DEVELOPMENT AND EVALUATION OF A TERRESTRIAL ANIMAL-BORNE VIDEO SYSTEM FOR ECOLOGICAL RESEARCH

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DEVELOPMENT AND EVALUATION OF A TERRESTRIAL ANIMAL-BORNE VIDEO SYSTEM FOR ECOLOGICAL RESEARCH

Remington James Moll

Dr. Joshua Millspaugh, Thesis Supervisor

ABSTRACT

Animal-borne video and environmental data collection systems (AVEDs) are integrated sensor systems that combine video from the animal’s perspective with data from other sensors (e.g., audio, location). By placing sensor data within the context of video, AVEDs provide a unique perspective not offered by other methods and facilitate research into animal behavior, foraging tactics, bioenergetics, wildlife damage issues, and inter- and intra-specific interactions. From 2006 to 2008, I assisted in developing the first terrestrial, store-onboard AVED designed for ecological research. To provide ecologists with a framework for evaluating AVED research, I reviewed the historical development, ecological research potential, and future challenges associated with AVEDs. I tested the hypothesis that AVED attachment increases the stress levels (fecal glucocorticoid metabolites [FGMs]) of captive white-tailed deer (*Odocoileus virginianus*). Using a repeated measures analysis of variance, I found no difference in FGMs between control and treatment individuals during a 6 week trial that included a 2 week treatment period. I demonstrate the utility of our AVEDs by describing contacts between white-tailed deer at the Baskett Wildlife Research and Education Area near Ashland, Missouri. My research shows that our AVEDs are powerful new tools for ecological research that do not elevate stress levels of captive white-tailed deer and enable ecological research opportunities that traditional methods (e.g., radio telemetry) have not provided.
CHAPTER 1

A NEW ‘VIEW’ OF ECOLOGY AND CONSERVATION THROUGH ANIMAL-BORNE VIDEO SYSTEMS

ABSTRACT

Over the past three decades, technological advances for monitoring wild animals have expanded the ability of ecologists to study animal behavior and space use. Currently, researchers are deploying animal-borne video and environmental data collection systems (AVEDs), which enable researchers to see what the animal sees in the field. AVEDs record fine-scale movements as well as features of the surrounding environment and thus provide essential context for understanding animal decisions and interactions with other individuals. These fine-scale data are often crucial for understanding potential conservation threats to species of concern. Here, we discuss the development and research potential offered by AVEDs. The benefits of AVEDs are greatest in hypothesis-driven studies that require a fine-scale perspective that other technologies cannot offer.

INTRODUCTION

Animal-borne video and environmental collection systems (AVEDs) (Heithaus et al. 2006) are an advanced form of biotelemetry that enable researchers to see what a wild animal sees in the field and hear what it hears. These systems can also collect physiological and animal location data from other animal-borne sensors (Table 1). AVEDs enable continuous video recording of behavior from the perspective of the animal, thereby providing observations of unhabituated, free-ranging species at a finer scale than other techniques can provide (e.g., Davis et al. 1999, Ponganis et al. 2000; see
Fig. 1 in Moll et al. 2007). Questions about foraging dynamics, reproduction, species interactions (e.g., predator avoidance tactics) and disease transmission often require detailed behavioral data, which AVEDs can provide.

However, AVEDs are rarely viewed as tools of scientific inquiry, perhaps because their public appeal and educational value have been emphasized more than their scientific potential. Unlike many technologies used for ecological research, AVEDs have garnered considerable media exposure. For example, National Geographic’s Crittercam AVEDs headline a weekly television program; the associated website heavily targets children and educators (http://www.nationalgeographic.com/crittercam). Given that public policy is as much shaped by public perception as it is by scientific data, this focus is justified (Nisbet and Mooney 2007).

Here, we evaluate the capabilities of AVEDs as instruments for ecological research and discuss the key issues and questions addressed through AVED studies. Despite the availability of other technologies (e.g., still imaging, Table 2), we focus on AVEDs because of their rapid development, research potential (i.e., collection of continuous video versus individual snapshots), integration with other sensors, increased application, and prevalence in the media. First, we compare current available animal-borne technologies and introduce common components of AVEDs. Next, we outline how researchers can maximize the scientific potential of this technology by describing how AVEDs can be used for fine-scale hypothesis testing and bioenergetics research and by addressing conservation questions that AVEDs have helped to answer. We conclude with a discussion of the challenges and limitations of AVEDs and suggest that they are best used as part of a holistic, hypothesis-driven research approach.
COMPARING ANIMAL-BORNE SENSOR, LOCATION AND IMAGERY TECHNOLOGIES

Animal-borne sensors can collect diverse data, including location information from telemetry; physiological data; motion patterns (from an accelerometer); estimates of proximity to other animals; temperature, and depth for aquatic animals; still images; and video (Table 2). Other reviews (Boyd et al. 2004, Cooke et al. 2004, Block 2005, Ropert-Coudert and Wilson 2005) discuss physiological sensors in biotelemetry and biologging studies.

Although the collection of animal location data is often limited by logistical constraints (e.g., manual tracking), error in location estimates (owing to animal movement and terrain; Lesage et al. 2000, Millspaugh and Marzluff 2001, Rodgers 2001, D’eon and Delparte 2005, Zerbini et al. 2006) and cost (i.e., satellite and GPS systems; Rodgers 2001), such data answer many research questions regarding animal behavior, space use, and population demographics (Table 2; Millspaugh and Marzluff 2001). Furthermore, telemetry can provide highly accurate location data for some taxa in environments that allow fine-precision tracking (e.g., fish in coastal waters; Cote et al. 2003). However, without knowledge of ‘why’ the animal was observed at a particular location, which commonly occurs with radio tracking techniques, it becomes difficult to ascertain the importance of the location (Cooper and Millspaugh 2001). Similarly, time–depth recorders (TDRs) can identify important habitats and threats (e.g., traffic of ships and other vessels) for aquatic species, and are now small enough to be used on animals <200 g (e.g., Bocher et al. 2000). However, more than one behavior sometimes results in similar TDR patterns, making interpretation difficult (e.g., Seminoff et al. 2006). Still
imaging and AVEDs both offer context that is often necessary for interpretation of location data and can correct data from other sensors.

Animal-borne video or still imagery are most appropriate for elusive species in inaccessible environments (e.g., deep-diving marine species) and for fine-scale assessments of animal behavior (e.g., food selection; Beringer et al. 2004) and species interactions. For example, still cameras recently captured the first evidence of group foraging behavior for emperor penguins (*Aptenodytes forsteri*; Takahashi et al. 2004). However, unless the interval between images is small (e.g., <10 s), it can be difficult to piece together animal behavior in these snapshots of activity because important detail could be lost. Still images might also provide insight into habitat use if sampling schemes are well-designed. Video can clarify fine-scale behaviors, such as reproduction, social behavior, and foraging (Marshall 1998) and can correct data from other sensors. For example, AVEDs revealed that several individual tiger sharks (*Galeocerdo cuvier*) were using shallow habitats over twice as much as was estimated by acoustic tracking methods (Heithaus et al. 2001). For most species, AVEDs can incorporate a limited number of additional sensors owing to weight limitations associated with increased power requirements (i.e., more batteries).

**TECHNOLOGY IN PROGRESS: THE ANIMAL-BORNE VIDEO SYSTEM**

AVEDs have progressed significantly since their advent in 1987, and technological advancements are likely to be rapid over the next decade. The first AVEDs, described by Greg Marshall, were deployed on loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) turtles (Marshall 1990). His work progressed into National Geographic’s ‘Crittercam’, the flagship AVED for marine research (Marshall
The Crittercam has since decreased in size and weight (see Fig. 2 in Moll et al. 2007), enabling deployment on smaller species, such as the emperor penguin (Ponganis et al. 2000). Other research teams have independently developed AVEDs for ecological investigations for many species, including horseshoe crabs (*Limulus polyphemus*; Passaglia et al. 1997), Weddel seals (*Leptonychotes weddellii*; Davis et al. 1999), white-tailed deer (*Odocoileus virginianus*; Beringer et al. 2004), and great cormorants (*Phalacrocorax carbo*; Grémillet et al. 2006).

AVED specifications are driven by study species and research questions. Requisites include a secure animal attachment technique, a video camera, a recording medium, a power source, and a reliable method for system retrieval. Attachment methods depend on study species; epoxy glues are used on animals with thick fur (Davis et al. 1999), animal harnesses are suitable for smaller aquatic animals and birds (Ponganis et al. 2000, Grémillet et al. 2006), suction cups are appropriate for animals with a tough outer carapace, such as turtles (Reina et al. 2005), and clamps secure AVEDs on marine species with large fins, such as sharks (Heithaus et al. 2001). Once attached, AVEDs begin recording at a preset time or are programmed to record in response to an environmental cue that is monitored by a system sensor (e.g., light intensity; Beringer et al. 2004). Video is then captured continuously (Beringer et al. 2004) or recorded at prescribed intervals (Bowen et al. 2002) and the total system lifespan is ultimately limited by storage space and battery power. Early AVEDs were analog systems that recorded on tape; today digital systems are commonly used, and new hard drive AVEDs hold promise for increased video storage capacity (Davis et al. 2004). Transmission-based systems are available (Beringer et al. 2004), but are restricted to terrestrial systems and are far less
common than onboard AVEDs. Transmission-based systems are limited by range and signal attenuation, especially in forested or mountainous terrains.

