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ACTIVITY MONITORING IN MULE DEER: ASSESSING TELEMETRY ACCURACY

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Quantifying animal activity can identify factors that influence animal behavior. For decades, researchers have tried to quantify ungulate activity using visual techniques, but time restrictions and limited visibility have necessitated alternatives to visual observation. Motion detection by radio transmitters attached to animals has allowed "hands-off" monitoring in many habitats and reduced human effects on animal behavior. However, transmitters potentially affect animal behavior (White and Garrott 1990:27–40).

The first method used to detect movement of radio-collared animals was signal-strength variation (Marshall 1965, Southern 1965). However, the first true activity sensors were piezoelectric sensors designed by Knowlton et al. (1968). With the inclusion of tip-switch motion sensors in radio-collars came graphic printouts that indicated if the animal's head was up or down based on pulse patterns. Steady, head-up patterns lasting from 1 minute (Gillingham and Bunnell 1985) to 5 minutes (Beier and McCullough 1988) have been used to indicate an inactive or bedded animal whereas head-down and changing head patterns indicate an active or nonbedded animal. Variable-pulse collars that sample instantaneous collar movement every 0.25 second also have been used (Gillingham and Bunnell 1985). Nevertheless, no one has yet been able to discriminate bedded, standing, feeding, walking, and running ungulates with high accuracy (>90%). Gillingham and Bunnell (1985) believed that more accurate data would be obtained by telemetry systems that quantified the amount of time between variable pulses rather than instantaneous samples.

Another challenge to activity monitoring has been handling large amounts of data. Evaluating strip charts is time consuming and labor-intensive. An automated system that would quantify activity and store the data in an immediately usable, electronic form would be an asset. We evaluated such a system for monitoring activity of desert mule deer (*Odocoileus hemionus crooki*). This new system used field computers that measured the time between variable-pulse signals as recommended by Gillingham and Bunnell (1985) and calculated a mean pulse rate. Further, we explored how our results could explain previous difficulties with telemetry accuracy and offer ideas for telemetry improvements.

METHODS

Mule deer were captured and radio-collared at the Elephant Mountain Wildlife Management Area and surrounding ranches in Brewster County in the Big Bend area of Texas (30°2′N, 103°32′W). Terrain included mountains and wide, flat valleys with elevations from 1,300–1,900 m. Vegetation ranged from grassland to desert scrub to pinyon pine (*Pinus cembroides* and *P. edulis*)–juniper (*Juniperus* spp.) associations. Nine male and 1 female deer were captured using drop-nets (Ramsey 1968) and net-guns (Barrett et al. 1982) and

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were fitted with radio-collars containing variable-pulse activity sensors. These sensors used mercury switches that added pulses to the base pulse rate of the collars each time the collar tipped from side to side (Advanced Telemetry Systems, Isanti, Minn.). Sensors were oriented perpendicular to the long axis of the animal's body. This contrasts with the normally parallel orientation of tip-switches. Because sensor sensitivity depends highly on collar fit, we tried to make all collars fit similarly at capture with respect to tightness.

Our data collection unit was computer-controlled and consisted of a 3.7-m pole with four 4-element yagi antennas fastened at the top at 90-degree angles to each other. Each antenna was attached to a multiplexer box that controlled antenna signal reception. The multiplexer connected to a receiver and a small computer (DCC 5040; Advanced Telemetry Systems, Isanti, Minn.). The computer controlled radio-frequency scanning to monitor deer for consecutive, 1-minute intervals. The computer measured the time between each pulse to the nearest 0.1 second, calculated pulse rates by inverting these times, and averaged these pulse rates to produce a mean pulse rate for each minute of monitoring. This mean pulse rate is more sensitive to concentrations of pulses (short periods of rapid movement) and is different from, but related to, the number of pulses transmitted in a minute (pulse rate). We hoped that this increased sensitivity would increase discrimination of behaviors (Gillingham and Bunnell 1985).

