EVALUATION OF GPS-SIZED EXPANDABLE RADIOCOLLARS DESIGNED FOR WHITE-TAILED DEER FAWNS

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SUMMARY OF FINDINGS

During May 2018–July 2019, we tested fit and function of 3 Global Positioning System (GPS)-sized expandable collar mock-up designs on newborn white-tailed deer (*Odocoileus virginianus*) fawns. We fitted 26 captive fawns with ear tags and collars (20 Vectronic Vertex, 3 Telonics TGW, 3 Telonics Recon) and ear-tagged 5 captive control fawns without collars. We collected neck measurements from fawns at birth and at approximately 6, 9, and 12 months of age. Additionally, we conducted observations of fawns to evaluate the potential effects of collars on behavior. The folds of all 6 Telonics mock-ups expanded prematurely by 75.8 ± 27.9 (SD) days resulting in extremely loose collars. Upon expansion, fawns were able to step through collars with their forelimbs resulting in collars positioned around the chest or waist. We observed one example in which premature expansion led to a dropped collar at just 80 days. On fawns ≥11 months of age, only 3 Vectronic Vertex mock-up collars dropped and none exhibited premature expansion. Neck measurements indicated newborn fawns would benefit from a smaller band circumference. For fawns through ≥10 months of age, we did not observe any collars being restrictive. Notable effects on fawn behavior included high-stepping during locomotion and erratic jumping, particularly when fawns were ≤1 month of age. Our results suggest that the GPS-sized expandable collars tested in this study would benefit from modifications before being deployed in the field. We recommend modifications to each design, such as an improved stitching patterns, alternative thread and elastic materials that facilitate a more gradual elastic expansion, decreased battery housing size and weight, and improved weight distribution of the electronic components.

INTRODUCTION

Knowledge of population parameters (e.g., sex ratio, age structure, survival, recruitment) informs decision-making for management of white-tailed deer (*Odocoileus virginianus*) populations (Jacobson et al. 1997, Keyser et al. 2005). Survival of white-tailed deer fawns is one of the most important factors influencing population growth. However, estimating survival of fawns to recruitment is logistically challenging using current very high frequency (VHF) collar technology (Moen et al. 1996, Rodgers et al. 1996, Bowman et al. 2000, Pusateri-Burroughs et al. 2006, Severud et al. 2015). Accurate estimation of survival requires capturing and collaring fawns soon after birth and intensively monitoring them for the first few months of life, as most mortalities occur during this time (e.g., predation, starvation, disease; Pusateri-Burroughs et al. 2006). The ideal design of radiocollars should ensure the welfare of the animal, minimize impacts on behavior, and

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maximize collar retention (Grovenburg et al. 2014). Expandable radiocollars are designed to stretch, open at folds, deteriorate, and drop off of animals to accommodate rapid neck growth throughout the first 12 months of life (Smith et al. 1998, Grovenburg et al. 2014). Multiple field studies have reported premature loss or failure of expandable radiocollars for deer fawns (Vreeland et al. 2004, Pusateri-Burroughs et al. 2006, Rohm et al. 2007, Hiller et al. 2008, Grovenburg et al. 2014, Obermoller et al. 2018). Ultimately, premature loss of collars reduces the sample size of studies, decreasing the power of inference.

Integration of GPS technology with expandable collar designs would allow researchers to more efficiently and effectively investigate survival and movements of white-tailed deer fawns (Bowman et al. 2000, McCance and Baydack 2017). The primary factor limiting use of GPS technology is the size and weight of the batteries required to support GPS transmitters (McCance and Baydack 2017). Additional modifications to expandable collar designs have been proposed to improve retention and facilitate a more gradual collar expansion (Diefenbach et al. 2003, Cherry et al. 2014, Grovenburg et al. 2014, Obermoller et al. 2018). Some of these modifications to expandable collar designs have been deployed in the field (Diefenbach et al. 2003, Bowman et al. 2014, Cherry et al. 2014, Grovenburg et al. 2014). However, testing of GPS-sized expandable collars in controlled settings is warranted before extensive deployment in field studies.