Battery power is often supplied by lithium-ion battery packs and is influenced by additional sensors and system features (see Fig. 2 in Moll et al. 2007), such as infrared lights for night vision. Following attachment and data collection, AVEDs are retrieved either by animal recapture (Beringer et al. 2004) or automatic release coupled with a VHF transmitter and acoustic tracking (Heithaus et al. 2001). Once retrieved, video and data from other sensors are downloaded for analysis and AVEDs are often reprogrammed and re-used.

ECOLOGICAL RESEARCH USING AVEDS

The benefits of AVEDs can be shown by discussing their recent contributions to fine-scale behavioral hypothesis testing, bioenergetics research, and animal conservation.

Behavioral studies: generating and testing fine-scale hypotheses

Human observation, inferences made from physiological sensors and images collected by stationary cameras provide invaluable data about animal behavior. However, these techniques have generated relatively little data on many elusive species, such as deep-diving marine animals. For these species, the lack of basic behavioral data makes it difficult to test, or sometimes even specify, behavioral hypotheses. For example, mouth and gut analyses suggest that carnivorous juvenile green turtles (*Chelonia mydas*) become herbivorous during adulthood, but there is little consensus among studies (Bjorndal 1997). AVEDs revealed green turtles feeding on jellyfish and ctenophores more than expected, identifying animal matter as a more important food source for adult turtles than previously thought (Heithaus et al. 2002a).
AVEDs not only help examine fine-scale hypotheses, but can also stimulate future work by providing a foundation of descriptive, life-history data from which researchers can build focused hypotheses. For example, data on the behavior of midwater fishes is scarce, largely owing to the difficulty of observing free-ranging populations. Previous trawl catch data recorded adult Antarctic toothfish (*Dissostichus mawsoni*) occurring at depths of 300–500 m (Eastman 1993). However, observations from AVEDs attached to Weddell seals suggest that they are common at depths of <200 m and, similar to Antarctic silverfish (*Pleuragramma antarcticum*), might migrate in response to changing environmental conditions, such as light intensity (Fuiman et al. 2002). These fish species are important prey for whales, seals, other fishes, and seabirds and thus their impact upon the Antarctic marine food web is substantial. Drawing conclusions about the distribution of prey at the population level from the back of a predator carrying an AVED should be viewed cautiously; however, such data can generate hypotheses and stimulate future research into the environmental conditions that govern animal abundance and movements.

AVEDs can also reveal fine-scale interactions between animals and their environment. To keep their carapaces free from algae and organisms, green turtles engage in symbiotic relationships with cleaner fish in reef habitats (e.g., Losey et al. 1994). However, turtles in habitats dominated by sea grass or sand lack access to these species, leading researchers to hypothesize that they clean their carapaces by other means. AVEDs revealed that green turtles adapted to such habitat by cleaning themselves on underwater sponges and rocks (Heithaus et al. 2002a). Previous research into green turtle dives has not revealed this self-cleaning behavior and rubbing behavior.
is likely to be misclassified as foraging in time-depth recorder (TDR) datasets (Hochscheid et al. 1999, Hays et al. 2000). Patches of sponges and rocks, therefore, might be an important, overlooked habitat component. Knowledge of these fine-scale interactions often is necessary for understanding the importance of micro-habitat selection.

**Energetic studies: benefits of integrating AVEDs with other sensors**

AVEDs have the greatest potential for explaining ecological mechanisms when video is integrated with other animal-borne sensors, because data can then be interpreted within the context of animal activity. Understanding the energy budgets of animals is important for predicting their survival in different habitats. For example, the potential of an organism for invasion can be reflected in its ability to maintain a net positive energy balance under a variable set of environmental conditions (e.g., Chess and Stanford 1998). Yet few field experiments have quantified animal energetics because of the difficulty of simultaneously measuring metabolic rates, energy expenditure, and animal behavior without affecting behavior.

Like any predator, predatory marine mammals must balance the high energy costs of hunting with the energy gain of prey capture. Precisely how they do this is often poorly understood. In Weddell seals, AVEDs showed that swimming costs increased linearly with the number of strokes taken, and prey intake and digestion increased the post-dive oxygen recovery by 44.7%, suggesting that there is a trade-off for the seals between the duration of hunts and the associated potential energy gain (Williams et al. 2004). Similarly, AVEDs revealed that harbor seal (*Phoca vitulina*) hunting tactics depend on prey visibility and that seals swim faster and spend more time pursuing and
handling cryptic prey than conspicuous prey (Bowen et al. 2004). If energy intake from prey ingestion is not sufficient to offset the costs of hunting, a negative net energy balance can result and, over time, seal survival can be compromised (Williams et al. 2004). By using AVEDs to quantify the energetic requirements of foraging and the profitability of prey species, researchers can build models to predict the prey abundance, species composition, and distribution necessary to sustain a population of top predators in an ecosystem.

Similarly, behavioral adaptations are crucial for enabling oxygen-limited marine species to perform deep dives. Marine mammals conserve energy and maximize oxygen use by traveling within a narrow range of speeds while submerged (Williams 1999). However, many species routinely perform deeper dives than predicted from their aerobic metabolic rates, suggesting that they have behavioral adaptations beyond efficient travel speeds (Kooyman and Ponganis 1998, Williams et al. 1999). AVEDs recorded changes in locomotor behavior during dives in four species: the Weddell seal, the northern elephant seal (*Mirounga angustirostris*), the bottlenose dolphin (*Tursiops truncatus*), and the blue whale (*Balaenoptera musculus*), revealing that energy-saving locomotory changes (i.e., prolonged gliding) throughout dives were similar for all species (Williams et al. 2000). This provides evidence for convergent evolution of swimming strategies to mitigate the common constraint of limited oxygen supply during dives in pinnipeds and cetaceans, despite considerable differences in body shape and propulsion technique. AVEDs also revealed that green turtles adjust their locomotor effort in response to changes in buoyancy during dives, further suggesting that swimming behavior has a central role in optimizing energy use in marine species (Hays et al. 2007).
Contributions to conservation

Much recent AVED work has focused on the largest remaining colony of endangered Hawaiian monk seals (*Monachus schauinslandi*) near Hawaii, the population of which has declined substantially. Critical oceanic monk seal habitat designated by the US Department of Commerce was limited to depths <40 m; AVEDs revealed adult male seals foraging almost exclusively on oceanic terraces and slopes at depths >40 m, including sites of commercial fishing operations (Parrish et al. 2000). Previous scat analysis studies might have underestimated the take of commercially fished species (e.g., lobster) owing to bias caused by differential digestion of animal matter (Goodman-Lowe et al. 1999, Antonelis et al. 2006), whereas AVEDs provide robust foraging data. Shortly after the AVED study in 2000 (Parrish et al. 2000), a US Federal Court ruling closed lobster and bottomfish fisheries in the surrounding region, charging the fisheries with a violation of the Endangered Species Act by failing to assess the impacts of harvest on monk seals (US District Court of Hawaii Civil Case No. 00–00068SPKFIY).

Conservationists are also concerned that commercial harvest of precious pink (*Corallium* sp.) and gold (*Gerardia* sp.) coral near Hawaii destroys habitat used by monk seals. Telemetry and TDR studies have documented seals occasionally performing dives deep enough to encounter coral beds, but they have not described behavior during such dives (Antonelis et al. 2006). Although AVEDs did not document seals using precious coral beds, they showed them foraging for fish in beds of black coral (*Cirrhipathes* sp.), suggesting that precious coral beds might also be used by monk seals (Parrish et al. 2002). Despite its small sample size (*n = 5*), this study serves as an indicator that coral harvest might have an impact on monk seal foraging and highlights the need for further
research. The emaciation and poor survivorship that characterize juvenile monk seals is suspected to be related to prey availability (Craig and Ragen 1999) and oceanic conditions (e.g., El Niño events; Antonelis et al. 2003), but the exact mechanisms are not fully understood. AVEDs recorded yearling seals foraging in oceanic sand fields on populations of flounders (Family Bothidae), which are especially susceptible to changes in oceanic regimes; this suggests that managing for these prey during unfavorable oceanic conditions might increase the survival of juvenile monk seals (Parrish et al. 2005). In both of these AVED studies, video data provided information that other methods had not captured, enabling researchers to link foraging behavior and prey selection with fine-scale habitat use to understand more fully the dynamics of seal movements, prey availability, foraging behavior and microhabitat selection (Parrish et al. 2002, Parrish et al. 2005).

In another example, fine-scale data provided by AVEDs helped resolve a perceived human–wildlife conflict. The predation of fishes by populations of European great cormorants and North American double-crested cormorants (*Phalacrocorax auritus*), which have grown rapidly in recent years, is viewed as a threat to commercial fisheries (Hatch 1995, Glahn et al. 2000). In addition, fishers claimed that unsuccessful foraging attempts by cormorants regularly injure fish, decreasing their market value. Video from AVEDs and dive tank-mounted cameras revealed that this non-lethal damage is negligible and that cormorants rarely injure prey without capturing it (e.g., 0.4% of cases in double-crested cormorants; Grémillet et al. 2006). These data help refute claims that cormorants have widespread impact upon the economic gain of commercial fisheries by injuring fish.
AVEDs have served as a vehicle for public outreach and education, which sets the stage for conservation by garnering public support and providing a framework of ecological knowledge. To be relevant, conservation education should frame scientific data in context (Nisbet and Mooney 2007) and should stimulate the public’s imagination (Brewer 2001). AVEDs facilitate imaginative education of ecological processes by providing intimate views from undisturbed animals in their natural surroundings. For example, several of the same video segments that provided data in our examples are available to the public on websites that also include information about the ecological role and conservation status of the species (http://channel.nationalgeographic.com/channel/crittercam).