We used visual observations to calibrate mean pulse rates to deer behaviors. During autumn 1990, workers in towers visually observed deer with 7X binoculars and 15–60X spotting scopes and noted specific behaviors while the telemetry receiver system operated at a nearby, elevated site. The telemetry system was connected to a laptop computer during calibration to permit an operator to note beginning and ending scan times. Two-way-radio communication assured synchronization of the computer operator and visual observers. Because of brush cover, bedded deer were not commonly observed. During summer 1991, tower observations continued, and data were supplemented using observers on foot. Two to 3 observers walked with H-element antennas and triangulated on deer believed to be bedded during mid-morning. Once a deer was located from a distance, the telemetry receiving system was erected nearby for data collection. The triangulated area was scanned with binoculars to visually confirm the animal was, in fact, bedded. If bedded status could not be confirmed with binoculars, the observers approached the deer at the end of the scanning session for confirmation.

We analyzed our ability to discriminate specific behaviors and examined overlap among pulse ranges. Mean pulse rates for each 1-minute interval were converted into relative mean pulse rates based upon each collar's base rate (54–65 pulses/minute). Thus, a relative mean pulse rate of 100% represented a collar without movement. Collars with movement ranged from 101% to about 300%.

We classified observed activities as either feeding, walking, standing, or bedded. Any deer involved in at least some feeding was categorized as feeding (stand-feed, walk-feed), and a walking deer walked, trotted, or ran for at least part of the minute but did not feed. Standing and bedded deer performed the respective activity during the 1-minute interval but did not feed, walk, trot, or run.

Data were combined for all deer observed for descriptive analysis. Statistical analysis was not possible because all 4 behaviors were not observed in all 10 deer. Many of the feeding deer could not be observed bedded because of vegetation. The most common description of accuracy is the percent of correctly identified activities. A value (relative mean pulse rate) for separating 2 pulse patterns accurately was selected by plotting the accuracy of identifying 2 activities against the value used (Fig. 1). The point where the lines crossed on the graph indicated the best accuracy for separating 2 activities.

To demonstrate overlap of pulse ranges among activities, relative mean pulse rates from 100–299% were split into 20 categories, each with a 10% range. For each activity, we plotted the frequency of its occurrence within each relative mean pulse rate category. Our telemetry system would be considered accurate if each behavior produced a different range of pulse rates.

RESULTS

We were not able to accurately discern all 4 activities with our 390 1-minute telemetry scans of 9 males and 1 female. Bedded deer were different from feeding and walking deer 82% and 75% of the time, respectively. Standing deer were different from feeding and walking deer 81% and 74% of the time, respectively. Bedded and standing deer were different 51% of the time and feeding and walking deer were different only 40% of the time. When longer scan times were used, an increased number of activities occurred. During a 1-minute scan, an average of 1.3 activities occurred whereas 2.0 activities occurred during an average 3-minute scan and 2.5 activities occurred during an average 5-minute scan. Because of the increased number of activities with longer scan times, we did not analyze specific activities for the longer times.

The frequency distributions of standing, bedded, feeding, and walking behaviors helped explain the low accuracy. There was considerable overlap in relative mean pulse rates of

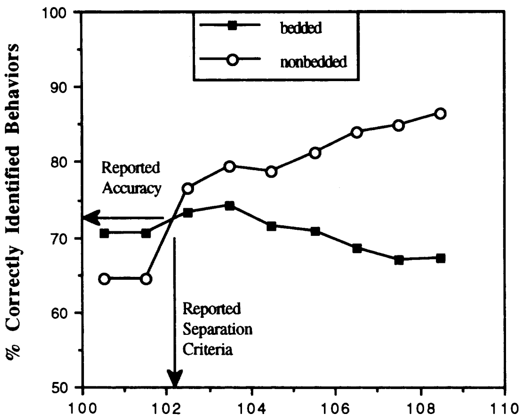

Fig. 1. Determination of behavior separation criteria by plotting percent of correctly identified bedded and nonbedded behaviors of desert mule deer against relative mean pulse rates using a 1-minute scan time, Brewster County, Texas, 1990 and 1991.

