RELIABILITY OF MOTION-SENSITIVE RADIO COLLARS FOR ESTIMATING ACTIVITY OF BLACK-TAILED DEER

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Abstract: Radio collars containing motion-sensitive devices were attached to four adult black-tailed deer (*Odocoileus hemionus columbianus*). Comparisons between telemetric data and concurrent visual observations of animal behavior were made to evaluate the extent that the equipment could reliably predict activity. Mercury tip-switch devices containing a 12-minute, motion-reset switch and variable-pulse collars that varied pulse rates instantaneously with amount of movement were tested. Pulse-rate patterns were broadly indicative of activity level but could not be used to identify specific behaviors. The tip-switch collar was found to be more accurate in predicting overall activity budgets. Proportion of time active could not be estimated from these telemetry data with greater than 90% accuracy ($P < 0.05$) for the tip-switch collars and 75% for the variable-pulse collars. The variable-pulse collar provided a poorer estimate of activity and was more difficult to radio-locate; the reliability of the motion-reset circuit in the tip-switch collar was questionable.

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Radio-instrumentation is often the major means of obtaining location and activity information about species whose habitats or circadian rhythms impede visual observations. Use of a particular nest-site or lodge by some species may enable estimation of activity patterns from radiolocations alone (Lancia and Dodge 1977), but often this has not been possible for free-ranging animals. Activity estimation from interpretation of signal quality as discussed by Cochran and Lord (1963) has been widely used (Lindzey and Meslow 1977, Lancia et al. 1979, and Erlinge 1980 among others). However, Singer et al. (1981) concluded that radio signal strength provided a poor index to the activity of European wild boar (*Sus scrofa*).

Knowlton et al. (1968) suggested use of motion-sensitive switches in telemetry transmitters to quantify animal activity. These devices have since received wide application (e.g., Kolz et al. 1973, Garshelis and Pelton 1980). Two types of motion-sensitive transmitters are in use. Tip-switch devices alter the transmitted pulse rate using a mercury-switch to indicate changes in collar position, either from side to side or from head-up to head-down, depending on switch orientation. Reset-collars transmit one of two discrete pulse-rates depending on the presence or absence of movement during a specified interval.

Garshelis et al. (1982) equipped 61 black bears (*Ursus americanus*) with both sensor types and provided criteria for determining activity based on pulse-modes for each. They concluded that tip-switches were more useful in making continuous judgements of activity and that they might be used to differentiate types and degrees of activity. Actual activity was not known, however, and tests were based on correlations between distance moved per hour and activity as indicated by criteria applied to collar pulse rate.

Radio collars are now used that combine tip-switches and reset-sensors to allow estimation of head position and movement, but their reliability and signal interpretation have not been evaluated. This study directly compares information from radio collars with simultaneous observations of the monitored animal's behavior. Both the tip-switch-motion and variable-pulse collars were studied.

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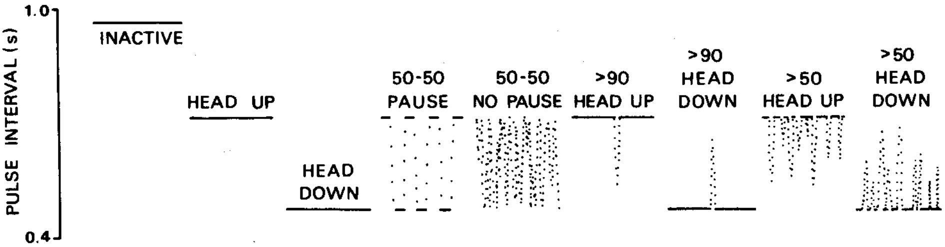

Fig. 1. Categories of tip-switch pulse patterns selected to characterize pulse information. Pulse interval in seconds.

METHODS

Two tip-switch motion sensing collars and two variable-pulse collars (Telonics, Mesa, Ariz.) were fitted to three female and one male adult black-tailed deer at the University of British Columbia Research Forest, Maple Ridge, British Columbia. Mercury-switches in the tip-switch collars were oriented to indicate head-up and head-down movements. Tip-switch collars also contained motion-reset circuits programmed to emit an inactive signal following ≃12 minutes of inactivity. Transmitted pulse rate of variable-pulse collars varied according to the amount of sensor movement, sampled at ≃0.25-second intervals.