IDENTIFYING CHALLENGES, LIMITATIONS AND DEVELOPMENTAL NEEDS

Despite the utility of AVEDs in conducting behavioral, energetics, and conservation-related research, several obstacles must be addressed to realize their full potential. A foremost challenge facing AVEDs is the assumption that systems do not compromise the natural behavior of an animal or induce harmful levels of stress. Other challenges include overcoming sample size constraints, increasing system lifespan, and storage capacity, decreasing system size, and weight, and efficiently analyzing voluminous video data.

Evaluating the effects of AVEDs on animal behavior and well-being

If research equipment affects the natural behavior of an animal, study results can be biased and the impact on the animal might be ethically unacceptable. Reviews of studies of telemetry transmitter effects suggest that tags should be <3–5% of animal body
mass, but smaller percentages are recommended for birds and aquatic animals (Kenward 2001, Withey et al. 2001, Demers et al. 2003). External tags on aquatic fauna should be <1–2% of body mass and fusiform or cylindrical shapes are recommended to minimize hydrodynamic drag (Marshall 1998, Sutton and Benson 2003, Wilson et al. 2004). Drag caused by tags can now be modeled using computer simulations (Pavlov et al. 2007), enabling optimization of tag design without conducting wind or water tunnel experiments (e.g., Bannasch et al. 1994). We encourage collaboration between ecologists and engineers to minimize the impact on animals.

AVEDs have a greater potential to affect animals than other technologies (e.g., telemetry transmitters) because they are larger, heavier, and cannot be implanted subcutaneously. Several studies have quantified animal response to AVED attachment (Ponganis et al. 2000, Heithaus et al. 2001, Bowen et al. 2002, Littnan et al. 2004, Grémillet et al. 2006). For example, maximum dive depth, dive duration, average descent rate, and average ascent rate did not differ in pre- and post-AVED attachment measurements in Hawaiian monk seals; however, the sample size was small (n = 10) and the samples showed considerable variation (Littnan et al. 2004). The large size of many AVED study species (e.g., seals) has limited the impact of AVEDs; smaller animals are likely to show more discernible responses. Of all AVED assessments, the only reported deleterious effect is for a relatively small species, the emperor penguin; individuals showed a 21–35% decrease in the duration of foraging trips while carrying an AVED (Ponganis et al. 2000).

A recent call for an ecological analog to the bioethics field in medicine (Minteer and Collins 2005) highlights the importance of measuring and minimizing the effects of
AVEDs on animals (Wilson and McMahon 2006). AVED research perhaps faces greater scrutiny from the public than do other animal-borne sensors owing to the charismatic nature of test subjects (e.g., lions Panthera leo), the media coverage associated with AVEDs, and their growing role in public outreach. Studies should be conducted before deployment to assess the impact of AVEDs, using carefully designed and replicated experiments that compare control and AVED-equipped animals. In addition to demographic and behavioral investigations, we suggest that researchers use physiological assessments, which are currently lacking in AVED research, to quantify effects. Non-invasive procedures, such as fecal glucocorticoid metabolite assessment, do not require repeated handling of study animals and are a sensitive measure of stress (Millspaugh and Washburn 2004, Schulz et al. 2005). Unless some attempt has been made to understand impact, study results should be viewed with caution.

Sample size issues

As with early telemetry research, AVED studies have suffered from small sample sizes (i.e., n often <10). There are now guidelines for sample sizes for telemetry research (e.g., Leban et al. 2001), but similar protocols for AVEDs are lacking, leaving researchers to derive sample size from personal knowledge or common practice. To overcome this challenge, we suggest that researchers ask focused ecological questions (e.g., what is the foraging success of age and sex class x of species y for prey species z?) and conduct pilot experiments to estimate the variation of desired parameters, which can lead to sound guidelines for necessary sample sizes. As in telemetry studies (Otis and White 1999), AVED researchers should expect high variation in individual behavior depending on age, sex, and local habitat characteristics. When researchers cannot
respond by deploying a large number of AVED systems, they need to focus on specific conditions to gain reliable insights into fine-scale mechanisms and use additional study, theory, and modeling to scale these insights up to broader conditions.

AVEDs are not commercially available, which restricts access for most researchers. The available units are mainly custom-built or are only available to researchers on loan for short time frames. For studies requiring high samples sizes (e.g., foraging), the lack of access to AVEDs is disadvantageous. Thus, AVEDs might not offer more information than can be obtained through traditional approaches and could be reduced to anecdotes for animals that do not forage frequently (e.g., sharks). With plummeting prices of video and battery technology, it is now possible to build units that could be purchased and used over the time frames necessary for ecological studies, thus providing a way to increase sample sizes. For example, it can be difficult to obtain large sample sizes for telemetry-based habitat use studies on wide-ranging species (e.g., sharks) because of the labor requirements of manual tracking; AVEDs can increase sample size for such studies because they provide habitat use data without requiring tracking (Heithaus et al. 2001). Many other animal-borne technologies have been successful because they are commercially available, and we encourage the commercial development of AVEDs.

**Battery power, system weight and storage capacity**

The lifespan of an AVED is contingent upon the size, weight, storage capacity, and battery power of the system. The size and weight of AVEDs have decreased over time. Larger species, such as seals, can carry larger systems and have therefore been the focus of early AVED research, although AVEDs have been deployed on animals
weighing <5 kg (e.g., horseshoe crabs; see Fig. 1 in Moll et al. 2007). Biotelemetry research was similarly focused on large species during its infancy (Ropert-Coudert and Wilson 2005), and yet there is now an external heart rate transmitter designed for small birds and bats that weighs <1 g (Bowlin et al. 2005). Commercial digital video cameras not much larger than postage stamps are currently available (e.g., http://supercircuits.com), but adapting them into field-worthy AVEDs will take time, and there are trade-offs between system size and system lifespan; smaller systems mean fewer batteries, less onboard storage and, ultimately, shorter system lifespan. As AVEDs become smaller and more species become candidates for AVED research, ecologists should collaborate with engineers to ensure system lifespan is maximized by optimizing energy use and video storage.

Onboard storage capabilities have advanced only marginally in the past ten years, but recently developed hard-drive video cameras have increased storage capacity from 6 h (Davis et al. 1999) to over 80 h (Davis et al. 2004). Transmission-based terrestrial AVEDs are limited predominately by battery power rather than data storage because video can be transmitted to a remote downloading station (Beringer et al. 2004). It is also crucial to incorporate video compression to maximize storage capacity; a duty-cycled system with advanced video compression and a large onboard hard disk could record months of data in the field, provided there is sufficient power. Systems can also be designed to transmit stored data wirelessly to downloading stations placed in locations frequented by animals, thereby releasing the onboard storage disk space. Similarly, packets of video data can be relayed through transmission nodes placed throughout the
habitat of an animal, creating a network through which data can travel, with a computer as the terminal destination (Akyildiz et al. 2002).

At this point, advancements in storage seem to be outpacing reductions in power consumption, making battery power and battery weight the major technological factors limiting AVEDs. Alternative battery sources, such as solar-powered or motion-recharged batteries, hold promise, but the immediate solution lies in designing intelligent systems that power off during specific behaviors by using animal-borne sensors (e.g., accelerometers). Research objectives requiring lower quality video might also lengthen battery life through reductions in video quality (e.g., lower frame rate).

**Efficient analysis of video data**

AVED researchers must analyze enormous amounts of data efficiently. So far, analysis has been carried out primarily by visual inspection by wildlife experts (e.g., Beringer et al. 2004), although computer software that categorizes and quantifies specific behaviors has aided some studies (e.g., Bowen et al. 2002). Semi-automated software analysis of video data is an indispensable element of AVED technology. Important applications include: (i) image stabilization for more efficient visual analysis; (ii) scene classification that organizes and quantifies video segments based upon specified behaviors, movements (Günsel et al. 1998) or sensor data (e.g., temperature); (iii) species-specific face detection algorithms (Burghardt and Calic 2006); and (iv) for AVED networks operating on populations of animals, analysis of data packet transmission history. In the case of (iv), software can be used to categorize video segments based on the presence or absence of other AVEDs within transmission range,
thereby enabling researchers to focus on video segments in which animal interaction is likely (Juang et al. 2002).

CONCLUSIONS AND FUTURE DIRECTIONS

AVEDs contribute to behavioral research, physiological studies, and animal conservation by integrating video recordings of animal activity from the perspective of the animal (see Fig. 1 in Moll et al. 2007) with other animal-borne sensor data. As the challenges described here are addressed, AVED research should evolve from small-scale, individual-focused studies to long-term investigations of populations. With AVEDs come many research opportunities, but research questions and techniques will have to coevolve with the technology to ensure that the contributions of AVEDs to ecology and conservation are maximized and efficient. AVED technology must also become more widely accessible to the scientific community through commercialization of this technology.

As with all novel technologies, there is a temptation to deploy AVEDs before research questions are clearly identified. For example, early telemetry research included many descriptive case studies without a clear idea of whether the question was important or whether data would be sufficient to answer it. Many early AVED studies have been descriptive in nature and have provided a foundation of basic knowledge upon which future experiments can be designed. Such studies have value for elusive species about which we know little. However, as in early telemetry studies, a large number of exploratory studies had value and were publishable; but their efficiency in building scientific knowledge would have been higher had study questions been more mechanistic, with less emphasis on their novelty and descriptive nature. Several studies have used
AVEDs to evaluate a priori hypotheses and thus have made fuller use of the technology (e.g., Parrish et al. 2000, Parrish et al. 2003, Grémillet et al. 2006, Heithaus et al. 2002b). Proof-of-concept pilot studies and even data from related species or those with similar niches can be useful for developing meaningful hypotheses.

