Techniques and Technology Note

Simultaneous Collection of Body Temperature and Activity Data in Burrowing Mammals: a New Technique

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ABSTRACT Integrating physiological and behavioral observations into ecological field studies of animals can provide novel insights into relationships among animal behavior, physiology, and ecology. We describe and evaluate a new technique for simultaneously collecting body temperature (T_b) and burrow use data for semi-fossorial mammals by combining light-sensitive radiotransmitters and implanted temperature-sensitive dataloggers. We used this approach to collect core T_b and activity data for 9 free-ranging arctic ground squirrels (*Spermophilus parryii*) in northern Alaska, USA, at approximately 5-minute intervals for 30–90 days each to address questions related to thermoregulation, energetics, foraging, sociality, and timing of activity in natural environments. (JOURNAL OF WILDLIFE MANAGEMENT 71(4):1375–1379; 2007)

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Effective integration of physiological and behavioral research techniques into ecological field studies can provide important and novel insights into the influence of specific behaviors on individual fitness. For example, small mammals change behavior to balance costs of thermoregulation with a need for energy from foraging (Bennett et al. 1984, Long et al. 2005), and feeding time of large mammals may sometimes be constrained by the need to maintain thermal equilibrium over extended periods of time (Belovsky 1981).

Advances in radiotelemetry and Global Positioning System (GPS) technology have improved the ease and accuracy with which spatiotemporal data can be collected for free-ranging animals (Merrill and Mech 2003). These data are used to evaluate patterns of movement, resource selection, spatial distribution, and activity to provide information relevant to the ecology and management of a population (Manly et al. 2002, Naylor and Kie 2004). Radiotelemetry also has been used effectively to monitor the body temperature (T_b) of free-ranging animals over extended periods of time (Golightly and Ohmart 1978, Zervanos and Salsbury 2003) in studies of behavioral thermoregulation and energetics. Few attempts have been made, however, to monitor behavioral and physiological parameters of free-ranging animals simultaneously with equivalent levels of frequency and precision. Field studies in which both behavioral and physiological data were collected fall into 2 categories: 1) location or activity data were collected throughout the study via radiotelemetry or GPS collars with occasional measures of physiological parameters such as T_b, body mass, or blood parameters associated with capture events; or 2) T_b was measured via radiotelemetry and behavioral data were collected by observing focal animals over select and relatively brief intervals (Chappell 1981, Vispo and Bakken 1993). Direct observation of animals in the field, however, is often limited by vegetation, topography, nocturnal habits, long-distance movements, or simple logistics (Gillingham and Bunnell 1985). In these cases, statistical analyses may be conducted at a relatively coarse temporal scale and results are more general than would be possible if consistent short-interval behavioral data were also available.

Consistent and simultaneous collection of short-interval data on behavior and T_b should improve understanding of the interrelationships among animal behavior, physiology, and ecology. Although surgically implanted dataloggers have been used previously to collect short-interval T_b data for some species (Boyer and Barnes 1999, Pulawa and Florant 2000), we know of only 2 studies in which light-sensitive transmitters were used to monitor activity (Hut et al. 1999, Long et al. 2005). The combined use of implanted dataloggers and light-sensitive transmitters represents a novel technique for simultaneous collection of short-interval T_b and activity data. The objective of this study was to evaluate the use of light-sensitive radiocollars together with implanted temperature-sensitive dataloggers to simultaneously record core T_b and activity patterns of burrowing mammals. Specifically, we evaluated this new technique based on equipment costs, quality and quantity of resulting data, and broadness of application to a variety of research questions. In addition, we describe technical challenges encountered during our application of this technique, as well as considerations for data analysis.

STUDY AREA

We monitored T_b and activity patterns of free-ranging arctic ground squirrels (*Spermophilus parryii*) from 10 May to 10 August 2001 near the Toolik Field Station (68°38′N, 149°38′W; elevation 809 m) operated by the Institute of Arctic Biology (University of Alaska Fairbanks) in the northern foothills of the Brooks Range, Alaska, USA. The study site consisted of about 50 ha along the eastern shore of Toolik Lake; detailed descriptions of vegetation and terrain

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on the study site are provided by Buck and Barnes (1999) and Long et al. (2005).

