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BRIEF REPORT

Remote Monitoring of Primates Using Automated GPS Technology in Open Habitats

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Automated tracking using a satellite global position system (GPS) has major potential as a research tool in studies of primate ecology. However, implementation has been limited, at least partly because of technological difficulties associated with the dense forest habitat of many primates. In contrast, primates inhabiting relatively open environments may provide ideal subjects for use of GPS collars, yet no empirical tests have evaluated this proposition. Here, we used an automated GPS collar to record the locations, approximate body surface temperature, and activity for an adult female baboon during 90 days in the savannah habitat of Amboseli, Kenya. Given the GPS collar's impressive reliability, high spatial accuracy, other associated measurements, and low impact on the study animal, our results indicate the great potential of applying GPS technology to research on wild primates. Am. J. Primatol. 70:1–5, 2008. © 2008 Wiley-Liss, Inc.

Key words: Amboseli; *Papio cynocephalus*; GPS collar tracking; wild baboons; temperature and activity monitoring

INTRODUCTION

Recent technological advances in satellite global positioning systems (GPS) and geographic information systems have revolutionized the field of wildlife telemetry, enabling researchers to greatly improve the overall quality and quantity of movement data collection and analysis compared with results obtained with traditional observational or tracking techniques [Harris et al., 1990; Millspaugh & Marzluff, 2001]. In particular, the use of automated systems enables researchers to record the locations of many individuals or groups efficiently and accurately on a pre-determined schedule, thereby optimizing researcher effort in the field and minimizing disturbance to study animals. Nonetheless, remarkably few studies of primates have utilized the advances of such a technology. This shortcoming is attributed to the difficulty in obtaining accurate GPS readings under the dense forest canopy characteristic of the habitat of many primates [Phillips et al., 1998; Sprague et al., 2004]. Some authors have suggested that results may be better for primates in open environments [e.g., Phillips et al., 1998], a proposition that has not yet been tested in the field.

The long-term monitoring of wild baboons (*Papio cynocephalus*) as a part of the Amboseli Baboon Research Project provides an ideal opportunity for evaluating the applicability of automated GPS technology to the study of wild primates in relatively open habitats. The study area is in Amboseli basin, Kenya (2°40′S 37°15′E, 1100 m altitude), a semi-arid, short-grass savannah with interspersed woodlands of *Acacia xanthophloea* and *A. tortilis*; for thorough ecosystem description, see Alberts et al. [2005]. Our history of success both in obtaining GPS readings with hand-held units and in attaching very high frequency (VHF) collar devices to females suggested considerable potential for utilizing GPS-enabled collars on study animals. Building on our ongoing project, here we present the results of a pilot project involving the tracking of a single female baboon in the Amboseli population to (1) test the reliability of the GPS data collection, (2) compare temperature data provided by the automated collar (body surface temperature) with air temperature collected at our nearby camp weather station, and (3) evaluate the relationship between travel and activity measures.

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METHODS

We deployed a GPS G2110 store-on-board collar (Advanced Telemetry Systems, Inc., Isanti, MN) on an adult female baboon in one of our study groups from 11 March 2006 to 08 June 2006. The collar weighed approximately 350 g, roughly 3% of the female's body mass and substantially less than the 5% of body mass recommended for maximum collar weight [American Society of Mammalogists, 1998]. It was programmed to record hourly positions daily between 0500 and 2100, a time window that began >1 hr before the baboons' morning descent from sleeping groves and ended >2 hr after evening ascent into sleeping groves. This schedule thus provided complete data on daily ranging patterns and included some time spent in trees, while also conserving battery life when the baboons were sedentary after dark. The collar was programmed to ''skip'' a reading attempt if no position was recorded within 120 sec, unless the unit determined satellite connections were imminent in which case the time window was extended. On a separate duty schedule (0600–1800), the collar emitted a VHF transmitter signal (powered by the same battery) that permitted observers to locate the animal/collar with traditional radio-telemetry techniques.

Collar deployment required immobilizing the subject for collar attachment. We darted the female from within 10 m using a blowpipe to inject a syringe containing Telazol^{TM} (Fort Dodge, IN); for details, see Altmann et al. [1993] and Sapolsky and Altmann [1991]. We made continuous qualitative observations of the females' behavior and appearance for over an hour before, during, and post-collar deployment. Because the collar was equipped with a release mechanism pre-programmed to automatically disengage 90 days after deployment, no recapture was needed to retrieve the collar/data.