different activities (Fig. 2). All of the standing observations ($n = 22$) produced pulses <120% of the collar base rates. Bedded behavior was similar, with 244 of 253 (96.5%) scans <120% of base rate. Surprisingly, 54 of 89 feeding deer (61%) and 18 of 26 walking deer (69%) also were in the 100–119% relative pulse range. Frequency distributions differed among activities. The highest bedded pulse recorded was in the 150–159% relative pulse range (frequency = 0.4%), whereas the highest feeding and walking activities produced pulses in the 280–289% (frequency = 1.1%) and 290–299% (frequency = 7.7%) ranges, respectively.

Because specific activities were not distinguishable with high precision, we tried to discriminate bedded from nonbedded (walking, feeding, standing) and active (walking and feeding) from inactive (bedded and standing) deer using 5 scan times. When a 1-minute scan time was used, bedded deer were distinguished from nonbedded deer 73% of the time. Two-, 3-, 4-, and 5-minute scans discriminated bedded from nonbedded deer 73, 77, 74, and 74% of the time, respectively. Active deer were discriminated from inactive deer 81, 76, 74, 74, and 74% of the time using 1-, 2-, 3-, 4-, and 5-minute scan times, respectively.

DISCUSSION

Our ability to discriminate specific behaviors was similar to those previously reported for radio telemetry. However, our ability to discriminate bedded from nonbedded and active from inactive was less reliable. Beier and McCullough's (1988) tip-switch system used a 5.25-minute scan time and parallel-oriented sensor for white-tailed deer (*O. virginianus*). They reliably distinguished bedded from nonbedded deer (97%) but could not discriminate among nonbedded activities. Similarly, Hansen et al. (1992) attained 98% agreement between direct observation and telemetry data when comparing inactive (standing and bedded) to active (walking, running, feeding) Dall's sheep (*Ovis dalli*), but could not discriminate among active behaviors using parallel-oriented activity sensors. Kufeld et al. (1988) used tip-switch collars to identify 3 categories: feeding, resting, and "other" behavior (standing, intermittent feeding, walking, and running). A 10-minute scan time was necessary to identify predominant activities with about 95% accuracy in female mule deer. The long scan time allowed a higher accuracy for constant activities (bedded and uninterrupted feeding) at the cost of not discriminating other activities of shorter duration (standing, intermittent feeding, walking, and running). Kufeld et al. (1988) classified 30% of their data as "other" behavior. Gillingham and Bunnell (1985) compared graphic output from tip-switch collars and variable-pulse collars in black-tailed deer (*O. h. columbianus*) and concluded that specific behaviors could not be discriminated, but pulse rates produced by the instantaneously-sampled, variable-pulse collars were related to the animal's level of activity. These results suggest that very different activities can produce the same amount of relative collar movement with