METHODS

Body Temperature and Handling

We live-trapped 12 adult ground squirrels (7 F, 5 M; body mass = 500–1,000 g) from 10 May to 17 May, and we trapped 2 additional ground squirrels (1 F, 1 M) on 3 June and 29 June, respectively. We anesthetized each ground squirrel with methoxyflurane (Metofane; Pitman-Moore, Washington Crossing, NJ) vapors within 24 hours for surgery (Long et al. 2005). For T_b measurements, we used Stowaway Tidbit temperature dataloggers (Onset Computer Corporation, Bourne, MA) programmed to record at 5-minute intervals, which allowed for 110 days of continuous recordings. Prior to implantation, we calibrated each logger in a waterbath, enveloped them in one layer of plastic heat-shrink tubing, and coated them with 3 thin layers of biologically inert plasticized-wax heated to 80° C (Elvax; Mini-Mitter Co., Sunriver, OR). Total package mass was 12–13 g. We inserted data loggers into the peritoneal cavity through a 2–3-cm midline incision in the skin and linea alba made in the ventrum beginning approximately 2 cm above the genitals. We closed the incision in 3 layers: the linea alba using absorbable sutures (chromic gut, size 3–0), subcutaneous tissue with synthetic absorbable suture (Dexon, 3–0), and skin with synthetic nonabsorbable suture (Prolene, 3–0). We held ground squirrels captive for 24 hours following surgery and checked for the integrity of the sutures before releasing them at the site of capture (Long et al. 2005). We removed temperature loggers by a second surgery during 4–10 August and downloaded data using an Optic Base Station (Onset Computer Corporation) linked to a laptop computer. No adverse physiological or anatomical effects were apparent in abdominal cavities of ground squirrels at this time (Long et al. 2005). The Institutional Animal Care and Use Committee at the University of Alaska Fairbanks (permit no. 01–30) approved all procedures.

Telemetry

We used radiotelemetry to monitor when ground squirrels were above or below ground. Prior to release following surgery, we placed ground squirrels under light anesthesia and fitted them with light-sensitive crystal-controlled radiotransmitters (model TXP-1/L; Televilt International AB, Lindesberg, Sweden) attached to neck collars formed from 30-cm antennas (Hut et al. 1999, Long et al. 2005). Collars consisted of one turn of the antenna wire covered with soft plastic tubing secured using 2 small zip ties. Collar and transmitter mass was 18–20 g, and estimated battery life of transmitters was 10 months.

The interpulse interval of the transmitter signal coded for ambient light intensity and we used it to infer presence of telemetered ground squirrels above or below ground. This interval varied discreetly between about 2,000 milliseconds (ms) in ambient light intensities <0.03 lux (below ground) and 1,200 ms at light intensities >0.03 lux (above ground; Hut et al. 1999, Long et al. 2005). The 0.03-lux threshold represented a very low level of light, roughly 2 orders of magnitude less than the amount of light produced by a regular wax candle at a distance of 1 m. The value of this threshold was previously determined by Hut et al. (1999), and was useful in this study because the only environment available to ground squirrels dark enough to cause the transmitters to produce a consistently dark interpulse interval was the burrow. A photosensor located on the ventral side of the transmitter modulated the pulse interval when light intensity increased above the 0.03-lux threshold. At the time of this study, the value of the light threshold could not be modified by the user. Each transmitter was identified by a unique radio frequency between 148 MHz and 150 MHz, with a minimum separation of 0.01 MHz between transmitters.