We encourage ecologists to implement AVEDs to answer research questions and management issues that cannot be addressed using traditional methods. We envisage future applications including research into animal interaction (Passaglia et al. 1997, Barlow et al. 2001) and disease transmission (e.g., by establishing contact rates between animals), explaining mechanisms for rare events or behaviors (e.g., tool use in New Caledonian crows Corvus monedula; Rutz et al. 2007), mitigating human–wildlife conflicts (e.g., reducing animal–vehicle collisions through study of road-crossing behavior), and continued research into factors influencing the survival of endangered species. AVEDs are especially suited for testing hypotheses about fine-scale behavior, and they are most effective as part of a system to capture many forms of data simultaneously.

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Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.

<table>
<thead>
<tr>
<th>Research species</th>
<th>System weight&lt;sup&gt;b&lt;/sup&gt;</th>
<th>System size</th>
<th>Sensors and features</th>
<th>Attachment method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>African lion (Panthera leo)</td>
<td>1.6 kg</td>
<td>6.7 x 14.9 x</td>
<td>Automatic release; infrared; transmission-based</td>
<td>Neck collar</td>
<td>G. Marshall</td>
</tr>
<tr>
<td>Emperor penguin (Aptenodytes forsteri)</td>
<td>1 kg&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9 x 25 cm&lt;sup&gt;d&lt;/sup&gt;</td>
<td>TDR</td>
<td>Harness</td>
<td>Ponganis et al.</td>
</tr>
<tr>
<td>Great cormorant (Phalacrocorax carbo)</td>
<td>240 g</td>
<td>10 x 5 x 4</td>
<td></td>
<td>Harness</td>
<td>Grémillet et al.</td>
</tr>
<tr>
<td>Green turtle (Chelonia mydas)</td>
<td>2 kg&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.1 x 31.7</td>
<td>TDR; sonic transmitter; automatic release</td>
<td>Epoxy glue</td>
<td>Heithaus et al.</td>
</tr>
<tr>
<td>Harbor seal (Phoca vitulina)</td>
<td>2 kg&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10 x 35 cm&lt;sup&gt;d&lt;/sup&gt;</td>
<td>TDR; temperature sensor; hydrophone; video activated by saltwater</td>
<td>Epoxy glue</td>
<td>Boness et al. 2006</td>
</tr>
</tbody>
</table>

<sup>a</sup> Specifications are approximate and may vary.

<sup>b</sup> Mass or weight, depending on species.

<sup>c</sup> Mass estimates are based on individual size and body type.

<sup>d</sup> Dimensions are approximate and may not be exact.
<table>
<thead>
<tr>
<th>Research species</th>
<th>System weight</th>
<th>System size</th>
<th>Sensors and features</th>
<th>Attachment method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawaiian monk seal (Monachus schauinslandi)</td>
<td>2 kg\textsuperscript{a}</td>
<td>10 x 35 cm\textsuperscript{d}</td>
<td>TDR</td>
<td>Glue</td>
<td>Parrish et al. 2000</td>
</tr>
<tr>
<td>Horseshoe crab (Limulus polyphemus)</td>
<td>NR</td>
<td>NR\textsuperscript{*}</td>
<td>Microsuction optic nerve electrode</td>
<td>NR</td>
<td>Passaglia et al. 1997</td>
</tr>
<tr>
<td>Leatherback turtle (Dermochelys coriacea) (&lt;1%)</td>
<td>2 kg\textsuperscript{a}</td>
<td>10 x 30 cm\textsuperscript{d}</td>
<td>TDR; automatic release</td>
<td>Suction cup</td>
<td>Reina et al. 2005</td>
</tr>
<tr>
<td>New Caledonian crows (Corvus moneduloides) (&lt;5%)</td>
<td>14.5 g</td>
<td>4.5 x 2.0 x</td>
<td>Tilt-switch VHF transmitter, tail</td>
<td>Harness</td>
<td>Rutz et al. 2007</td>
</tr>
<tr>
<td>Tiger shark (Galeocerdo cuvier) (NR)</td>
<td>2-4.5 kg\textsuperscript{a}</td>
<td>8.8 x 25.4 cm\textsuperscript{d}</td>
<td>TDR, thermistor, VHF and ultrasonic transmitters; automatic release</td>
<td>Dorsal fin</td>
<td>Heithaus et al. 2001</td>
</tr>
</tbody>
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Table 1. continued.

<table>
<thead>
<tr>
<th>Research species</th>
<th>System weight&lt;sup&gt;b&lt;/sup&gt;</th>
<th>System size</th>
<th>Sensors and features</th>
<th>Attachment method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weddell seal</td>
<td>NR&lt;sup&gt;c&lt;/sup&gt; (NR)</td>
<td>13 x 35 cm&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Accelerometer, pressure transducer; water speed sensor; compass bearing sensor; hydrophone; infrared LEDs</td>
<td>Rubber cement and glue</td>
<td>Davis et al. 1999</td>
</tr>
<tr>
<td>(Leptonychotes weddellii)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White-tailed deer</td>
<td>2.1 kg (≤3%)</td>
<td>Camera: 2.2 x 6.9 cm&lt;sup&gt;d&lt;/sup&gt; x 3 x 1.5 x 0.3 cm</td>
<td>Light-activated; transmission-based transmitter</td>
<td>Attached to antlers or neck collar</td>
<td>Beringer et al. 2004</td>
</tr>
<tr>
<td>(Odocoileus virginianus)</td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

<sup>a</sup>Abbreviations, NR, not reported; TDR, time depth recorder; L, length; D, diameter; UNP, unpublished data; VHF, very high frequency

<sup>b</sup>Value in parenthesis is approximate system weight relative to study animal

<sup>c</sup>Dry weight; systems reported to be neutrally or slightly positively buoyant underwater

<sup>d</sup>Fusiform or tubular in shape (size listed as diameter x length)
Table 2. Applications, advantages, and disadvantages of animal-borne sensors recording location, imagery, or sound.

<table>
<thead>
<tr>
<th>Method</th>
<th>Applications</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic</td>
<td>Animal</td>
<td>Records animal vocalizations and environmental stimuli</td>
<td>Might be difficult to interpret animal vocalizations without visual or location data</td>
<td>Davis et al. 1999</td>
</tr>
<tr>
<td>recording</td>
<td>communication and behavior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS sensors</td>
<td>Animal space use, including habitat use and animal movements</td>
<td>On-board storage eliminates manual tracking, higher frequency of observations than telemetry; often highly accurate</td>
<td>Variable accuracy and recording rates across habitats; often requires correction factors; size limitations of sensors; costly</td>
<td>Rodgers 2001</td>
</tr>
<tr>
<td>Satellite telemetry</td>
<td>Large-scale animal movements (e.g., migration)</td>
<td>Long-range transmission capability; ability to collect high number of locations; does not require manual tracking</td>
<td>Less accurate than telemetry or GPS sensors; only provides large-scale movements; costly for tags and recording data</td>
<td>Zerbini et al. 2006</td>
</tr>
</tbody>
</table>
Table 2. continued.

<table>
<thead>
<tr>
<th>Method</th>
<th>Applications</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Still images</td>
<td>Behavior, habitat use; animal</td>
<td>Provides information for rare and elusive species; relatively inexpensive and lightweight</td>
<td>Discontinuous accounts of behavior can be difficult to interpret; limited by battery life, data storage, system weight, trigger times, and robustness of apparatus</td>
<td>Takahashi et al. 2004</td>
</tr>
<tr>
<td>Telemetry</td>
<td>Habitat use, animal movements, demographics, and physiology</td>
<td>Generates location data; can be highly accurate for some taxa in certain environments; common method with broad literature base; transmitters can be very small; widely available</td>
<td>Behavior must be inferred from location data, which can be unreliable owing to tracking errors; costly in personnel time</td>
<td>Millspaugh and Marzluff 2001</td>
</tr>
<tr>
<td>Time-depth</td>
<td>Underwater recorder vertical movements of marine animals</td>
<td>Generates reliable depth data at high resolution (often &gt;1 measurement s⁻¹); small sensors can be applied to many species</td>
<td>Behavior must be inferred from depth data; only provides data on vertical space use</td>
<td>Bocher et al. 2000</td>
</tr>
</tbody>
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Table 2. continued.