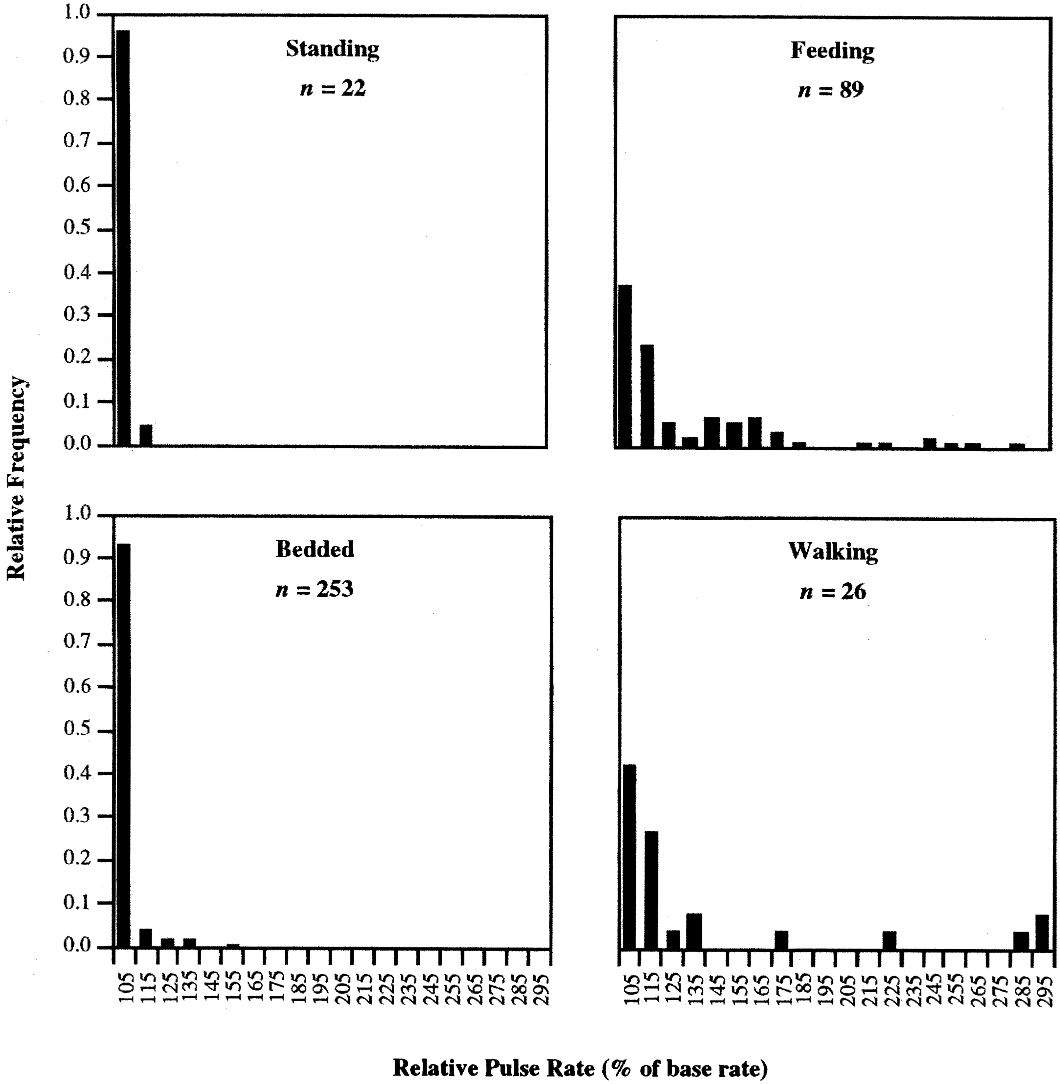

Fig. 2. Relative frequency of mean relative pulse rates for 4 activities of desert mule deer in Brewster County, Texas, 1990 and 1991. Data are based on 390 1-minute samples. Numbers on horizontal axis represent midpoint of 10% ranges.

perpendicularly- or parallel-oriented activity sensors. Gillingham and Bunnell (1985) further noted accuracy for identifying active black-tailed deer did not exceed 90% and 75% for tip-switch and variable pulse collars, respectively. This suggests that variable pulse sensors are more sensitive to movements during bedded and standing periods. Contrary to Gillingham and Bunnell's (1985) expectation, quantifying the time between pulses, as we did, did not increase accuracy.

Past studies have noted many examples of activity misclassification. Early in the development of telemetry technology, Jackson et al.

(1972) recognized the problem of overlapping patterns of collar movement among different activities and grouped activities into broad categories. However, they did not attempt to rigorously validate their technique. In Beier and McCullough's (1988) study, 3 of 196 (2%) nonbedded scans were identified incorrectly as a bedded deer, all attributed to a single deer standing vigilant. Gillingham and Bunnell's (1985) tip-switch collars transmitted an inactive signal only 31% of the time when an animal was bedded because of grooming and slight movements. An inactive signal was transmitted only 4% of the time when a deer was observed standing. In contrast to our findings, they did not observe any inactive pulse rates when deer were moving, but such occurrences had been reported to them (Gillingham and Bunnell 1985).