To date, GPS-sized expandable radio-collar designs have not been fitted to white-tailed deer fawns and have been deployed only within the last decade on other neonatal ungulates in the wild (moose [*Alces alces*], Severud et al. 2015; fallow deer [*Dama dama*], Kjellander et al. 2012) or in captivity (domestic horse [*Equus caballus*], Hampson et al. 2010). Using animals in a captive facility allows researchers to evaluate the efficacy of GPS-sized collars over time and observe collar fit and function, the overall health and well-being of animals, and the impact GPS-sized units may have on the behavior of fawns. Also, collars that become overly restrictive on captive fawns may be safely removed. Because most prior studies have deployed GPS-sized collars on species which give birth to considerably larger young than white-tailed deer (Hampson et al. 2010, Kjellander et al. 2012, Severud et al. 2015), it is logical to assume that the relatively larger offspring would better support the weight of a GPS collar. Therefore, testing of GPS-sized collars on white-tailed deer fawns in a controlled setting is warranted to ensure animal welfare for the duration of collar evaluations.

OBJECTIVES

1) Evaluate the efficacy of GPS-sized expandable radiocollars designed for white-tailed deer fawns
2) Determine the effects of GPS-sized radiocollars on the behavior of white-tailed deer fawns

METHODS

Study Site

We conducted our study at the Whitehall Deer Research Facility on the University of Georgia campus in Athens, GA. We held captive deer in 1-2-acre outdoor paddocks, each containing 12-14 adult does and their fawns. We provided all deer with pelleted feed, hay, and water *ad libitum.* The University of Georgia Institutional Animal Care and Use Committee approved all methods under Animal Use Proposal A2018 03-019-Y2-A0.

Animal Capture and Handling

We captured 31 fawns during May–July 2018. We captured, handled, and released each fawn within the first 24 hours after birth. We collected morphometric measurements of fawns (i.e., total body length, chest girth, hindfoot length, and neck circumference at upper, middle, and lower neck), affixed individually identifying ear tags in both ears (Allflex USA Inc., DFW Airport, Texas, USA), and fitted 26 fawns with GPS-sized expandable radio-collars. We fitted 20 fawns with Vectronic Vertex collars (Vectronic Aerospace GmbH, Berlin, Germany), 3 fawns with Telonics TGW collars (Telonics, Inc., Mesa, Arizona, USA) and 3 fawns with Telonics Recon collars (Telonics, Inc., Mesa, Arizona, USA). Five uncollared fawns served as experimental controls for our behavioral assessments. After handling, we immediately returned fawns to the outdoor paddocks where they were housed with their mothers until weaning.

Collar Fit and Function

We conducted assessments of collar fit and function 3 times per week on each collared fawn throughout the first 12 months of life. Using binoculars, we remotely observed fawns in outdoor paddocks, recorded scores of collar fit and body condition, and examined necks of fawns for signs of hair loss or lesions (Table 1). Additionally, we examined the expandable folds of each collar, recording the date at which each fold opened. To calculate collar retention, we recorded the date at which collars failed, dropped, or required removal to ensure animal welfare. At approximately 6, 9, and 12 months of age, we manually restrained all fawns to inspect the integrity of collars, evaluate the condition of fawns, and collect neck circumference measurements.

Vectronic Vertex

Vectronic Vertex (Vectronic GmbH; Figure 1) collars weighed about 138 g with the battery, VHF transmitter, and GPS transmitter located within a single large housing at the front of the collar (dimensions = 6.2 cm x 3.9 cm x 4.4 cm). The housing was attached to the collar using high-performance glue and 2 plastic cable ties. The antenna was coated with a thin protective layer of plastic and measured 26.5 cm with 20.5 cm of its full length exposed. The neck band was 4 cm wide, composed of nylon and rubber materials with an initial circumference of 22.3 cm. The neck band included 6 expansion folds (3 sections of 2 folds each) which were each 2 cm long. The section of folds furthest from the housing had a single stitch running through the middle of its folds, the middle section had 2 stitches (2.4 cm apart) through its folds, and the section closest to the housing had 2 stitches (3.1 cm apart) through its folds. Fully expanded, the circumference of the neck band was approximately 34 cm, not including stretch of the elastic band material.