We recorded telemetry signals for each ground squirrel every 1–5 minutes using 1 of 4 multichannel data-logging receivers (model RX900, Televilt, and model TR-5; Telonics, Mesa, AZ). We connected 2 receivers to omni-directional antennas placed atop anchored masts, roughly 6 m in height, near the center of the study site, and connected the remaining 2 to directional antennas placed atop masts of similar height at opposite ends of the study site. Each receiver was powered with a 12-V car battery that we exchanged every 4 days to maintain constant power to the receivers. We sampled transmitter frequencies in a continuous loop, with receivers remaining tuned to each frequency for 10–20 seconds depending on signal strength. We downloaded data from each receiver biweekly. Occasionally, the interpulse intervals included aberrant values resulting from positional changes of the animals, general noise on the frequency band being scanned, or missed pulses. We filtered out these values based on the following 2 criteria developed by Hut et al. (1999): 1) the pulse interval was outside the range from minimal (light) to maximal (dark) values; or 2) the pulse interval deviated >50 ms from the preceding or following series of 50 measurements.

Validation of Telemetry Data

Prior to placement on a ground squirrel, we tested each transmitter for consistency of the pulse interval in the 2 respective light environments by placing the transmitter in a known-light environment and continuously recording the pulse interval for roughly 30 minutes. We also tested transmitters for lag time in response to an instantaneous light–dark transition using a receiver and hand-held stop-watch. In addition, we conducted behavioral observations at 1-minute intervals over one daily active period each for 6 ground squirrels (total observation time of approx. 90 hr) in order to corroborate telemetry data with observed presence above or below ground.

RESULTS

Of 14 temperature dataloggers implanted during our study, 11 reliably recorded T_b every 5 minutes. Three loggers failed due to an electrical short caused by contact with metal

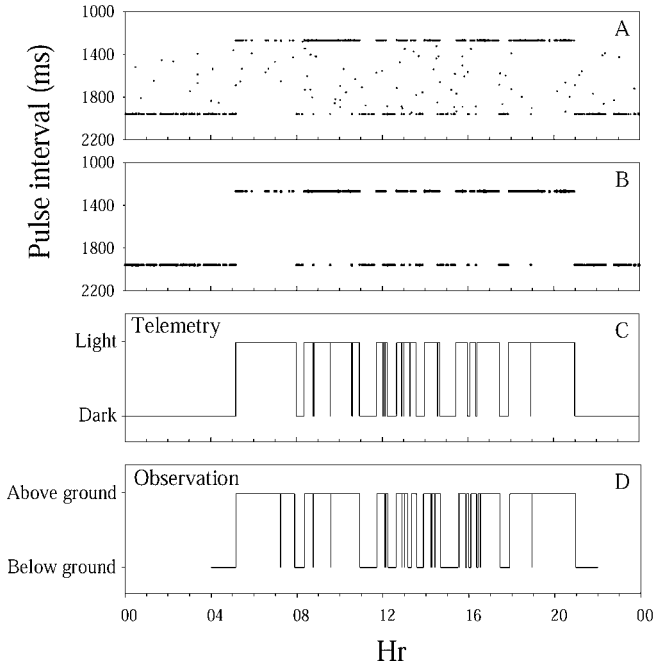

Figure 1. Patterns of burrow use for a female arctic ground squirrel near Toolik Lake, Alaska, USA, on 16 July 2001 based on radiotelemetry and direct observation. (A) Raw pulse interval data in milliseconds (ms) produced by a light-sensitive radiotransmitter. (B) Same data filtered to exclude aberrant values (see text). (C) Actogram constructed from the telemetry data of panel B indicating presence above (light) or below (dark) ground. (D) Simultaneous observations of presence above or below ground collected at 1-minute intervals from 0400 hours to 2200 hours.

