 min each.

All captive foxes had at least one continuous 24-h period recorded in addition to frequent shorter observations in the morning and evening. Data were analyzed by taking the mean HR for 75 beats to represent one data point for an individual behavior episode. The HR for the chased foxes represents a 75-beat mean taken when the HR was at its highest point during the chase. As BT was recorded simultaneously with each heartbeat, the BT data point also was the mean of 75 values. Data were analyzed further by sex and time of day. Time of day data were classified as sunrise (1 h before and after), daytime, sunset (1 h before and after), and nighttime. Continuous data for individual foxes were analyzed for heart rate patterns. Because of early technical difficulties, slightly more HR than BT data were recorded.

Statistical analyses were by one- and two-way ANOVA, and Fisher's LSD at a significance level of $P < 0.05$. Means are reported with standard errors.

Results

Accuracy of the transmitted HR compared with ECG recordings was >99%. The aboveground range of the transmitters was approximately 0.5 km and was reduced by about half when the animal was underground. There was no evidence of background noise attributable to skeletal muscle potentials. All foxes survived the surgery and no evidence of systemic infections was noted. Some foxes had a local reaction where the leads exited the abdominal incision. Animals having transmitters for >1 year invariably developed lesions at the electrode terminus. This was usually characterized by the loop or the stainless steel sleeve erupting from the skin to the outside. Removal of the loop at this point usually resulted in rapid healing.

The HR for each behavior category was significantly different from any other ($P = 0.0001$, Fig. 1). The only difference between sexes was for the sleeping HR, which was higher ($P = 0.04$) in females than in males (88.9 ± 1.7 vs. 84.2 ± 1.5). The HR showed no significant effect for time of day ($P = 0.13$).

The sleeping heart rate pattern was consistent with sinus arrhythmia, with a heart rate increase upon inspiration and a decrease upon expiration (Fig. 2). The arrhythmia appeared to be dampened during the resting state and absent at higher activity levels. The HR accelerated at 17.6 beats/s for the particular animal represented in Fig. 2 when it ran spontaneously.

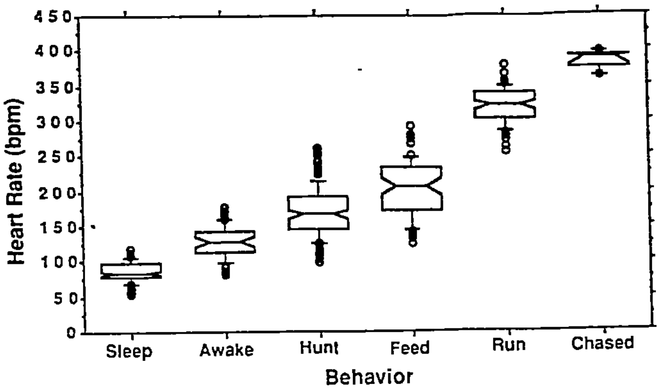

FIG. 1. Box plots of heart rates (HR) for various behaviors of captive red foxes. All HRs were significantly different from each other ($P = 0.0001$). Notches in the box plots represent 95% confidence bands about the median; the T-bars delimit 80% of the observed values. Sample sizes were as follows: sleep 179; rest 72; hunt 167; feed 64; run 75; chased 6.

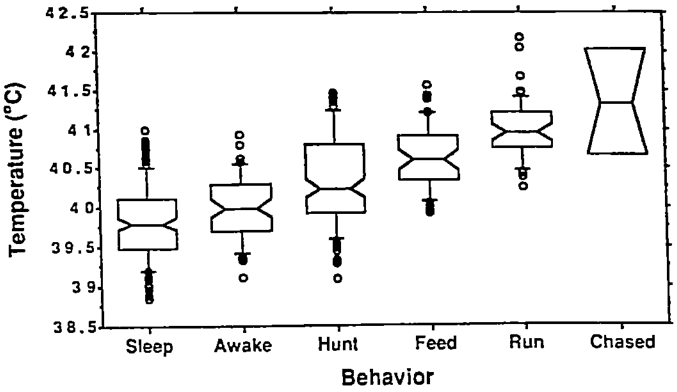

FIG. 3. Box plots of body temperatures (BT) for various behaviors of captive red foxes. All BTs were significantly different from each other except for running and being chased ($P = 0.0001$). See Fig. 1 for explanation of box plots. Sample sizes were as follows: sleep 155; rest 63; hunt 143; feed 51; run 51; chased 4.