Instrumented animals were held in a 1-ha enclosure containing cover, forage, and supplemental food throughout the 2-month experimental period. A 9-m high platform adjacent to the enclosure enabled a continuous, unobstructed view.

Radiotelemetry data were received and recorded with a whip antenna, a Telonics Model TR-2 receiver combined with a TDP-2 digital processor, and a Rustrak two-channel chart recorder geared to move at 40.6 cm/hour (Gulton MCS Div., Manchester, N.H.). The chart recorder, which sampled with a striker bar at 500-millisecond intervals, was run from an automobile (12 V) ensuring a relatively constant power supply.

Eight behaviors, including walking, running, standing, food-searching, feeding, grooming, ruminating, and lying, were recorded on an OS-3 Behavioral Recorder (Observational Systems, Redmond, Wash.) during successive 2-hour sampling periods. Feeding was subdivided into three classes: feeding with head up, feeding with head down but not at ground level, and feeding on the ground (0–25 cm). The behavior recorder's clock was used to mark the time on the chart recorder at the beginning and end of every 2-hour observation period; linear interpolation was used to estimate chart times between these points. Only one animal was studied during each 2-hour trial period, and observers were alternated between trials to ensure alertness. Each animal was usually observed for four consecutive periods to minimize omission of behaviors.

Location of the receiving station was altered to examine effects of distance and vegetation on signal amplitude. Fifty-six trials were conducted with the receiver 15 m from the penned area. Two sets of 16 trials were conducted ≃800 m from the pen; one with unobstructed reception and one through a 40-year-old coniferous stand. Observations were made between 0700 and 1800 hours. A total of 88 hours of tip-switch and 81 hours of variable-pulse evaluations was obtained.

The chart recorder plotted signal amplitude (dBV) and pulse interval (ms). To make detailed comparisons with observational data, we established a set of rules to separate various pulse-patterns that were recognizable a priori. Criteria were needed that would enable retention of information but were simple to apply and easily recognized by other researchers. Encoding pulse information for tip-switch collars is not strictly quantitative (Fig. 1). For example ">90 head-up" or "-down" means one or two tips from a predominant position during a 1-minute interval (0.6 cm) on the chart; ">50 head-up" or "-down" represents patterns between the "50-50" and ">90" pattern.

For tip-switch data, recognition of patterns was based on the dominance of "head-up" or "head-down" postures (Fig. 1). The longer the collar was in one position, the more prevalent the line on the chart. Distinct pausing in "head-up" then "head-down" positions would result in "50-50 pause," whereas continuous movement back and forth resulted in "50-50 no pause" without distinct demarcation between

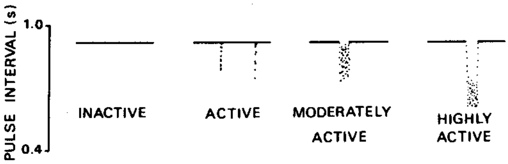

Fig. 2. Variable-pulse patterns used to encode pulse information. Pulse interval in seconds.

"head-up" or "head-down." To be classified as continuously "head-up" or "head-down," the pattern had to last at least 1 minute.

The transmitted pulse rate of the variable-pulse collars theoretically increases with amount of movement, so that activity can be estimated as deviations from a slow baseline "inactive" rate. Therefore, variable-pulse criteria were based on presence or absence of a continuous baseline. Continuous baseline for 30 seconds (0.3 cm) was considered to separate "active" from "inactive." Gaps of 15 seconds (0.16 cm) were used to differentiate "active" from "moderately-" or "highly-active" patterns (Fig. 2).

For both types of collars, periods of interference were characterized by dramatic changes in signal strength or pulse rate, or abnormal pulse rates for up to 20 minutes, and were not analyzed.

Amplitude data for both collar types were encoded separately based on variation between processed signals. A rank of one (little variation) to three (large variation) was assigned to reflect changes in signal strength from pulse to pulse. These classes were designed to reflect collar movement on the animal and not changes in the animal's location relative to the receiver.