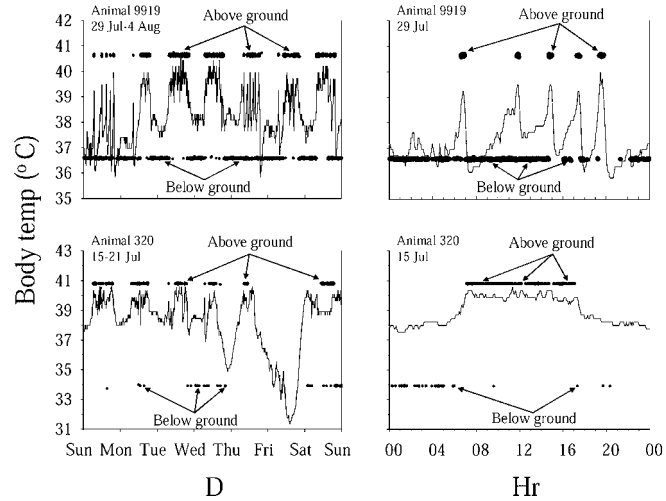

Figure 2. Body temperature (T_b; ° C) and patterns of burrow use for 2 arctic ground squirrels near Toolik Lake, Alaska, USA, during 2001. We plotted data for each ground squirrel for one continuous week and for one full day. The burrow system of ground squirrel number 9919 was located within line-of-sight of 1 of 4 antennas used to monitor signals from the light-sensitive transmitters; the burrow system of ground squirrel number 320 was located on the opposite side of a small hill from the nearest antenna.

scissors used to trim the heat-shrink tubing covering the loggers. Three mortalities (2 capture-related and 1 surgery-related) occurred between 15 May and 15 June. One additional mortality from predation occurred on 23 June. Radiocollars were maintained on 12 of 14 ground squirrels until mortality or final capture occurred in August; we removed the collars from 2 males due to wear of fur and skin underneath. For 11 of 14 ground squirrels a single transmitter functioned continuously until mortality or final capture. Failure of transmitters on remaining ground squirrels was due to moisture leaking into the plastic packaging of the transmitters. Data loss from failed transmitters was minimal, however, as we were generally able to replace faulty transmitters within 24 hours. The combination of mortality and equipment failure resulted in a final sample size of 9 ground squirrels (5 F, 4 M) for which we collected T_b and activity data simultaneously for $\geq$30 days (we collected data for 6 ground squirrels for the duration of the study).

Overall, quality of telemetry data was high and aberrant values comprised <5% of daily activity data for each ground squirrel. Pulse intervals of the light-sensitive transmitters generally were accurate to within 10 ms and lag time in response to an instantaneous change in the light environment did not exceed 1 second. In addition, pulse intervals were reliable indicators of presence of focal ground squirrels above or below ground (Fig. 1). Similarity between observational data and telemetry data was about 90%, and inconsistencies between the 2 methods were related to very short burrow visits (typically <5 min) that occurred between 2 consecutive sampling bouts (Fig. 1). We consistently recorded telemetry data every 1–5 minutes for ground squirrels using burrow systems located within line-of-sight of an antenna ($n = 6$; Fig. 2), as ground squirrels typically remained within 100 m of their burrows. We recorded signals less frequently for ground squirrels using burrows that were fully or partially obscured from antennas as a result of topography ($n = 3$; Fig. 2). In those instances, recorded pulse intervals consisted primarily of light signals, as pulse intervals produced while ground squirrels were in burrows were inhibited more by topographical features such as rocks or hills than those produced while ground squirrels were on the surface. Additional gaps in telemetry data occurred occasionally for all ground squirrels as a result of extreme weather conditions, interference from engines and electronic devices, and temporary movement of ground squirrels behind buildings at the field station, rocks, or other features of the terrain that interfered with reception of transmitter signals. The abundance of high-quality data we obtained made it possible to evaluate general patterns of T_b and burrow use over relatively long time periods or to conduct more detailed analyses on a daily or sub-daily basis (Fig. 2).

At the time of this study, total cost per animal of temperature loggers and light-sensitive transmitters was US$109 and $313, respectively. Data-logging receivers were substantially more expensive, at a price of about $3,500 per receiver for the 2 Telonics units and $5,000 per receiver for the 2 Televilt units. Overall cost of surgical and other supplies necessary for logger implantation (e.g., heat-shrink tubing and Elvax) was roughly $2 per animal.