The GPS collar was equipped with a sensor that recorded temperature whenever a locational fix was taken. As in previous Amboseli Baboon Research Project collar deployments, we adjusted the length of the collar such that it fitted loosely against the animal's neck to avoid skin infections and ectoparasite infestations; sized in this way, the temperature sensor rested loosely on the fur of the baboon's neck; we consider it to provide an estimate of the animal's surface temperature. We investigated daily temperature patterns from these recordings by calculating the average temperature value across days for each hour of the day. We qualitatively compared these patterns to approximate core temperature for baboons and to meteorological data automatically recorded at the same times at a weather station (WeatherHawk, Inc., Logan, UT) established at our nearby research camp (the collared animal ranged 2–17 km from camp during this study).

An additional feature of the GPS unit we tested was an activity sensor, which recorded a cumulative count of tilt switch movements (i.e., times that the baboon's head moved up/down or left/right; hereafter called ''toggles'') since the last successful GPS reading. We investigated hourly activity patterns by calculating the average toggles for each hour across days. We also calculated travel rate (m/hr) during this time window by determining the straight-line distance between successive GPS locations ($n = 1{,}484$) and quantitatively compared patterns obtained by the two types of data. Because the 0500 recording represented total toggles since the last hourly reading at 2100 the previous evening, we divided that total by 8 to obtain the average hourly toggles for 0500.

RESULTS

The GPS collar operated for 144 days once initialized at the field site, including 1 day testing before deployment, 90 days deployment on the baboon, and 52 days post-deployment at our research camp. During the 88 days of full-day field deployment, the collar recorded a total of 1,485 locations out of 1,496 programmed opportunities, a 99.3% success rate. These locations were acquired while the baboon ranged through or rested within a variety of habitat types, including tree groves, open savannah, and shrubland. As with our use of VHF collars, the GPS-collared female exhibited typical foraging, mating, ranging, and social behaviors for the duration of collar attachment. No injuries or illness either directly or indirectly associated with wearing the collar was observed during the study.

Average time required by the collar to obtain a GPS reading was less than a minute (mean 50.9 sec ± 18.59 SD, range 36–144 sec). Average fix times were longest in early morning (0500) and evening (1900–2100) hours, when baboons were arboreal in sleeping groves (0500 and 1900–2100: mean 64.2 sec ± 24.23 SD; during 0600–1800: mean 46.8 sec ± 14.15 SD). Accuracy of the GPS collar readings was high (mean position dilution of precision (PDOP) = 3.0 ± 1.05 SD, range 0.0–6.0). Considering categories of PDOP accuracy [British Colombia Ministry of Environment, Lands and Parks, 2001], 84% of the PDOP values we obtained were highly accurate (PDOP <4), 16% were acceptably accurate (PDOP 4–8), and 0% were poorly accurate (PDOP >8). PDOP values from 0800 to 1800 were slightly more accurate than those from the earliest and latest hours.

Mean temperature recorded by the collar was 32.6°C ± 2.48 SD, range 25.5–38.9°C, reflecting effects of both baboon core body temperature [38°C in air temperature of 25°C; Funkhouser et al., 1967; Hiley, 1976] and ambient conditions, as expected at the skin (Fig. 1a). Although variability in temperature across hours of the day generally followed the same pattern for the collar as that for air