<table>
<thead>
<tr>
<th>Method</th>
<th>Applications</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video</td>
<td>Behavior, habitat</td>
<td>Captures detailed accounts of animal behavior and habitat use, provides context for other sensor data, offers a perspective from the view of the animal energetic output; reproduction</td>
<td>Systems are large and limited by battery life, data storage and cost; not commercially available; small sample sizes are common; terrestrial systems susceptible to damage and lens obstruction</td>
<td>Marshall 1998</td>
</tr>
<tr>
<td>(AVED)</td>
<td>use, animal</td>
<td></td>
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<td></td>
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</table>

Note: For a comparison of biotelemetric physiological sensors, see Cook et al. 2004.
CHAPTER 2

STRESS RESPONSE OF CAPTIVE WHITE-TAILED DEER TO VIDEO COLLARS

ABSTRACT

Animal-borne video and environmental data collection systems (AVEDs) are an advanced form of biotelemetry that combines video with other sensors (e.g., GPS). Applications of AVEDs are diverse, including investigations into animal behavior, foraging tactics, predator/prey interaction, mate selection, and behavioral energetics. Because AVEDs are often larger and heavier than traditional animal-borne tags (e.g., radio tags), evaluation of AVED effects is essential to ensuring unbiased data and the ethicality of their application. We investigated the stress response (i.e., fecal glucocorticoid metabolite [FGM] secretion) of captive white-tailed deer (*Odocoileus virginianus*) to evaluate the effects of AVED dummy collars. We fit 7 deer with AVEDs (treatment) that weighed ≤4% of deer body mass and another 9 deer served as controls (i.e., captured and handled, but no AVED). We systematically collected fecal samples over 3, 2-week periods: pretreatment, treatment, and post-treatment; treatment deer wore AVEDs only during the treatment period. There was no difference in FGMs across all time periods ($F_{2,218} = 1.94, P = 0.147$) and no difference between FGMs of control and treatment individuals ($F_{1,14} = 0.72, P = 0.411$). There was a significant negative relationship between air temperature and FGM levels ($t = -3.66, df = 221, P < 0.001$). The highest FGM values were not indicative of high stress hormone values for white-tailed deer. Testing tag effects is an important prerequisite for field studies on free-
ranging animals. Our study suggests that AVEDs worn for 2 weeks do not stress captive white-tailed deer.

INTRODUCTION

Over the past 30 years, technological advancements have changed ecological research, both in available field and analytical methods and the research questions that can be answered (Read and Clark 2002). New technologies can provide data that were previously impossible or impractical to obtain. For example, satellite telemetry has recently been used to map large-scale animal movements (i.e., >1,000km), which can provide important context for international management of wide-ranging endangered species (e.g., leatherback turtles [*Dermochelys coriacea*] in the Atlantic Ocean; Hays et al. 2004). Due to reductions in size and cost, sophisticated animal-borne sensors are becoming increasingly common tools for ecological research (Cooke et al. 2004, Ropert-Coudert and Wilson 2005).

Recent reviews of animal-borne technologies have focused on biotelemetry (Cook et al. 2004) and animal-borne video and environmental data collection systems (AVEDs; Moll et al. 2007), which are an advanced form of biotelemetry that can combine video with a variety of sensors (e.g., GPS, audio, accelerometer; He et al. in press). In addition to location information, these systems offer video of events as seen by the animal. The applications of AVEDs are widespread, including investigations into animal behavior (Heithaus et al. 2002), foraging tactics (Davis et al. 1999), predator/prey interaction (Heithaus and Dill 2002), mate selection (Passaglia et al. 1997), behavioral energetics (Williams et al. 2000), and food selection (Beringer et al. 2004). Early AVED research focused on elusive aquatic species (e.g., seals; Marshall 1998); terrestrial systems have
been recently developed for both mammals (Beringer et al. 2004) and birds (Rutz et al. 2007). Despite their technological sophistication, AVEDs are still constrained by the fundamental assumption that underlies all animal-borne instrumentation: tagged animals are assumed to behave in the same manner as non-tagged animals (White and Garrott 1990).

In addition to examining this assumption, evaluating animal response to animal-borne tagging is crucial in light of recent emphasis placed on conducting wildlife research ethically (Minteer and Collins 2005, Wilson and McMahon 2006). Often, institutional animal care and use committees require researchers to justify potential impacts by demonstrating that techniques either do not harm the study subjects or that the best available techniques are being used (Wilson and McMahon 2006). Despite the abundance of studies implementing animal-borne tags (e.g., radio telemetry studies), assessments of their effects are uncommon and have produced mixed results (Withey et al. 2001).

Often, tags are assumed to have negligible effects on large animals (Withey et al. 2001). However, significant deleterious effects have been reported for several large animals, including moose (*Alces alces*) calves (Swenson et al. 1999) and mountain goat (*Oreamnos americanus*) kids (Côté et al. 1998). Brooks et al. (2008) showed that even small changes in the weight and fit of tags can cause behavioral responses in large mammals. Because AVEDs are larger and heavier than traditional animal-borne tags they might be more likely to induce behavioral and physiological impacts, even on large animals. Further, the fine-scale video data collected by AVEDs is more likely to be biased by subtle tag effects than coarser behavioral data (e.g., broad-scale movement...
data) collected by traditional animal-borne tags (Brooks et al. 2008). Evaluations of AVED effects are also important due to their prevalence in the media and their frequent use on species of conservation concern (Moll et al. 2007).

We evaluated the stress response of captive white-tailed deer (*Odocoileus virginianus*) to AVED attachment by using fecal glucocorticoid metabolite (FGM) analysis (Millspaugh et al. 2002), which provides a quantitative, non-invasive, and sensitive measure of the effects of stressful stimuli on animals (Harper and Austad 2000, Wasser et al. 2000, Millspaugh and Washburn 2004). Stress hormone assessment is a useful tool for evaluating the effects of animal-borne tags (e.g., Creel et al. 1997, Wells et al. 2003, Rittenhouse et al. 2005, Schulz et al. 2005) because it quantifies subtle changes in animal physiology rather than behavioral or demographic effects, which often only result after individual stress levels are very high (Millspaugh and Washburn 2004).

Previous FGM research has detected short-term effects from attached transmitters (<24 hours; Wells et al. 2003), demonstrating the technique can detect acute stressors associated with attaching animal-borne tags. Deer wore AVEDs for two weeks, a typical time of deployment for terrestrial, store onboard AVEDs (He et al. 2008).

**STUDY AREA**

We conducted our study at the United States Department of Agriculture/Animal and Plant Health Inspection Service/Veterinary Services outdoor captive animal facility, located on the Colorado State University Foothills Research Campus in Fort Collins, Colorado, USA. Seventeen white-tailed deer (8 M, 9 F) were housed in 4 adjacent ~40 m² pens separated by 2.5 m tall dividers consisting of wood paneling and woven mesh wire. All individuals were 2 years old and hand-raised in captivity from birth; male deer
were castrated. Four weeks prior to the study, we randomly assigned deer to pens; 3 pens housed 4 deer (2 M, 2 F) each and 1 pen housed 5 deer (2 M, 3 F). The pens were located within a ~850 m² exercise yard into which we periodically released the animals; during our study large snowdrifts in the yard limited animal release to approximately once every two weeks. We provided water, commercial deer chow, and hay ad libitum throughout the study.

**METHODS**

We collected 1 fresh (<10-min-old) fecal sample from each deer each day during 3 treatment periods: 1) pretreatment, from 29 January to 14 February 2007, during which no animals wore dummy AVEDs, 2) treatment, from 15 February to 28 February 2007, during which treatment individuals wore dummy AVEDs, and 3) post-treatment, from 1 March to 14 March 2007, during which no animals wore dummy AVEDs. Within each sex we randomly assigned individuals to the control or treatment group to obtain 9 control (5 F/4M) and 8 treatment subjects (4 F/4M). Castrated male FGM levels were assumed to be similar to intact females (Chao and Brown 1984), as has been reported in other mammals (e.g., Graham and Brown 1996). During our study, 1 female treatment individual died due to a fall and is excluded from the analysis.

Given that time of day might affect FGMs in mammals (e.g., Touma et al. 2003), we began fecal sampling at the same time each day (~0700 hrs) and concluded when 1 sample was obtained from each individual (usually before 1000 hrs). After manually homogenizing samples upon collection (Wasser et al. 1996, Millspaugh and Washburn 2003), we placed them in a cooler with ice packs, and transported them to an on-site freezer kept at -15°C (Wasser et al. 2000, Millspaugh et al. 2002).
We handled all animals in a chute system after the morning sampling on 14 February 2007 and fit treatment individuals with dummy AVEDs. System components for the dummy AVEDs were the same dimensions, weight, and configuration as true white-tailed deer AVEDs (He et al. in press), but did not contain electronic system components (video camera, microphone, etc.). Dummy AVEDs consisted of leather neck collars (width ~10cm) with affixed plastic, weighted boxes; all collars weighed 1400-1500 g, constituting 2-4% of the subject deer’s body weight (Fig. 1). We handled all animals in the chute system again after morning sampling on 28 February 2007 and removed dummy AVEDs.

At the end of the 6 week sampling period, we shipped all frozen fecal samples overnight to the University of Missouri for FGM analysis. We assayed samples from every third day of collection, which resulted in sufficient sample sizes for white-tailed deer FGM levels (Millspaugh and Washburn 2003); of the first 3 days, we randomly selected 31 January 2007 (i.e., the third day of sampling) to begin the sequence. We followed sample preparation procedures described by Millspaugh et al. (2002) and extracted FGMs using a modified form of Schwarzenberger et al. (1991) described by Wasser et al. (2000). We used an \( ^{125} \text{I} \) corticosterone radioimmunoassy (RIA) kit (ICN #07-120103, MP Biomedicals, Costa Mesa, CA) to quantify FGMs. These procedures were previously validated by Millspaugh et al. (2002) for white-tailed deer. Inter-assay variation for 5 assays was 5.1% and average intra-assay variation for 20 random samples was 1.7%.

We compared FGM levels between treatment and control animals across periods using PROC MIXED in SAS (SAS Institute 2004), treating individual deer as random
effects. We used the REPEATED statement to accommodate the repeated measures of FGM from the same individual and modeled three covariance structures, including compound symmetry, unstructured, and autoregressive structures (Littell et al 1998). We used Akaike’s Information Criterion with a sample size correction (AICc) to select the best model for covariance structure. We used the autoregressive covariance structure, which was the best covariance model by 6.1 AICc units over the compound symmetry model; fitting the unstructured covariance model proved computationally extensive (Littell et al 1998).