DISCUSSION

Combining light-sensitive radiotransmitters with temperature-sensitive dataloggers was a useful technique for collecting short-interval T_b and activity data for 9 free-living arctic ground squirrels during long intervals of their active season, with partial data from an additional 5 animals limited by mortality or malfunction of dataloggers. Only a small proportion (<5%) of each activity data set consisted of aberrant values and modulation of pulse intervals on entry into or exit from burrows was nearly instantaneous. Because the light-intensity response threshold of the transmitters (0.03 lux) was relatively sensitive, burrows were the only environment available to ground squirrels dark enough to cause transmitters to produce "dark" pulse intervals. In addition, although topography prevented consistent recording of telemetry signals for some ground squirrels, quantity of activity data collected during our study was substantially greater than previous studies of burrowing mammals in which both behavioral and physiological parameters were measured (Chappell and Bartholomew 1981, Vispo and Bakken 1993). For individuals for which transmitter signals were often obscured, we recorded presence above or below ground much more frequently than would have been possible by direct observation, and activity data for other animals were nearly continuous. Topography near Toolik Lake, Alaska, however, is relatively flat, and vegetation in this tundra and heath environment is primarily low growing. Continuous collection of telemetry data may be more challenging in topographically complex environments or in environments with higher densities of trees or shrubs (Rempel et al. 1995, D'Eon et al. 2002). Consistent collection of telemetry data in those environments may necessitate the placement of antennas atop higher masts than used in this study or increasing the number of receivers and antennas placed within the study area. Failure of transmitters due to leakage of water could easily be eliminated by improving the waterproof quality of the transmitter covering.

Short-interval data on T_b and burrow use activity could be used to address a variety of questions related to behavioral and physiological ecology of burrowing mammals. For example, Long et al. (2005) used these data to evaluate the role of a series of thermal and nonthermal variables on the amount of time each day individual ground squirrels committed to above-ground activity. Similar data were used by Hut et al. (1999, 2002) to investigate diurnal rhythmicity in burrowing mammals, with the resulting hypothesis that diurnal ground squirrels may use subtle changes in light intensity to entrain circadian rhythms as they self-select their photic environment by entering and exiting burrows. We suggest that the technique described here represents a powerful new means of addressing these and similar questions of interest in the fields of mammalian behavior, physiology, and ecology.

Despite the many potential applications of this technique, there are at least 2 challenges associated with analysis of the resulting data that should be considered by researchers contemplating use of the technique. First, data collected at 1–5-minute intervals are not statistically independent within an individual, which can affect the validity of statistical analyses depending on the question being asked (Neter et al. 1996). A second potential problem is identifying an appropriate sampling unit for analysis, and a trade-off may exist between analyzing data at a fine temporal scale and maintaining sufficient independence among sampling units. Long et al. (2005) described one solution to this problem, but the appropriateness of pooling data across various periods of time will depend on goals of the analysis, and we caution researchers to consider this problem carefully. A final point of concern is that although T_b and activity data are collected at short intervals using this technique, rarely are data from the transmitters and temperature loggers recorded at precisely the same moment. As a result, criteria such as those described by Long et al. (2005) may need to be developed to determine for each record of T_b whether a focal animal was above or below ground.

The combined use of implanted temperature loggers and light-sensitive transmitters to simultaneously collect short-interval T_b and activity data represents a unique tool to aid researchers in testing hypotheses related to the physiological and behavioral ecology of burrowing mammals. Equipment necessary to implement the technique is moderately priced, and the quantity and quality of physiological and behavioral data that can be acquired make the technique cost-effective. This technique could be adaptable to a variety of mammalian species, and it is our hope that its use will provide new insights into the relationships among behavior, physiology, and ecology of burrowing mammals.

MANAGEMENT IMPLICATIONS

Management and conservation of semi-fossorial mammals requires detailed knowledge of relationships among behavior, physiology, and fitness. Simultaneous collection of short-interval T_b and activity data may often provide important insights into such relationships, and we, therefore, recommend that managers and researchers attempt to incorporate this technique into studies of burrowing mammals whenever possible. We caution, however, that the technique may be less effective in topographically complex environments, and that care must be taken to ensure appropriate analysis of data resulting from application of the technique.

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