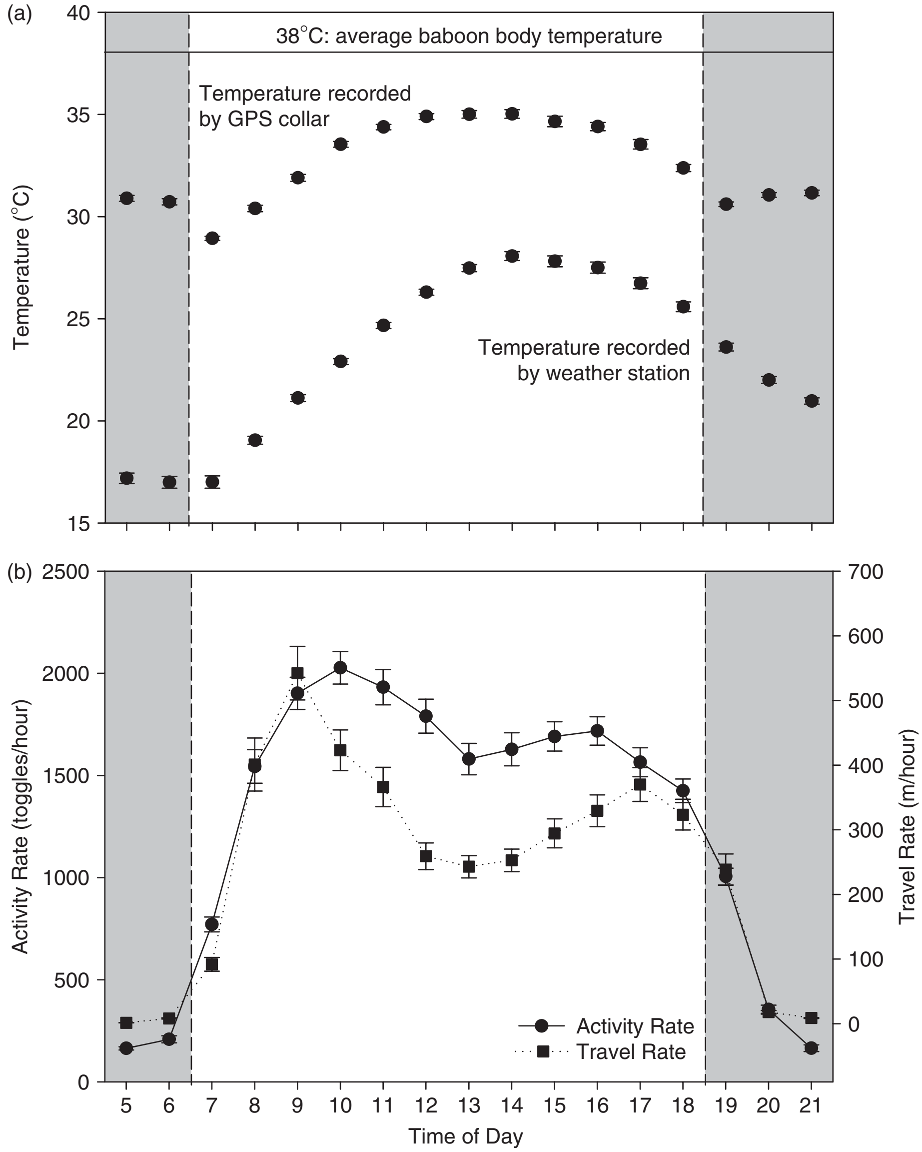

Fig. 1. Daily patterns in (**a**) in temperature recorded by GPS collar outfitted on a wild baboon and recorded at the Amboseli Baboon Research Project weather station, and (**b**) activity rate (toggles/hr) and travel rate (m/hr) for a GPS collar outfitted on a wild baboon; horizontal line at 38°C represents average baboon core body temperature in air temperature of 25°C [Funkhouser et al., 1967; Hiley, 1976]. Hourly values represent rates over the preceding time interval. Gray shading indicates hours during which baboons are typically in sleeping groves; points and error bars represent mean ± SE.

temperature recorded from our base camp weather station, the two sources of temperature readings differed quantitatively; temperature at the female's neck differed from air temperature most in the early morning (maximum difference at 0600: mean 13.69°C ± 2.80 SD) and least in late afternoon (minimum difference at 1500: mean 6.70°C ± 2.28 SD).

Mean collar-recorded activity was 1,262.8 toggles/hr ± 878.56 SD, range 0–4,685. Daily patterns indicated a steady increase in activity during the morning hours, a slight midday depression, and then a decrease again in late afternoon until sunset (Fig. 1b). Travel rates calculated from the collar's GPS data (m/hr) followed a similar daily pattern, with a midday depression bracketed by morning and evening peaks in travel around 0900 and 1700, respectively (Fig. 1b). From 0700 to 1900 (typical hours of daylight activity in Amboseli), hour of the day and travel rate both contributed significantly to activity rate in a univariate analysis of variance (adjusted $R^2 = 0.252$, $F = 30.4$, df = 12; $P < 0.0005$ for overall model and also for both travel rate and hour of the day). Unsurprisingly, during hours of darkness (0500–0600 and 1900–2100) when the baboons are in trees, usually sleeping, collar-recorded activity was much lower than that during daylight hours (0700–1800): mean 380.0 toggles/hr ± 388.86 SD, range 0–2,252 for nighttime hours, and a mean 1,630.2 toggles/hr ± 755.07 SD, range 94–4,685 for daylight hours. Nonetheless, despite the virtual absence of locomotion at night, nocturnal activity also varied more than ten-fold across days (34.13–396.88 toggles/hr).