For each animal and collar type, the proportion of various patterns corresponding to observed behaviors was calculated based on each trial. Suitable pulse patterns for behavior or activity recognition were considered to be those that were unique or highly related to a particular behavior. One-way analysis of variance was used on $\arcsin\sqrt{x}$ of proportions (patterns and behaviors) to examine differences between animals fitted with the same collar type. Similar transformed tests were carried out on the amplitude data to examine distance and cover effects on signal attenuation.

Motion-reset sensors on the tip-switch collars were tested before and after the study period for mean delay and variation. Delay periods during the trials were checked for activity both from observed patterns and as measured on the chart recorder. Attempts were made to correlate amount of movement of the variable-pulse collars and the pulse rate received from the collar under hand-held conditions prior to collar instrumentation.

Following identification of unique patterns, the chart recorder information was again digitized using these patterns, their duration, and signal attenuation data. Based on this telemetric information, the animal was estimated to be active or inactive. Differences between observed and predicted information during each 2-hour period were tested using *G* tests on contingency tables (Sokal and Rohlf 1981:731–747) to establish the reliability of each collar.

RESULTS AND DISCUSSION

The following questions must be addressed in identifying suitable patterns: (1) does the observed pattern correspond uniquely to a particular behavior or group of behaviors; (2) if the specified pattern is not observed, can we assume the behavior has not occurred; and (3) can we predict proportion of time active?

Due to the method of comparing observed behaviors with telemetrically recorded information, small variations in speed of the chart recorder would result in errors of estimating overlap. This error is likely not more than 1% of the duration of most behaviors. Behaviors of short duration, such as running or grooming, might have an error as high as 2–3%. Differences of this magnitude do not affect the conclusions.

Tip-Switch Collars

Only two patterns from tip-switch collars appear indicative of specific behaviors—"inactive" and ">50% head-down" (Table 1). An inactive pulse rate was transmitted 31% of the time the animals were lying and 4% of standing periods. The latter was a result of the doe spending long periods standing; the buck never stood still for more than 5 minutes. In each case the animals would be determined not to be moving and relatively inactive. Contrary to reports of similar collars that have transmitted inactive signals while observed moving (R. W. Archibald and A. N. Hamilton, pers. commun.), movement was never found to occur during inactive pulse rates. Although the inactive pattern uniquely described periods of inactivity, it did not always occur when animals were inactive (Table 1). The ">50% head-down" pattern was

Table 1. Proportion of correspondence of tip-switch pulse patterns to total duration of behavior during trials when behavior occurred (*N*) based on pooling of collar data.

		Observed pattern					
		Inactive		Head-up		Head-down	
Behavior	*N*	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Running	39	<0.01[a]		0.12	0.21*	<0.01	
Walking	44	<0.01		0.14	0.18**	<0.01	
Standing	45	0.04	0.06	0.46	0.23**	<0.01	
Feeding	44	0.0[c]		0.14	0.17	0.05	0.09**
Head-up	25	0.0		0.56	0.36	<0.01	
Head-down	43	0.0		0.06	0.17	0.08	0.10*
Ground	39	0.0		0.06	0.15	0.03	0.08*
Grooming	45	<0.01		0.43	0.26**	<0.01	
Lying	31	0.31	0.23	0.60	0.23	0.01	0.02

[a] Pattern occurred <0.01 of time during observed behavior.

[b] Proportions do not sum to 1 because of elimination of periods of signal interference.

[c] Pattern never occurred during observed behavior.

* *P* of equal means for replicate collars <0.05.

** *P* of equal means for replicate collars <0.01.

relatively restricted to head-down feeding. However, only slight movements of the head produced by both standing and grooming animals also resulted in a similar pattern.

When the "50-50 with pause" pattern is considered, it initially appears to reflect head-down or ground feeding and is produced only 9% of the time the animal stands. However, during the trials with these collars, animals stood more than twice as much as they fed (Fig. 3a). The actual percentage of standing or the ratio of standing to feeding may be the result of using captive animals. The important point is that the telemetry data did not separate these behaviors without an independent estimate of their relative durations.