Because FGMs in ungulates might be influenced by air temperature (e.g., Millspaugh et al. 2001), we performed a mixed effects linear regression analysis in the program R (R Development Core Team 2004) to quantify the effects of temperature on captive white-tailed deer FGMs. Assuming a 24-hour lag time between a stress event and an associated FGM increase in white-tailed deer (Millspaugh et al. 2002), we coupled each FGM sample with the temperature 24 hours prior to collection (±5 min; Colorado Climate Center 2007).

RESULTS

Despite fluctuations in FGM levels throughout our study, there was no significant effect of dummy AVEDs on captive white-tailed deer FGM levels when compared with FGM levels of control animals ($F_{1,14} = 0.72, P = 0.411; \text{Fig. 2}$). Also, there was no significant difference between FGMs across periods ($F_{2,218} = 1.94, P = 0.147$), and no significant interaction between treatment and period ($F_{2,218} = 0.51, P = 0.602$). Most importantly, none of the FGM values we observed were indicative of high stress values for white-tailed deer (i.e., FGM values of >60 ng/g; Millspaugh et al. 2002). The largest
change in mean FGM levels from one sampling interval to the next was a 7.3 ng/g mean increase across all deer (11.1 ng/g to 18.4 ng/g) which coincided with deer handling and the beginning of the treatment period (Fig. 2). This increase was also associated with a 12.9°C decrease in mean temperature (from 1.7°C to -11.2°C).

There was a significant negative relationship between air temperature and FGMs (slope -0.062, $t = -3.66$, SE = 0.0.17, $df = 221$, $P < 0.001$); as temperature decreased, FGMs increased and vice versa. For example, a 1.9°C increase in mean temperature (from -11.2°C to 0.7°C) between February 24 and February 27 2007 was associated with a 5.5 ng/g decrease in mean FGMs (from 18.4 ng/g to 12.9 ng/g).

DISCUSSION

Researchers assessing the impact of animal-borne tags on large, terrestrial mammals generally report no effects, although such evaluations remain uncommon (Withey et al. 2001), despite their crucial role in ensuring the robustness of subsequently collected data (White and Garrott 1990, Wilson and McMahon 2006). Often, behavioral or demographic metrics are used to measure tag effects. Radio collars worn for >1 year did not affect the behavior of female alpine chamois (Rupicapra rupicapra rupicapra; Nussberger and Ingold 2006) or the survival of juvenile guanacos (Lama guanicoe; Bank et al. 2000). Similarly, vaginal radio tags did not affect reproductive output in white-tailed deer (Bowman and Jacobsen 1998) or elk (Cervus elaphus nelson; Johnson et al. 2006). In contrast, Swenson et al. (1999) observed decreased survival of moose calves with affixed ear transmitters and Côté et al. (1998) reported a decline in mountain goat kid survival due to increased abandonment by mothers immobilized and fit with radio collars. Brooks et al. (2008) found that, while foraging, plains zebras (Equus burchelli
antiquorum) wearing GPS collars weighing 0.6% body mass had a >50% lower travel rate compared to zebras fitted with collars weighing 0.4% of body mass, suggesting even small changes in collar weight might have behavioral effects. Often, behavioral and demographic effects arise from large stressors; physiological methods, such as FGM analysis, can provide a more sensitive measure of stress prior to overt demographic responses (Creel et al. 2002).

We found no difference in FGMs between treatment and control animals, suggesting AVED collars weighing ≤4% of individual body mass worn for ≤2 weeks have a negligible impact on captive white-tailed deer stress levels. Other FGM evaluations have shown no effects of attached transmitters on a variety of species, including African wild dogs (Lycaon pictus; Creel et al. 1997), three-toed box turtles (Terrapene carolina triunguis; Rittenhouse et al. 2005), and mourning doves (Zenaida macroura; Shulz et al. 2005). Wells et al. (2005) observed a spike in FGMs following attachment of transmitters in dickcissels (Spiza americana) that quickly returned to baseline levels within a day. We observed a similar spike across both treatment and control animals following handling on February 14 2007 (Fig. 2). However, this spike coincided with the largest temperature decline during our study (a 12.9°C decrease over 3 days) and therefore might have been a temporary reaction to low temperatures.

The significant negative relationship between FGMs and air temperature during our study might have been driven by several large fluctuations (>10°C) in temperature over short periods (i.e., ≤3 d) that were associated with an inverse change in FGMs (e.g., when temperatures decreased, FGMs increased). A similar relationship between stress hormones and acute air temperature changes (i.e., changes within 3 d) has been reported
in birds (e.g., Romero et al. 2000, Frigerio et al. 2004). Our data suggest that FGM levels of captive white-tailed deer in Colorado are low during the winter. Low levels of FGMs in winter have also been reported for white-tailed deer in Texas (Chao and Brown 1984) and Missouri (Millspaugh et al. 2002). In contrast, Bubenik et al. (1983) report a peak in cortisol during the winter for captive white-tailed deer in Ontario, Canada. Given the short duration of our study, conclusions regarding the annual relationship between temperature and white-tailed deer FGMs cannot be made. Our data suggest that our study animals were not chronically stressed by cold weather, but that FGM levels responded inversely to sudden changes in air temperature.

Overall, the fluctuations we observed during our study can be considered biologically insignificant based on adrenocorticotropic (ACTH) challenges in captive white-tailed deer (Millspaugh et al. 2002), which suggest that FGM levels of >60 ng/g would be biologically indicative of a stress response. Our study animals wore AVEDs for 2 weeks, which is longer than most AVED deployments (Moll et al. 2007). Physical effects and chronic stress from wearing tags for longer periods should be considered for longer studies. We observed some neck abrasion from the AVED collars; efforts should be made to ensure good fit of neck collars and pads or inflation tubes should be considered for heavier tags (Krausman et al. 2004).

MANAGEMENT IMPLICATIONS

We found AVEDs weighing ≤4% of individual body mass to not increase stress levels of white-tailed deer during a 2 week deployment. Our study suggests that temperature is a more important stressor than AVEDs. As technology improves, system lifespan will increase and system size will decrease, enabling longer deployments on
smaller species (Moll et al. 2007). We encourage managers and researchers to assess
AVED effects on animal behavior and physiology for longer durations.

**LITERATURE CITED**

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Figure 1. (A) Front view of the AVED dummy collar, consisting of a leather neck collar with attached weights and (B) a captive male white-tailed deer wearing an AVED dummy collar while bedded.
Figure 2. Fecal glucocorticoid metabolite (FGM) levels (ng/g) of captive white-tailed deer in control ($n = 9$) and treatment ($n = 7$) groups during pretreatment, treatment, and post-treatment periods. Significant differences between pretreatment (baseline), treatment, and post-treatment FGM levels and are denoted with asterisks ($P < 0.5$). Error bars show one standard error.
CHAPTER 3

A TERRESTRIAL ANIMAL-BORNE VIDEO SYSTEM FOR LARGE MAMMALS

ABSTRACT

Animal-borne video and environmental data collection systems (AVEDs) are integrated sensor systems that collect video from the animal’s perspective and integrate it with data from other sensors, including audio, location, temperature, acceleration, and other data. By placing sensor data within the context of video, AVEDs provide a unique perspective not offered by other methods and facilitate research into animal behavior and foraging tactics, animal energetics, wildlife damage issues, and inter- and intra-specific interactions. Marine AVEDs have outpaced their terrestrial counterparts in technological sophistication and store all data onboard. Terrestrial systems have been transmission-based and thus have been limited to species that are easily tracked or habituated to humans. We present the first terrestrial, store-onboard AVED developed for large mammals and demonstrate the utility of our AVEDs by quantifying and describing contacts between white-tailed deer (*Odocoileus virginianus*). We observed 11 contacts between white-tailed deer during 4 deployments. Contacts comprised a total of 1367 seconds (20.6 min, $\bar{x} = 124.3$ s/contact, SE = 41.5). Our AVEDs revealed several behaviors during contacts between individual white-tailed deer, including inspection, avoidance, and grooming. These data are not captured by other techniques (e.g., radio telemetry) and demonstrate the utility of continuous video and other sensors from the animal’s perspective. Although AVEDs are a powerful new tool for wildlife research and
management, their use should be preceded by careful formulation of research and management objectives.

INTRODUCTION

New technologies facilitate novel findings in a variety of ecological disciplines by improving the accuracy and efficiency of existing techniques, increasing the volume and scale of collected data, and providing previously inaccessible forms of information (Read and Clark 2006). For example, innovation of the transistor in the 1940s enabled the development of wildlife radio-tags, which have greatly increased our understanding of the movements, demographics, physiology, and behavior of numerous species and are now a dominant tool in ecological studies (Millspaugh and Marzluff 2001, Kenward 2001a,b). Recent technological advances in animal-borne sensors, including animal-borne video and environmental data collection systems (AVEDs; Moll et al. 2007), have expanded researchers’ abilities to answer ecological questions by non-invasively providing multiple forms of data simultaneously, including physiologic, behavioral, location, and environmental data that had been previously inaccessible.