DISCUSSION

Our results demonstrate that an automated GPS collar successfully captured location data as well as several other types of information, thereby providing reliable remote behavioral and physiological monitoring of a savannah-dwelling wild primate. Considering both the proportion of recorded readings and the time required to acquire a GPS position, the collar unit was remarkably successful and efficient at obtaining GPS locations. The rate at which the collar acquired positions (>99%) was substantially higher than comparable values presented in previous tracking studies [Rumble et al., 2001; Sprague et al., 2004]. Although technological differences in the specific GPS collars used in each study may contribute to this discrepancy, habitat variability between studies is probably a major factor in acquisition success rate. Difficulties associated with obtaining GPS readings under dense forest canopies have been well documented [Sigrist et al., 1999], and the open savannah habitat and less dense woodland tree cover characterizing much of our study area likely contributed to our acquisition success.

Connection to satellites during fix times is energetically draining, and therefore shorter fix times conserve battery power and thereby extend the useful life of the collar for data collection. The time required to obtain locations was typically low in our study, even in the more structurally obscured portions of the habitats when the baboon was likely in woodland groves. A further consideration when analyzing fix time is the recording schedule; long time gaps between consecutive readings (such as we had between 2100 and 0500) increase fix times as the collar must reassess local satellite locations. The additional time needed for this reassessment therefore contributed to our greatest fix time being at the first recording of the day (0500).

PDOP values are widely recognized as an indication of the accuracy of location readings [for explanation, see Dominy & Duncan, 2001], and researchers can ''screen'' GPS data by eliminating readings with low accuracy (high PDOP values) to reduce location error [D'Eon & Delparte, 2005; D'Eon et al., 2002; Rempel et al., 1995]. We had no such low-accuracy data. Further, the low temporal variation in this measure in our study is particularly encouraging as an indication that accuracy was not compromised once a position was recorded, even when the unit required additional time to obtain locations in the early morning and the evening time blocks when the baboons are arboreal in sleeping groves. Given the low variability in this measure in conjunction with an overall high accuracy, analysis of other or more subtle differences potentially contributing to variation in accuracy (e.g., habitat obstruction) is not warranted in this setting.

In addition to the acquisition of spatial data, collars with automated data collection and storage offer a novel means of non-invasive temperature and activity monitoring. For example, temperature data used in conjunction with an assessment of ambient meteorological variables as in Hill et al. [2004] will facilitate a wide range of studies in which animal-relevant thermal environments can be characterized. In this study, we provide a novel insight into this potential by presenting both collar-recorded temperatures and local ambient temperatures recorded simultaneously by a nearby weather station. The collar-recorded temperatures exhibited the same patterns of temporal change throughout the day as those from the weather station. However, as expected for a temperature measurement that is predominantly capturing the surface temperature of a large homoeothermic animal and thus influenced by both body and air temperature, the daily magnitude of the changes was much smaller for the collar data. Finally, the collar's activity sensor can provide valuable insight into animal movement and activity if the relationship between observed daytime behavior and remotely measured activity (toggles) are calibrated [e.g., Adrados et al., 2003]. During daylight hours, activity measures varied significantly with hour of day and travel rate, a pattern probably driven largely by head movements specifically related to locomotion. It may be feasible to determine the number of activity counts that are produced by each unit of locomotion and thereby estimate the amount of travel vs. other activities during periods of remote monitoring. However, distinguishing among non-locomotor daytime behaviors (e.g., foraging, grooming) may pose calibration challenges because of frequent changes in activity and heterogeneity in performance of each (e.g., foraging on berries vs. grasses). Investigations of variation in overall activity during periods known not to involve travel will be of interest even without attribution of measurements to specific activities. For example, in a study of longer duration than the present one, the activity sensor should permit testing hypotheses such as (1) animals will be less active at night following long day journeys and will have short day journeys after very restless nights (i.e., addressing a function of rest or sleep), (2) recent events such as predation will lead to greater nocturnal restlessness, and (3) immediate conditions such as a female's fertile period, or greater predator vulnerability during a full moon, will increase nocturnal activity/restlessness.