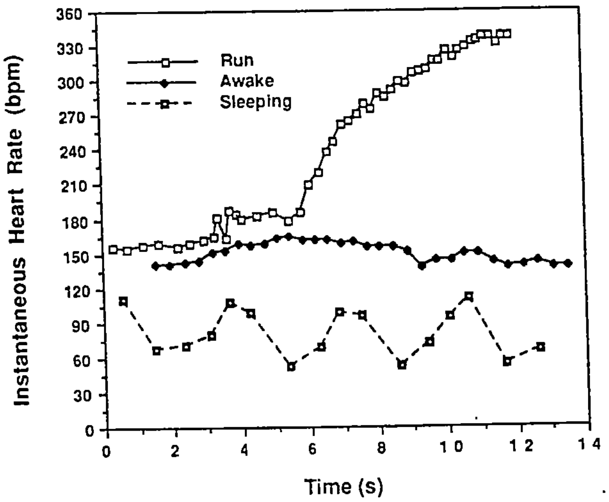

FIG. 2. Heart rate patterns of a single male red fox. Patterns were representative of levels of activity for all foxes studied. Sleeping pattern variances indicate respiratory sinus arrhythmia.

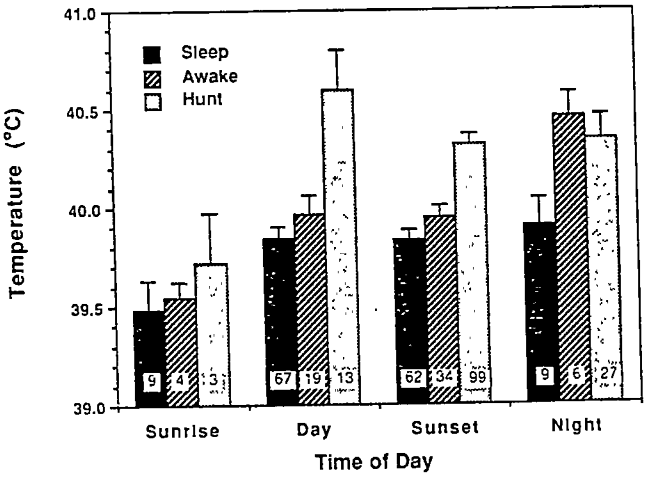

FIG. 4. Diurnal variation of body temperatures (BT) for sleeping, resting, and hunting behaviors of red foxes. Resting BT was lowest at sunrise and highest at night ($P = 0.0005$). See text for explanation of time groups. Numbers within bars represent sample sizes.

BTs, measured for the same behavior categories as HRs, were significantly different from each other between the 2 years of the study for every category except being chased, which was studied only in the 2nd year ($P = 0.03$). The 1st year's temperatures were consistently higher (by approximately 3°C) than the 2nd year's, owing to calibration errors between the two seasons. The 2nd year's BTs were lower than rectal temperatures. The two data sets were subsequently standardized by applying a correction factor to the 2nd year's data. Thus, although the reported mean BTs probably do not accurately reflect the core body temperatures of red foxes, the relative changes in BT due to differing activity levels were consistent. All BTs were significantly different from each other with the exception of running and being chased ($P = 0.0001$, Fig. 3).