Telonics TGW and Recon

Telonics TGW (Telonics, Inc.; Figure 2) and Telonics Recon (Telonics, Inc.; Figure 3) collars weighed about 140 g and 150 g, respectively. The primary differences between the TGW and the Recon designs were the battery housing material and the distribution of electronics. On the Telonics TGW, the battery, VHF transmitter, and GPS transmitter were located in 3 housings: a polymeric housing contained the battery (dimensions = 5.5 cm x 2.9 cm x 3.3 cm) and 2 plastic housings contained the VHF (dimensions = 1.8 cm x 0.5 cm x 1.8 cm) and GPS (dimensions = 2.8 cm x 0.9 cm x 2.8 cm) transmitters. On the Telonics Recon collar, the battery, VHF and GPS transmitters were distributed between 2 housings: an aluminum housing contained both the battery and the VHF transmitter (dimensions = 4.3 cm x 2.6 cm x 3.5 cm) and a plastic housing contained the GPS transmitter (dimensions = 2.8 cm x 0.9 cm x 2.8 cm). The battery housings of both the TGW and the Recon designs were attached to the collar using 4 screws and glue. The antenna of each Telonics model measured 26.8 cm with 20.9 cm of its full length exposed. The collar bands of both Telonics models were 3.8 cm-wide and composed of nylon and rubber (i.e., elastic portion) sewn to a 3.7 cm-wide strip of static polymer. The length of the static polymer material for each model was 15 cm and initial length of the elastic portion of each was 7.9 cm. Therefore, the initial band circumference (i.e., pre-expansion) of each Telonics model was 22.9 cm. The bands of both designs included 6 expansion folds (3 sections of 2 folds each) which were each 2 cm long. The section of folds closest to the housing had a single stitch running through the middle of its folds, the middle section had 2 stitches (1 cm apart) through its folds, and the section furthest from the housing had 4 stitches (0.5 cm apart) through its folds. Fully expanded, the circumference of the band was 34.9 cm, not including stretch of the elastic band material.

Fawn Behavior

We conducted focal observation sessions of each fawn to evaluate effects of collars on their behavior during the first 12 months of life. The frequency of our sessions decreased as fawns aged: $\leq$30 days of age, we aimed to conduct $\geq$1 morning and $\geq$1 evening session every week for each fawn; during 30-60 days of age, we conducted 1 morning session per week; during 60-200 days of age, we conducted 1 morning session every other week; and during 200-365 days of age, we observed each fawn during 1 morning focal session every 4 weeks. We conducted focal sessions from 4.5-m stationary observation platforms within paddocks during crepuscular sampling periods: in the evening from 06:00 to 10:00 EST or in the evening from 17:00 to 21:00 EST. Before conducting the first focal session of a sampling period, the observer sat quietly for 15 minutes to minimize impacts of human activity on the behavior of deer in the paddocks. During a focal session, we recorded the body orientation and behavior of the focal fawn each minute for 30 minutes. We recorded the overall body position, neck position, head position, and head tilt of the fawn based on a pre-determined scoring system (Figure 4). We coded all behaviors (e.g., vigilant, sleeping, foraging, suckling) in a preconstructed ethogram (Table 2). If the focal fawn moved out of sight for >5 minutes, we terminated the focal session and censored the data. We kept a running tally of fawn vocalizations, mother vocalizations, and the number of times a fawn exhibited any attention to its collar. We monitored fawn-mother proximity throughout focal sessions using a laser rangefinder and a compass. Every 5 minutes, the observer recorded a distance (m) and compass azimuth for the fawn and mother, then solved for the Euclidean distance using the Law of Cosines. We averaged all fawn-mother distances to obtain a mean fawn-doe proximity for each session. If the mother of the focal fawn was not visible, the observer did not record this information during the session.

RESULTS

For fawns $\geq$342 days old, no Vectronic collars exhibited premature expansion. Three Vectronic collars dropped from fawns in the outdoor paddocks, but none due to compromised stitching or elastic material. In one case, a fawn shed its collar at 256 days of age by snagging and tearing its collar (at the expandable material) on a perimeter fence while being moved through the facility. In the other 2 cases, fawns shed their collars at 265 and 276 days of age due to a large tear in the expandable material of the collars, likely caused by collars catching on fencing in outdoor paddocks. Overall, Vectronic collars accommodated the neck growth of fawns during the first year of life. As the necks of fawns grew larger, collars initially became tight (but not restrictive) around the lower neck. Added pressure to the expandable materials of the collar eventually caused 1-2 expansion folds to open, increasing the band circumference of the collar. The initial expansion, in most cases, resulted in some hair loss from the neck as loosened collars moved more freely around and along necks of fawns. This likely caused some minor discomfort; however, fawns quickly grew into the expanded collars.