Comparison of Fig. 3a and 3b illustrates how proportions of behaviors can vary between animals. Animals equipped with variable-pulse collars walked 67% more and fed 30% less than tip-switch instrumented animals. Due to dependence of observed telemetric pattern on frequency of a behavior, only unique pattern-to-behavior correspondences enable accurate behavior recognition. Estimation of the error associated with identifying behaviors not characterized by specific patterns will depend on relative durations of the behaviors in question that appear specific to each animal. Although it is desirable to know the error associated with comparing patterns to behaviors, it must be stressed that this depends on the activity budget of the animal unless a particular pattern occurs only as the result of one behavior. Therefore errors associated with estimating behaviors from observed patterns cannot be determined for the general case.

Given the relative distribution of the behaviors and the incomplete correspondences between pattern and behavior, specific behaviors cannot be estimated accurately. Large standard deviations (Table 1) result from a pattern that overlaps highly with a behavior on one occasion and fails to occur during another. Several times, the focal animal remained lying for more than 1 hour, but grooming and slight movements prevented the collar from ever transmitting an inactive pulse. At other times, the inactive pulse accounted for 80–90% of the time the animal was lying. The ">90% head-down" pattern was omitted from Table 1 because it was rarely produced.

Tip-switch pulse patterns also varied significantly between collared animals for a majority of behaviors (Table 1). This variability can be attributed to differences in movement such as more head-tipping while walking as well as differences in collar fit. Slight differences in snugness of the collar allow the collar to slide on the neck rather than affect the mercury switch during some behaviors. Only "inactive" and the ">50%" patterns appear free of this problem; the latter is possibly undetectable due to considerable variation. Similar differences probably occur seasonally in males due to a marked influence of the rut on neck size and in both sexes with age.

Thus far, the 12-minute delay periods prior to inactive patterns have not been addressed. Both tip-switch collars were hand-tested before

Table 1. Continued.

Observed pattern									
50-50 with pause		50-50 no pause		>90% head-up		>50% head-up		>50% head-down	
$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
0.02	0.23	0.22	0.24	0.08	0.18	0.43	0.39	<0.01[b]	
0.01	0.13	0.03	0.08**	0.06	0.08**	0.47	0.24	0.02	0.03
0.09	0.08**	0.01	0.03*	0.08	0.05*	0.20	0.18	0.02	0.05
0.45	0.22	<0.01		0.04	0.05	0.12	0.09	0.10	0.14
0.08	0.32	<0.01		0.06	0.07	0.20	0.31	0.02	0.06
0.45	0.27	0.01	0.02	0.04	0.10	0.10	0.13	0.16	0.19
0.66	0.33	<0.01		0.03	0.05	0.09	0.27	0.03	0.10
0.10	0.14	0.03	0.07*	0.12	0.10**	0.21	0.17	0.02	0.06
<0.01		<0.01		<0.01		<0.01		<0.01	

instrumentation, and delays were found to be 754 ± 7 seconds and 740 ± 3 seconds ($\bar{x}$ ± SD, $N = 4$). Comparing the delay interval prior to an inactive signal to known behaviors, for all 23 occurrences of the 754-second collar, we found that the animal was lying, although grooming and rumination did occur. These movements apparently do not always affect the motion-reset sensor. Five of the 26 740-second periods prior to an inactive pulse rate corresponded to walking and/or feeding. On two other occasions the animal stood up and lay down again during this period. To ensure that this was not a synchronization problem, the chart recorder tape was examined. For periods when the record of the full delay period was complete, 23.8% ($N = 21$) and 33.3% ($N = 18$) of the periods for the two collars contained changes in the received pulse rate less than 10 minutes before inactive onset. The majority of these occurred less than 5 minutes before inactive pulse rates. At least once, both collars changed pulse rate 60 seconds prior to an inactive signal.