In conclusion, our results support the considerable potential for use of automated GPS collars for research on some wild primates. We demonstrate that GPS technology is not solely important for the study of nocturnal or elusive species, for which it may be essential; rather, remote monitoring through use of this technology has broad and as yet untapped potential even with species for which direct observation is both possible and successful.

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REFERENCES

Adrados C, Verheyden-Tixier H, Cargnelutti B, Pépin D, Janeau G. 2003. GPS approach to study fine-scale site use by wild red deer during active and inactive behaviors. Wildl Soc Bull 31:544–552.

Alberts SC, Hollister-Smith J, Mututua RS, Sayialel SN, Muruthi PM, Warutere JK, Altmann J. 2005. Seasonality and long term change in a savannah environment. In: Brockman DK, van Schaik CP, editors. Primate seasonality: implications for human evolution. Cambridge: Cambridge University Press. p 157–196.

Altmann J, Schoeller D, Altmann SA, Muruthi P, Sapolsky RM. 1993. Body size and fatness of free-living baboons reflect food availability and activity levels. Am J Primatol 30:149–161.

American Society of Mammalogists. 1998. Guidelines for the capture, handling, and care of mammals as approved by the American Society of Mammalogists. J Mammal 74:1416–1431.

British Colombia Ministry of Environment, Lands and Parks. 2001. British Columbia standards, specifications, and guidelines for resource surveys using Global Positioning System (GPS) technology. Victoria, Canada: British Columbia Ministry of Environment, Lands and Parks.

D'Eon RG, Delparte D. 2005. Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. J Appl Ecol 42:383–388.

D'Eon RG, Serrouya R, Smith G, Kochanny CO. 2002. GPS radiotelemetry error and bias in mountainous terrain. Wildl Soc Bull 30:430–439.

Dominy NJ, Duncan B. 2001. GPS and GIS methods in an African rain forest: applications to tropical ecology and conservation. Conserv Ecol 5:537–549.

Funkhouser GE, Higgins EA, Adams T, Snow CC. 1967. The response of the savannah baboon (*Papio cynocephalus*) to thermal stress. Life Sci 6:1615–1620.

Harris S, Cresswell WJ, Forde PG, Trewhella WJ, Woollard T, Wray S. 1990. Home-range analysis using radio-tracking data—a review of problems and techniques particularly as applied to the study of mammals. Mammal Rev 30:97–123.

Hiley PG. 1976. The thermoregulatory responses of galago (*Galago crassicaudatus*), the baboon (*Papio cynocephalus*) and the chimpanzee (*Pan satyrus*) to heat stress. J Physiol 254:657–671.

Hill R, Weingrill T, Barrett L, Henzi S. 2004. Indices of environmental temperatures for primates in open habitats. Primates 45:7–13.

Millspaugh JJ, Marzluff JM. 2001. Radio-tracking and animal populations: past trends and future needs. In: Millspaugh JJ, Marzluff JM, editors. Radio tracking and animal populations. San Diego: Academic Press. p 383–393.

Phillips KA, Elvey CE, Abercrombie CL. 1998. Applying GPS to the study of primate ecology: a useful tool? Am J Primatol 46:167–172.

Rempel RS, Rodgers AR, Abraham KF. 1995. Performance of a GPS animal location system under boreal forest canopy. J Wildl Manage 59:543–551.

Rumble MA, Benkobi L, Lindzey F, Gamo RS. 2001. Evaluating elk habitat with GPS collars. In: Sibbald AM, Gordan IJ, editors. Tracking animals with GPS, Proceedings of the Conference. Aberdeen, Scotland: The Macaulay Land-use Research Institute. p 11–17.

Sapolsky R, Altmann J. 1991. Incidences of hypercortisolism and dexamathasone resistance increase with age among wild baboons. Biol Psychiatry 30:1008–1016.

Sigrist P, Coppin P, Hermy M. 1999. Impact of forest canopy on quality and accuracy of GPS measurements. Int J Remote Sens 20:3595–3610.

Sprague DS, Kabaya H, Hagihara K. 2004. Field testing a global positioning system (GPS) collar on a Japanese monkey: reliability of automatic GPS positioning in a Japanese forest. Primates 45:151–154.