The collar folds of all 6 Telonics mock-ups expanded prematurely by 75.8 $\pm$ 27.9 (mean $\pm$ SD) days. The ill-fitting collars moved freely along and around the necks of fawns, causing significant hair loss on the necks of all 6 fawns. Once the stitching of folds was compromised and the elastic material began to degrade, all 6 fawns were able to step through collars with their forelimbs. This displacement resulted in collars positioned around the chest or waist of fawns. For 2 fawns, premature collar drop occurred ≤20 days after the last fold expanded at approximately 80 days of age. For the other 4 fawns with Telonics mock-ups, we removed fully-expanded collars from the chest or waist at approximately 6 months of age when we restrained fawns to collect neck measurements.

We collected >200 hours of behavioral observations to date. Notable effects of collars on fawn behavior included high-stepping with forelimbs during locomotion, erratic jumping behavior, and several instances of forelimbs getting caught in ill-fitting collars. Each of these atypical behaviors were most prevalent in younger collared fawns, from newborn to approximately 3-4 weeks of age. High-stepping and erratic jumping behavior occurred most frequently in fawns fitted with Vectronic collars. We observed several instances of young fawns (<4 weeks old), fitted with both Telonics and Vectronic collars, getting their forelimbs caught in loose-fitting collars (pre-expansion). In these cases, a fawn's leg was restrained in the collar for 1-6 minutes.

DISCUSSION

Based on our preliminary results, we developed several recommendations for Telonics, Inc. and Vectronic Aerospace GmbH to improve their GPS-sized expandable radiocollars for white-tailed deer fawns. At this time, we cannot recommend the collar designs tested in our study for use in field studies. However, with modifications to each collar design and further testing in controlled settings, researchers may have access to viable GPS fawn collar options in the foreseeable future.

We recommended that Vectronic decrease the initial band circumference of their collar, improve weight distribution, and reduce size and weight of the battery housing in order to minimize effects on behavior. Poor weight distribution, paired with an initial collar band circumference that was larger than the necks of newborn fawns (Table 3), caused the battery housing to swing side to side as fawns moved forward. The high-stepping behavior appeared to be the fawns' attempts to step around the housing while it swung, to minimize contact with their forelimbs. The erratic jumping behavior observed in young collared fawns appeared to be a display of discomfort and frustration with cumbersome, loose-fitting collars. Decreasing the initial band circumference may alleviate some of these behavioral issues and lessen the chance of a fawn getting a forelimb caught in a loose-fitting collar. Weight of the Vectronic Vertex collar was focused at the front where a single large housing held all of the electronics. We believe that distributing electronics more evenly around the collar, perhaps in multiple smaller housings, would reduce the effects of collars on fawn behavior.

For the Telonics TGW and Recon collars, we recommended a slightly smaller initial band circumference to accommodate the smaller necks of newborn fawns (Table 3). A better-fitting collar may minimize issues with high-stepping and decrease the chance of a fawn getting a forelimb caught in a loose-fitting collar. The primary issues with the Telonics collar designs focused around the expandable material intended to accommodate rapid growth of fawns during the first year of life. Weak thread and elastic, as well as a potentially flawed stitching pattern, caused collars to expand and deteriorate at an accelerated rate. Exposure to environmental elements (e.g. sunlight, temperature, humidity, precipitation) likely played a role in the rapid expansion and degradation of collar materials. To increase collar retention and promote a more gradual elastic expansion, we recommended incorporating an improved stitching pattern and more durable thread and elastic material. Ideally, Telonics would utilize materials more similar to those on the expandable band of the Vectronic Vertex collars. We recommended the use of the polymeric-style housing (TGW) rather than the aluminum housing (Recon) because of lighter weight. When designing collars intended for newborn fawns, minimizing weight wherever possible is important. Therefore, we recommended that Telonics decrease collar weight to improve fit, reduce pressure on expandable materials, and prevent premature expansion.