There was no difference between sexes for any BT category ($P = 0.51$). There was a significant time of day effect for the resting BT category ($P = 0.0005$, Fig. 4), the sunrise BT being the lowest and night BT the highest. The sleeping and hunting BTs followed the same pattern as those in the resting category. There were not enough data points for the other categories to make these comparisons.

Discussion

The difference in sleeping HR between sexes was probably due to the difference in body weights. Males were significantly heavier than females (5.3 ± 0.2 vs. 4.6 ± 0.1 kg, $P = 0.01$) and smaller animals tend to have higher basal metabolic rates (Schmidt-Nielsen 1972). This is the first report of respiratory sinus arrhythmia (RSA) in red fox. Sinus arrhythmia has been described in fish (Shelton and Randall 1962), crocodilians (Huggins *et al.* 1969), woodchucks (*Marmota monax*) (Smith and Causby 1980), dogs (Anrep *et al.* 1936), cats (Eldridge 1972), and humans (Melcher 1976). It is thought that RSA depends on autonomic activity via rhythmic alteration of vagal impulses to the sinoatrial node (Wheeler and Watkins 1973). The exact neurophysiological mechanism of RSA is unknown, but most findings indicate that RSA reduces HR when oxygen is less abundant (Smith and Causby 1980). Thus, during expiration, HR decreases. The adaptive significance of this in red foxes is not known. The only other report of RSA in free-ranging wild animals was in the woodchuck (Smith and Causby 1980); the authors suggested that RSA may be adaptive to the fossorial and low-oxygen environment of these animals by decreasing cardiac output between breaths. However, the fact that dogs, cats, and foxes demonstrate RSA and are not fossorial does not support this as a universal theory. The RSA found in foxes can be used to determine sleeping respiratory rates by graphing the HR and counting the peaks or valleys. The sleeping respiratory rate of foxes in this study was 16–20 respirations per min (rpm). Inspiration increased HR in foxes by 86.0% above expiration values, which was virtually identical with the percent difference between minimum and maximum HRs reported for woodchucks (87.5%, Smith and Causby 1980).

The RSA was virtually absent when foxes were awake. The relative unchanging HR of the resting, but not moving, fox was characteristic (Fig. 2). Indeed, the sleeping and resting patterns were consistent enough to allow recognition of these behaviors even if the animal could not be observed.

BTs increased with the degree of physical exertion (Fig. 3), which was not surprising as BT is related to activity level (Nielsen 1969). Increased BT in response to increased activity is an adaptive mechanism to increase the rate of chemical reactions in active tissues (McArdle *et al.* 1986).

The diurnal variation in BT was interesting. Foxes are primarily nocturnal, with peak activity at sunrise and sunset (Maurel 1980; Tester 1987). Nocturnal activity generally begins 1 h after sunset and ends 1 h before sunrise (Maurel 1980). The variation in the resting BT for red foxes suggested differing diurnal physiological settings, as is also reported for wolverine (*Gulo gulo*), opossum (*Didelphis virginiana*), and humans (Folk and Folk 1980). Folk and Folk (1980) stated that examination of most mammals would probably reveal two classes of resting BT, representing high and low physiological settings. The lowest BT was at sunrise, the highest at night when foxes were most active. The higher daytime hunting BT could have been a function of higher ambient temperatures contributing to a base-line BT for this activity.

This study has demonstrated that radio telemetry can reliably transmit physiological indices in unrestrained red foxes. This technology could be used to evaluate psychogenic and physiological responses to various environmental and human stressors, to estimate energy expenditure, to monitor response to novel and repetitious stimuli such as prey, or to assess inter- and intra-specific relationships. Combining video monitoring with heart rate – body temperature data collection provides a more accurate assessment of an animal's physiological state during a given behavior. We have viewed situations in which the outward appearance of a fox was unremarkable, but its elevated heart rate indicated quite a different internal state. Thus, monitoring heart rate while viewing behavior allows the ethologist or physiologist to better understand and evaluate an animal's response to its environment.

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