Animal-borne video and environmental data collection systems (AVEDs) are integrated sensor systems that collect video from the animal’s perspective and integrate it with data from other sensors, including audio, location, temperature, acceleration, and other data (Moll et al. 2007). By placing sensor data within the context of video, researchers have addressed numerous hypotheses about animal behavior and foraging tactics (Heithaus et al. 2002a, Beringer et al. 2004, Rutz et al. 2007), animal energetics (Williams et al. 2000, Hays et al. 2007), wildlife damage issues (Grémillet et al. 2006), and inter- and intra-specific interactions (Passaglia et al. 1997, Heithaus and Dill 2002).
Video accounts of interactions could aid in disease transmission modeling by revealing the frequency and nature of contacts between animals (Anderson and May 1986, McCallum et al. 2001). Often, location data from radio telemetry or GPS sensors are analyzed to describe animal contacts (e.g., White et al. 2000, Ramsey et al. 2002, Atwood and Harmon 2003, Kauhala and Holmala 2006). However, location error limits the resolution of such data (D’Eon 2003, D’Eon and Delparte 2005). Moreover, individuals within close proximity of each other might not engage in physical contact (Schauber et al. 2007). Recently developed proximity collars offer increased resolution (<1m; Douglas et al. 2006, Prange et al. 2006), but do not describe the nature of physical interactions between animals, which can strongly influence disease transmission potential (e.g., when sexual transmission is common; Anderson and May 1986). Video data from AVEDs overcome these limitations by providing direct recording of animal interaction, enabling detailed descriptions of contact events.

Most AVED-based research has focused on marine species, and technological advancements in aquatic AVEDs have outpaced their terrestrial counterparts (Marshall 1998, Moll et al. 2007, Marshall et al. 2007). Aquatic AVEDs store data on-board, whereas terrestrial systems have been transmission-based (Beringer et al. 2004, Carruthers et al. 2007, Rutz et al. 2007, Taylor et al. 2008, G. Marshall, National Geographic, unpublished data). Currently, onboard aquatic AVEDs can record a maximum of 10 hours (Marshall et al. 2007). Although terrestrial, transmission-based systems can offer longer recording times (>70 hrs; Beringer et al. 2004), they require constant close contact between the researcher and tagged animal in order to record transmitted video. Consequently, they are limited to species that are easily tracked or
habituated to humans (Millspaugh et al. 2008). Additionally, if researchers lose contact with a tagged animal because of animal movement or signal attenuation, transmitted data is lost and battery power is wasted (Millspaugh et al. 2008). Store-onboard AVEDs overcome these limitations, enabling research on elusive, free-ranging species for which non-invasive behavioral data is often difficult to obtain (Moll et al. 2007). Here, we describe the first terrestrial, store-onboard AVED developed for large mammals. We demonstrate its utility by describing contact rates among white-tailed deer (Odocoileus virginianus).

**STUDY AREA**

We conducted research at the Thomas S. Baskett Wildlife Research and Education Center (BREA), a 911 ha area located 5 km east of Ashland, Missouri, USA (38°48′N latitude, 92°12′W longitude) managed by the University of Missouri. Topography was characterized by rolling hills with abundant ridge tops and ravines that feed into bottomland streams. The BREA was composed of contiguous forest dominated by oak (Quercus spp.) and hickory (Carya spp.) (Rochow 1972) with interspersed old fields remnant from previous land use (i.e., farming). Detailed descriptions of forest vegetation at BREA are provided by Rochow (1972) and Pallardy et al. (1988). Dominant plant species in old fields included Sericea lespedeza (Lespedeza cuneata), foxtail (Setaria sp.), common ragweed (Ambrosia artemisiifolia), and goldenrod (Solidago sp.).

Prior to our deployments on free-ranging deer at BREA, we conducted 2 deployments on 2 semi-wild adult white-tailed deer inhabiting a 7 ha enclosure on the north-central edge of BREA. The pen was enclosed by a 3m fence consisting of 10 x10
cm wire mesh topped with one strand of barbed wire. A small pond provided water *ad libitum*. Topography and vegetation of the pen were consistent with the greater BREA. Deer were provided occasional supplemental feed in the form of whole corn and foraged on natural vegetation within the pen.

**METHODS**

**System Description**

Our AVED included a camera, microcomputer, and sensor board attached to a neck collar with affixed battery packs (Fig. 1). The AVED camera was a modified webcam, the Logitech Quickcam 5000 (P/N 961419-0403, Logitech International, Fremont, Calif.). We removed the external housing from the Quickcam and retained electrical parts, including the microphone. The camera can capture video at 30 frames per second (fps) at 640 x 480 pixel resolution within a 78° (W) x 66° (H) field of view. We decreased the frame rate to 5 fps and the resolution to 176 x 144 (low resolution recording sessions) or 320 x 240 (high resolution recording sessions) in order to reduce file size and maximize battery life. The camera sent video to the microcomputer via a USB2 port.

Our microcomputer was the Stargate Gateway (SPB400, Crossbow Technology Inc., San Jose, Calif.), which included a single-board computer with an Intel 400MHz X-Scale processor (PXA255, Intel Corp., Santa Clara, Calif.; Fig. 1). We included a MTS420CC sensor board to record 2 dimensional acceleration (in absolute g-force), air pressure (millibars), temperature (°C) capturing 2 data points per second and latitude/longitude locations at 5 minute intervals (MICA2/DOT Professional Kit, Crossbow Technology Inc., San Jose, Calif.). The sensor boards transmitted data
wirelessly to the microcomputer via a short range, sensor network wireless data protocol; however, all transmission occurred between individual components within the system and did not require transmission to an external storage device. All video, audio, and sensor data were stored on a 4 gigabyte (GB) compact flash card attached to the microcomputer (Fig. 1). We achieved a 7.0 – 9.1:1 compression ratio for video files using video compression techniques described by He et al. (2008) to maximize storage capacity. We powered our AVED with 36-44 Energizer L91 batteries (Energizer Holdings, Inc. St. Louis, Missouri) arranged in series. The total power draw for all components was 400 milliamps at 5V (2 watts) when the system was active and <20 milliamps at 5V (0.1 watts) when system was in sleep mode (e.g., at night). Lab tests suggested our AVED should record 40-45 hours of video and sensor data.

We enclosed the camera, microcomputer, and sensor boards in a 16.2 x 12.1 x 5.4 cm waterproof container (Pelican 1020 Micro Case, Pelican Products, Inc., Torrance, Calif.) and attached it to a 7.5-cm-wide 5-ply butyl collar using bolts and electrical tape (Fig. 1). We adjusted the camera 25-30° ventrally to capture landscape views. We attached an inflatable bicycle tube to the inside of the collar to ensure a good fit and reduce neck abrasion (Fig. 1). At the apex of the collar, we built a blow-off device to release the AVED (Fig. 1). The blow-off instrument consisted of a programmable computer board that controlled an electrical charge which released a pin and allowed the collar to drop from the animal’s neck (Fig 1). We attached a small radio transmitter (Advanced Telemetry Systems, Isanti, Minn.) to the AVED to enable system retrieval after automatic release. Although our complete AVED systems are not commercially available, we used commercially available parts, with the exception of the blow-off
controller, which was engineered at the University of Missouri. System weight was approximately 1500g and estimated cost was US $1500.

Field Deployments

We conducted 4 field deployments from November 2006 to March 2008. We deployed 2 AVEDs simultaneously on 2 adult semi-wild deer (1 M, 1 F) in the 7 ha enclosed pen from 6 December to 9 December 2006. We deployed 2 AVEDs on free-ranging deer at BREA; the first was on an adult female from 28 November to 2 December 2007, the second on a female fawn from 14 March to 20 March 2008. We immobilized semi-wild deer by dart gun or hand injection; free-ranging deer were caught using Clover traps and immobilized by hand injection. We used an estimated 0.055 mg/kg of medetomidine HCl and 2.5 mg/kg of ketamine HCl to immobilize deer (Millspaugh et al. 2004). We fitted the AVED around the neck of the deer and positioned the camera at the base of the neck. We inflated a bicycle tube lining the inside of the collar to an appropriate fit. We used 0.275 mg/kg of atipamizole to reverse sedation after fitting the AVED to the animal (Millspaugh et al. 2004).

We programmed our AVEDs to record video on a fixed schedule and used a duty-cycle to focus video recording sessions on times when the animal was active (i.e., not bedded). During the December 2006 deployment, we scheduled video recording sessions of 1-3 hours that began at 0630, 1200, and 1430 hours daily. During the November 2007 deployment, we used a similar schedule, but incorporated the accelerometer-based duty-cycle. During the March 2008 deployment, we programmed AVEDs to record continuously during daylight until day 3, after which the November 2007 schedule was followed.
To operate the duty-cycle, we programmed the sensor board to monitor the accelerometers while the Stargate microcomputer was asleep to detect activity and then wake the Stargate. This was accomplished by periodically sampling (~2 Hz) the accelerometer inputs, processing them to detect changes between samples of greater than 5° in position of the AVED in either the X or Y axis, incrementing a counter on change or decrementing on no change, and then sending a wake-up signal to the Stargate if the count exceeded a programmed threshold of 10. In a similar fashion, the motion of captured video frames (i.e., the change in video from frame to frame) was processed by the Stargate microprocessor to detect inactivity and subsequently end the recording session and enter sleep mode.

We programmed the sensor boards to capture GPS time/location, every 5 minutes while the system was “awake” (i.e., not in power save mode). At each 5 minute interval, the sensor board collected GPS data continuously for 1 minute. All other sensor data (acceleration, light, temperature, etc) was sampled continuously at a 2 Hz rate while the system was “awake”. We programmed AVEDs to automatically release after 7-10 days. Our AVEDs constituted 3-5% of individual deer body mass and have been shown to have no impact on stress levels of captive white-tailed deer stress if worn for ≤2 weeks.