The VHF technology of fawn collars currently used in field studies limits the abilities of researchers to efficiently estimate fawn survival, recruitment, movements, and habitat use. Enhancing our understanding of these factors would improve management of white-tailed deer populations (Moen et al. 1996, Rodgers et al. 1996, Bowman et al. 2000, Severud et al. 2015). Integrating GPS technology with expandable collar designs would provide researchers with more accurate information regarding the behavior of white-tailed deer (Bowman et al. 2000, McCance and Baydack 2017). With the primary limiting factor being the size and weight of batteries required to support GPS transmitters, we believe that further testing of GPS-sized collars in controlled settings is warranted before extensive deployment in field studies. The results of this study will provide important information to telemetry technology companies seeking to improve collar performance and produce less invasive collar designs.

Telonics, Inc. and Vectronic GmbH applied modifications to collar designs based on the preliminary results of this study and the recommendations we provided to each company. We will conduct additional testing of modified GPS-sized expandable collar designs during 2019-2020.

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LITERATURE CITED

Bowman, J. L., C. O. Kochanny, S. Demarais, and B. D. Leopold. 2000. Evaluation of a GPS collar for white-tailed deer. Wildlife Society Bulletin 28:141-145.

Cherry, M. J., D. J. Morin, R. J. Warren, and L. M. Conner. 2014. A low-cost GPS solution for studying spatial ecology of white-tailed deer fawns. Proceedings of the 37th Southeast Deer Study Group Meeting. Southeastern Section of The Wildlife Society,16-18 February 2014, Athens, Georgia, USA.

Diefenbach, D. R., C. O. Kochanny, J. K. Vreeland, and B. D. Wallingford. 2003. Evaluation of an expandable, breakaway radiocollar for white-tailed deer fawns. Wildlife Society Bulletin 31:756-761.

Grovenburg, T. W., R. W. Claver, C. N. Jacques, T. J. Brinkman, C. C. Swanson, C. S. DePerno, K. L. Monteith, J. D. Sivers, V. C. Bleich, J. G. Kie, and J. A. Jenks. 2014. Influence of landscape characteristics on retention of expandable radiocollars on young ungulates. Wildlife Society Bulletin 38:89-95.

Hampson, B., J. Morton, P. Mills, M. Trotter, D. Lamb, and C. Pollitt. 2010. Monitoring distances travelled by horses using GPS tracking collars. Australian Veterinary Journal 88:176-181.

Hiller, T. L., H. Campa, III, and S. R. Winterstein. 2008. Survival and space use of fawn white-tailed deer in southern Michigan. American Midland Naturalist 159:403-412.

Jacobson, H. A., J. C. Kroll, R. W. Browning, B. H. Koerth, M. H. Conway. 1997. Infrared-triggered cameras for censusing white-tailed deer. Wildlife Society Bulletin 25:547-556.

Keyser, P. D., D. C. Guynn Jr., and H. S. Hill Jr. 2005. Population density-physical condition relationships in white-tailed deer. Journal of Wildlife Management 69:356-365.

Kjellander, P., I. Svartholm, U. A. Bergvall, and A. Jarnemo. 2012. Habitat use, bed-site selection and mortality rate in neonate fallow deer *Dama dama*. Wildlife Biology 18:280–291.

McCance, E. C., and R. K. Baydack. 2017. Critical considerations for an urban deer collaring program. Environment and Ecology Research 5:195-203.

Moen, R., J. Pastor, Y. Cohen, and C. C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. Journal of Wildlife Management 60:659-668.

Obermoller, T. R., G. D. Delgiudice, and W. J. Severud. 2018. Assessing expandable Global Positioning System collars for moose neonates. Wildlife Society Bulletin 42:314-320.

Pusateri-Burroughs, J., H. Campa, III, S. R. Winterstein, B. A. Rudolph, and W. E. Moritz. 2006. Cause-specific mortality and survival of white-tailed deer fawns in southwestern lower Michigan. Journal of Wildlife Management 70:743-751.

Rodgers, A. R., R. S. Rempel, and K. F. Abraham. 1996. A GPS-based telemetry system. Wildlife Society Bulletin 24:559-566.

Rohm, J. H., C. K. Nielsen, and A. Woolf. 2007. Survival of white-tailed deer fawns in southern Illinois. Journal of Wildlife Management 71:851-860.

Saito, M., and G. Idani. 2018. Giraffe mother-calf relationships in the Miombo Woodland of Katavi National Park, Tanzania. Mammal Study 43:1-7.