Although these errors were scattered throughout the trials and are not indicative of a sudden collar malfunction, the collars were again tested for delay after removal from the animals. Eight samples, four each from "head-up" and "head-down" positions, for both collars resulted in highly similar reset times of 761 ± 1 second and 745 ± 1 second ($\bar{x}$ ± SD). Collars could be moved slowly without always affecting the tip-switch and terminating inactive pulse rates. S. M. Tomkiewicz (Telonics, pers. commun.) suggested this might be explained by differences in planes of the two sensors. In the test collars, the reset and tip-sensors were at right angles, which might allow some movements to affect one sensor and not another. Changes in pulse mode within 1 minute of transmitting inactive rates might also be explained in this manner. Depending on switch orientation, large movements may remain undetected. Delay periods were not included with the duration of the inactive pattern when comparing observed behaviors to received patterns (Table 1).

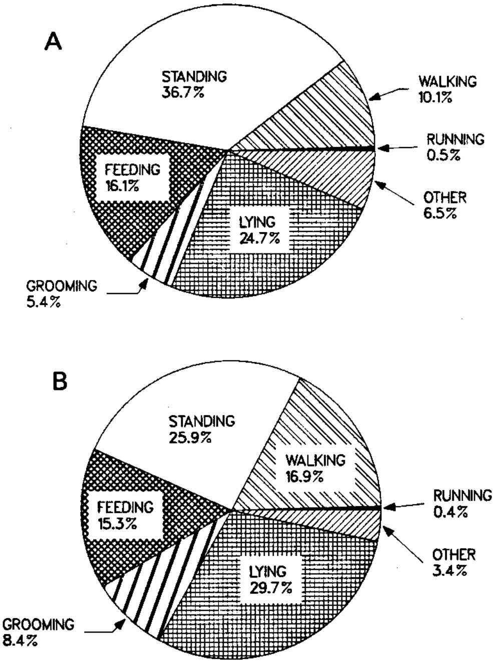

Fig. 3. a. Proportions of activities observed during the 87.4 hours of data collected for tip-switch instrumented animals (0700–1800 hours). b. Activity budgets for variable-pulse collars based on 80.6 hours of observation.

Table 2. Proportion of correspondence of variable-pulse patterns to total duration of behavior during trials when behavior was present.

		Observed pattern							
		Inactive		Active		Moderately active		Highly active	
Behavior	*N*	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Running	35	0.16	0.28	0.52	0.32	0.13	0.26	0.17	0.17
Walking	40	0.20	0.19**	0.56	0.13	0.13	0.11**	0.08	0.08*
Standing	41	0.63	0.13*	0.32	0.10	0.03	0.03**	0.01	0.02
Feeding	41	0.40	0.26**	0.57	0.24**	0.01	0.03	<0.01[a]	
Grooming	41	0.38	0.20**	0.56	0.18**	0.04	0.04*	<0.01	
Lying	27	0.84	0.12	0.14	0.09	<0.01		<0.01	

[a] Pattern occurred <0.01 of time during observed behavior.
* *P* of equal means for replicate collars <0.05.
** *P* of equal means for replicate collars <0.01.

Variable-Pulse Collars

The presence or absence of a particular variable-pulse pattern does not allow the identification of specific behaviors (Table 2). Many of the activities resulted in significantly different correspondences when the two animals were compared. As can be seen from patterns corresponding to running, and as was the case when hand-held test correlations between pulse rate and motion were attempted, increased movement does not necessarily result in higher pulse rates. The collar does not integrate over the inter-pulse period but rather assesses the amount of movement periodically (0.25 sec). In the hand, the collar can be rapidly moved between pulses and, providing it is motionless at sampling time, an inactive rate is transmitted. In addition to pulse interval, the 500 millisecond sampling rate of the chart recorder might also result in missed activity. However, prolonged movements should be detected.

If the collar integrated the amount of movement between signals rather than sampling instantaneously, more accurate information might be obtained. Table 2 does show that the presence of the highly active pattern indicates locomotion and that the deer were not lying if either the "moderately-" or "highly-active" patterns were detected. Within an active classification, locomotion might be detected between 10 and 15% of occurrence but other behaviors would remain unknown.

Signal Attenuation

For both types of collars, variation in signal attenuation was smallest when the animal was inactive and varied most during activity. However, there appear to be problems with using only signal amplitude to predict activity level. Considering only those times when the focal animal was known to be inactive, the amount of variation in signal strength changed from collar to collar, and day to day for a given collar, but remained relatively constant during a day.