Misclassification of specific activities arises because bedded and standing ungulates are not always motionless (inactive), and ungulates that are feeding and walking slowly commonly do not move their head and neck. Bedded and standing mule deer often activated our perpendicularly-oriented sensors when they looked around. This right-to-left head movement is likely a minor problem with parallel-oriented sensors. In contrast, feeding deer may keep their head down for several minutes with imperceptible head and neck movement from side to side or up and down. An unalert deer walking slowly with its neck held horizontally also moves a radio-collar little. A further problem is that activities such as standing, feeding, walking, trotting, and running are frequently of short duration. A deer may stand alert, feed, and walk several times within a minute. To detect each activity using 1- to 5-minute scan times is difficult; to group several activities together as "other" loses resolution and potentially biases results. Sample intervals of <1 minute might identify specific activities more reliably. This was not possible to assess with our data but would be possible if our system were reprogrammed for shorter intervals.

We suggest a common perspective on animal activity in regard to specific behaviors. Activity ranges along a continuum with specific activities overlapping greatly in the amount of actual head and neck movement. Little movement (low relative mean pulse rates) could indicate an animal is sleeping, bedded but vigilant, standing and vigilant, feeding with little neck movement, or walking with little neck movement. Accurate identification of specific activities seems possible only when such low-level collar movements can be discriminated from high-level movements (feeding with neck movement, walking with neck movement, trotting, and running) and the proportion of these activities does not change throughout the study period. The latter requirement, however, is often the research question being pursued. In many situations we may have to be content to describe changes in relative activity over time (low, moderate, and high activity) rather than identifying specific behaviors, and then use additional data such as visual observations and linear movements to help explain these changes (Relyea 1992:5–34).

IMPLICATIONS OF THE TECHNIQUE

There are several important considerations when monitoring animal activity using radiotelemetry. Telemetry systems should be tested for accuracy on wild, free-ranging animals for applicability to field conditions. Different scan times should be tried, and the seasonal effects on accuracy should be determined where appropriate. Another consideration is the time between activity fixes. An animal's activity during any minute likely depends more on the minute of activity immediately preceding and less on the minute of activity that occurred the day before. An appropriate length of time is difficult to determine but should be based upon knowledge of the study animal and how frequently the animal switches among behaviors.

Although some systems have successfully discriminated (>90%) bedded versus nonbedded or active versus inactive behaviors in ungulates, our system using relative mean pulse rates, perpendicularly-oriented sensors, and 1- to 5-minute scan times could not. Furthermore, no system has reliably identified specific activities at a higher resolution than this simple dichotomy because of similar body motions among different activities. The additional time savings of instant computer analysis of incoming data in our system was very efficient and, in the future, should be coupled with parallel-oriented activity sensors. This new combination could take advantage of the higher reliability of parallel sensors in discriminating active (or nonbedded) from inactive (or bedded) animals, and the computer program could be rewritten to recognize and record either pattern without the researcher interpreting outputs from chart recorders.

SUMMARY

We evaluated a new, automated telemetry system for monitoring activity in desert mule deer. The system quantified time between pulses using a perpendicularly-oriented activity sensor. The increased automation brought increased monitoring efficiency, but the system could not accurately discriminate specific activities (bedded, standing, walking, and feeding). At a lower resolution, bedded activities could be discriminated from nonbedded activities 73–77% of the time and less active behaviors (bedded and standing) could be discriminated from more active behaviors (walking and feeding) 74–81% of the time using 1-, 2-, 3-, 4-, and 5-minute sample intervals. We recommend incorporating the automation technology with more accurate, parallel-oriented, tip-switch collars.

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