Severud, W. J., G. D. DelGiudice, T. R. Obermoller, T. A. Enright, R. G. Wright, and J. D. Forester. 2015. Using GPS collars to determine parturition and cause-specific mortality of moose calves. Wildlife Society Bulletin 39:616-625.

Smith, B. L., W. P. Burger, and F. J. Singer. 1998. An expandable radiocollar for elk calves. Wildlife Society Bulletin 26:113-117.

Vreeland, J. K., D. R. Diefenbach, and B. D. Wallingford. 2004. Survival rates, mortality causes, and habitats of Pennsylvania white-tailed deer fawns. Wildlife Society Bulletin 32:542-553.

Table 1. System used for scoring collar fit and body condition of white-tailed deer (*Odocoileus virginianus*) fawns at Whitehall Deer Research Facility in Athens, GA, USA, during 2018-2019 for testing of Global Positioning System (GPS)-sized expandable radiocollar designs.

Collar fit score	Body condition score	Neck hair loss score	Neck lesions score
1 = Very loose	1 = Emaciated	0 = No hair loss	0 = No lesions
2 = Little loose	2 = Thin	1 = Coat thinning	1 = Single lesion ≤1cm
3 = Good fit	3 = Prime	2 = Single bald patch ≤1cm	2 = Multiple lesions ≤1cm
4 = Little tight	4 = Heavy	3 = Multiple bald patch(es) ≤1cm	3 = Single lesion >1cm
5 = Very tight	5 = Obese	4 = Bald patch(es) >1cm	4 = Multiple lesions >1cm

Table 2. Ethogram used for recording behavior of white-tailed deer (*Odocoileus virginianus*) fawns during focal sessions at Whitehall Deer Research Facility in Athens, Georgia, USA, during 2018-2019 for testing of Global Positioning System (GPS)-sized expandable radiocollar designs.

Behavior	Code	Definition
Locomotion	L	Focal animal is moving forward (e.g., walking, running, jumping)
Foraging	F	Focal animal is eating or drinking (not suckling)
Suckling	S	Focal animal is actively suckling at adult doe
Grooming	GG	Focal animal is grooming another individual
Groomed	GD	Focal animal is being groomed by another individual
Grooming self	GS	Focal animal is grooming itself
Urogenital grooming	UG	Focal animal is being groomed by another at the urogenital region
Vigilant	V	Focal animal has eyes open and appears to be alert
Sleeping	SL	Focal animal has eyes closed and appears to be asleep
Undefined	U	Focal animal is exhibiting an undefined behavior
Out of sight	OS	Focal animal has moved out of sight

Table 3. Neck measurements (mean ± SD) collected from white-tailed deer (*Odocoileus virginianus*) fawns at 4 different ages at Whitehall Deer Research Facility in Athens, Georgia, USA, during 2018-2019 for testing of Global Positioning System (GPS)-sized expandable radiocollar designs.

Fawns measured	Age (months)	Mean upper neck (cm)	Mean middle neck (cm)	Mean lower neck (cm)
51	0	16.4 ± 1.4	16.6 ± 1.4	18.5 ± 1.5
22	6	26.0 ± 2.1	26.7 ± 2.4	30.7 ± 3.2
20	9	29.7 ± 2.9	30.8 ± 2.8	38.4 ± 4.4
18	12	31.4 ± 2.7	31.0 ± 2.6	34.1 ± 3.2

Figure 1. Vectronic Vertex collar deployed on white-tailed deer (*Odocoileus virginianus*) fawns at Whitehall Deer Research Facility in Athens, Georgia, USA, during 2018-2019 for testing of Global Positioning System (GPS)-sized expandable radiocollar designs.