The proportion of signal variation assigned a rank of one (smallest) was found to be significantly different ($P < 0.01$) for three of the collars when 15-m and 800-m receiving sites were compared. The amount of observed animal activity, however, did not differ significantly ($P > 0.10$) and eliminates the possibility of coincidental differences in collar movement. Samples were not large enough to examine the possible effect of different activity levels on amplitude information between the two 800-m receiving locations, although significant differences in the proportion of the smallest amplitude class were observed.

Although not a definitive treatment of signal strength, these results suggest that variation in received signal can change with both day and distance from the transmitter even when the animal is inactive. This would imply not only a need for familiarity with individual collars, but also a knowledge of the animal's location when trying to predict activity level from signal attenuation.

Estimating Activity Budgets

To examine the accuracy of estimating activity budgets based on telemetric information for both collar types, we re-examined pulse pattern and signal amplitude. Animals were considered to be inactive if they were either lying or standing still. Although standing represents a significant energetic increase over lying (Parker et al. 1984), these activities cannot be separated based on the above results.

For the variable-pulse collars, animals were considered to be inactive if an inactive pulse pattern (Fig. 2) was present for ≥2 minutes (≥1.27 cm on chart recorder). Two minutes was chosen largely for convenience in reading charted patterns.

Because the tip-switch collar can be moved dramatically in the head-up position (head-up feeding for example) with no change in pattern, the occurrence of "head-up" patterns with no amplitude variations was compared to observed behaviors. "Head-up" patterns suggested that a period of at least 10 minutes was required to determine if an animal was inactive unless a "head-up" pattern was adjacent to an inactive pattern. In this case, again including only patterns corresponding to no amplitude variation, the animal was found to be inactive regardless of pattern duration. Only standing and lying behaviors occurred during "head-up" patterns exceeding 10 minutes in length. For patterns with durations less than 10 minutes, lying occurred only 10.8% of the time and, therefore, an animal could not be assumed to be inactive.

In comparing estimates of active/inactive ratios from telemetric data to observe behaviors for tip-switch collars, we predicted the animal to be inactive if: (1) an inactive signal was received; (2) a "head-up" pattern with no amplitude variation was received immediately before or after an inactive signal; or (3) if a "head-up" pattern with no amplitude variation persisted for >10 minutes. At all other times the animal was predicted to be active.

When the telemetric prediction of activity was compared to the observed behaviors, 9.3% ($N = 43$) of the tip-switch trials and 26.3% ($N = 38$) of the variable-pulse trials were significantly different ($P < 0.05$) from observed active/inactive ratios. When lying alone was used as the observed inactivity, differences were much greater (37.2 and 55.3%, respectively).

The determination, based on observed behaviors, of a 10-minute interval to separate active from inactive may have contributed to the higher reliability of the tip-switch collars. However, if the variable-pulse collar was working as predicted, such an interval estimate should not be necessary. Another potential drawback of the variable-pulse collar is its difficulty in radio-locating. Quigley et al. (1979) found a constant signal much easier to triangulate. Problems with an animal wearing a variable-pulse collar might be multiple.

IMPLICATIONS

Field biologists, constantly under pressure to acquire the most information for their investment and efforts, must be careful in extracting detailed information from radio collars fitted with motion-sensing devices. Both types of collars tested will provide large amounts of data, but this study suggested that only a degree of activity can be extracted, and even that is based on some speculation. Motion-sensors were originally placed into the collar configuration as mortality-sensors, and it was only at the request of biologists that this delay was shortened to provide more activity information; data must be evaluated, not simply accepted because a technology can provide it. The number and orientation of mercury switches in the collar may be critical to the study being conducted and should be discussed with the collar's designer before commencing.

The choice of collar-type depends on the researchers' objectives and should be carefully considered. Although reset-sensors show some inconsistency, it appears that both identification of inactivity and overall estimation of activity budgets are more reliable using the tip-switch configuration than the present variable-pulse collar. However, specific behaviors cannot be identified from the pulse patterns, and errors associated with behavior estimation cannot be calculated.

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