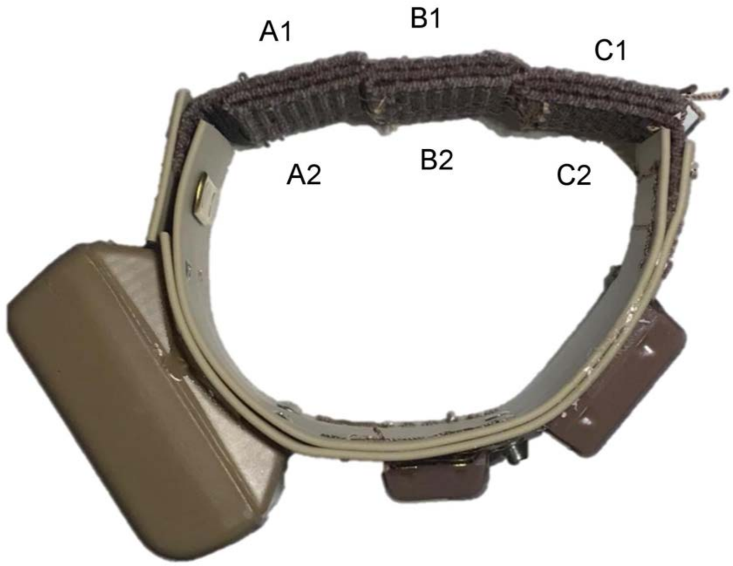

Figure 2. Telonics TGW collar deployed on white-tailed deer (*Odocoileus virginianus*) fawns at Whitehall Deer Research Facility in Athens, Georgia, USA, during 2018-2019 for testing of Global Positioning System (GPS)-sized expandable radiocollar designs.

Figure 3. Telonics Recon collar deployed on white-tailed deer (*Odocoileus virginianus*) fawns at Whitehall Deer Research Facility in Athens, Georgia, USA, during 2018-2019 for testing of Global Positioning System (GPS)-sized expandable radiocollar designs.

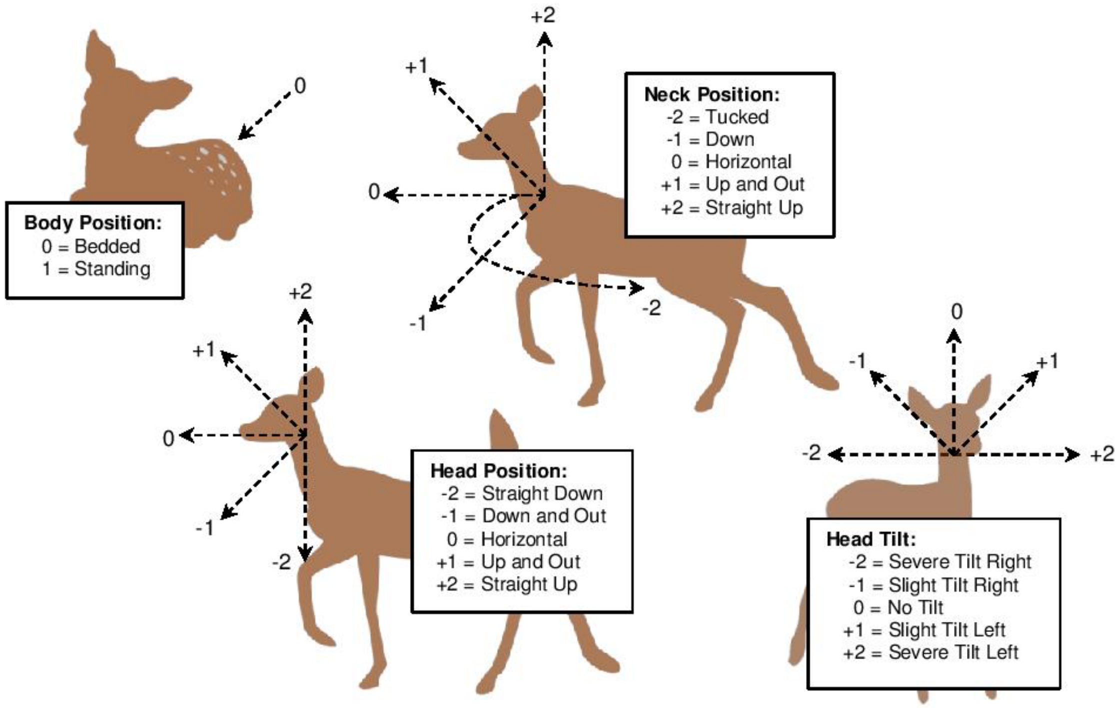

Figure 4. System for scoring body orientation during focal observation sessions of white-tailed deer (*Odocoileus virginianus*) fawns at Whitehall Deer Research Facility in Athens, Georgia, USA, during 2018-2019 for testing of Global Positioning System (GPS)-sized expandable radiocollar designs.