**System Retrieval and Video Analysis**

After collars automatically released, we located AVEDs via radio tracking using a VHF telemetry receiver (Lotek Wireless, Inc., Newmarket, Ontario) and downloaded data from the compact flash card to a computer. We downloaded video files in .cif format and subsequently converted to .avi format for compatibility with video analysis software. We
downloaded all sensor data in comma-separated value (csv) file format compatible with Microsoft Excel (Microsoft Corp., Redmond, Wash).

We identified contacts between deer via manual inspection using the program Zoom Player (Inmatrix LTD, Hafia, Israel) and Windows Media Player (Microsoft Corp., Redmond, Wash.). A contact began as soon as an animal could be identified in the video and lasted until that animal was no longer seen; if the same animal reappeared in the video within 3 minutes, we considered it 1 continuous contact. For each contact, we recorded the species, sex, approximate distance to the individual, contact duration, and whether physical contact was observed.

RESULTS

We collected a total of 5783 minutes (96.4 hrs) of video and sensor data from 4 deployments. From 6 December 2006 to 9 December 2006, we collected 736 minutes (12.3 hrs) of data over 2 days ($\bar{x} = 367.8$ min/day, SE = 155.3) from a semi-wild adult female white-tailed deer and 1817 minutes (30.3 hrs) over 4 days ($\bar{x} = 454.3$ min/day, SE = 27.5) from a semi-wild adult male white-tailed deer. From 30 November 2007 to 4 December 2007, we collected 733 minutes (12.2 hrs) of data over 5 days ($\bar{x} = 146.6$ min/day, SE = 34.4) from a free-ranging adult female white-tailed deer. From 14 March 2008 to 20 March 2008, we collected 2495 minutes (41.6 hrs) of data over 4 days ($\bar{x} = 623.7$ min/day, SE = 152.1) from a free-ranging female white-tailed deer fawn. We also collected audio data during both deployments on free-ranging deer and GPS locations during the March 2008 deployment (Fig. 2).

Our AVEDs performed well despite harsh environmental conditions. During the December 2006 and November 2007 deployments, temperatures were frequently below
0° C and snow depth ranged from 10 to 18cm; AVEDs functioned properly during these deployments despite being submersed in snow while deer were bedded. However, low temperatures likely decreased expected battery life by 20-30% during the December 2006 deployment. During 2 deployments (December 2006 female and November 2007), our AVEDs had reduced recording times due to blown fuses in the battery packs. During the March 2008 deployment, physical jarring disconnected the wiring of the microcomputer, which altered the recording schedule to include recordings at night and reduced the duration of recording sessions. Video quality was sufficient to determine sex (in the fall) and approximate distance to observed individual.

Over 4 deployments, we observed 11 contacts between white-tailed deer comprising a total of 1367 seconds (20.6 min, \( \bar{x} = 124.3 \) s/contact, SE = 41.5; Table 1, Fig. 3). Contact rate for semi-wild deer were 0.02 contacts per hour of video (range = 0 – 0.03, SE = 0.02); the single recorded contact lasted for 72 seconds. Contact rate for free-ranging deer were 0.38 contacts per hour of video (range = 0.02 – 0.74, SE = 0.36); mean contact duration was 131.8 seconds (\( n = 10 \), range 2 – 418s, SE = 45.5). One contact included direct, physical contact via mouth-to-body grooming lasting 418 seconds (Table 1, Fig. 3); physical contact rate for free-ranging deer was 0.04 physical contacts per hour of video (range 0 – 0.08, SE = 0.04).

**DISCUSSION**

To our knowledge, this is the first description and application of a store-onboard terrestrial AVED. In marine species, store-onboard AVEDs have provided first-ever accounts of animal behavior (Heithaus et al. 2002b), new insights into the habitat use of endangered species (Parrish et al. 2000), and descriptions of reproductive behavior at sea.
(Boness et al. 2006). Previous terrestrial studies using transmission-based AVEDs have been limited to species that can be easily tracked or are habituated to humans (e.g., Rutz et al. 2007, Carruthers et al. 2007) and thus there have been few terrestrial AVED studies. As technology advanced, terrestrial store-onboard systems were an inevitable technological advancement. Our store-onboard AVED overcomes many limitations of transmission-based terrestrial systems and could facilitate research into animal interactions, energetics, wildlife damage, habitat use and other fine-scale behavioral phenomena that are often not captured using other traditional radio tracking, especially in elusive species (Moll et al. 2007).

Although transmission-based AVEDs offer increased data storage capacity through external storage devices, advancements in onboard storage are rapidly progressing and duty-cycling can aid in increasing system lifespan. Our system stored 41.6 hours of video on a 4 GB flash card; hard-drive AVEDs are in development and will increase recording time substantially, especially when coupled with video compression (Davis et al. 2004, He et al. 2008). As storage issues are overcome, the major constraint of system lifespan will be battery power. We implemented a duty-cycle that used onboard video processing and accelerometer data to trigger a low-energy sleep mode when the AVED-equipped animal was inactive. Our duty-cycle used changes in acceleration to trigger recording mode; other sensor data could be used to duty-cycle (e.g., light intensity; Beringer et al. 2004). Although duty-cycling does not increase the total duration of video captured, it can enable researchers to focus recording sessions on specific behaviors of research interest, thereby optimizing battery power consumption.
Our AVEDs provided continuous, descriptive accounts of contacts in semi-wild and free-ranging white-tailed deer, including direct, physical contacts. Other methods used to describe contact rates, including radio telemetry and GPS methods, do not describe animal behavior at a given location and rely on the assumption that animals within close proximity are “in contact” with each other. Our video revealed that white-tailed deer might not engage in physical contact, even if within close proximity (e.g., <15m), and that behavior during encounters with other deer varies. Video data provides crucial context that, despite its importance to data interpretation, is not captured by other methods. For example, given recent evidence that chronic wasting disease might be transmitted orally (Sigurdson 1999, Mathiason et al. 2006), mutual grooming between individuals might be an important behavioral vector for transmission; however, this behavior would not be captured using location-based techniques or proximity collars. We also observed contacts between tagged and untagged animals, which other animal-borne technologies have not provided (Prange et al. 2006). Like animal-activated stationary cameras (Vercauteren et al. 2007a,b), our AVEDs can also quantify and describe contacts between captive and free-ranging animals, which has important implications for potential disease transmission (Demarais et al. 2002). However, unlike stationary cameras, AVEDs combine continuous accounts of contacts from the animal’s perspective with data from other sensors (e.g., animal location) to give a more complete picture of animal behavior than the snapshots of activity recorded by stationary cameras at a given location.

We noted several limitations when implementing our AVED. A fundamental restriction is that events can only be recorded when they occur within the field of view of
the camera. Wide-angle camera lenses would mitigate this limitation, but ultimately all events would not be recorded and therefore video data is limited to activity occurring within a given field of view. Similarly, occasional obstructions of view, both physical (e.g., dirt on camera lens) and environmental (e.g., trees), reduced visibility across the landscape. Field of view limitations highlight the need to specify hypotheses before AVED deployment and adjust system components accordingly. For example, an investigation into food selection might require a different camera angle and video resolution than a habitat use study. A final obstacle was efficient analysis of video data. Although video processing software has aided other AVED studies (Bowen et al. 2002), the majority of video data are manually inspected (Moll et al. 2007). Recent advancements in automated wildlife video processing (Calic et al. 2005, Burghardt and Calic 2006, Burghardt and Campbell 2007) could supplement manual video analysis for future AVED studies. We described contacts between white-tailed deer to demonstrate the utility of our AVEDs; however, we discourage generalizations about white-tailed deer contact rates from our data due to our experimental design (i.e., we only instrumented females during winter months, etc.).

MANAGEMENT IMPLICATIONS

Our terrestrial, store-onboard AVED provides behavioral, location, and movement data for large, elusive, free-ranging mammals in a non-invasive manner and could aid in management and understanding of disease transmission, wildlife damage, and resource selection. Our AVEDs revealed several behaviors during contacts between individual white-tailed deer, including inspection, avoidance, and grooming. These data are not captured by other techniques and demonstrate the utility of continuous video and
other sensors from the animal’s perspective. Although AVEDs are a powerful new tool for wildlife research and management, their use should be preceded by careful formulation of research and management objectives.

**LITERATURE CITED**


Figure 1. A terrestrial, store-onboard animal-borne video and environmental data collection system (AVED) developed for large mammals.
Figure 2. Locations and still frames from an free-ranging fawn at the Baskett Wildlife Research and Education Center near Ashland, MO equipped with an animal-borne video and environmental data collection system (AVED) from 14 March 2007 to 17 March 2007. From clockwise starting at top left, still frames show the individual bedded, foraging, self-grooming, and encountering another white-tailed deer fawn.
Figure 3. Still frames from video captured by an animal-borne video and environmental data collection systems (AVED) deployed on white-tailed deer at the Baskett Wildlife Research and Education Center near Ashland, MO. Images show a bedded, AVED-equipped, free-ranging female white-tailed deer viewing a female deer foraging (left) and an AVED-equipped, free-ranging female deer grooming a female deer (right, image shows the head profile of the groomed individual).
Table 1. Duration and description of observed contacts between white-tailed deer during 3 deployments of animal-borne video and environmental data collection systems (AVEDs) between December 2006 to December 2007.

<table>
<thead>
<tr>
<th>Study animal</th>
<th>Date</th>
<th>Contact start (time of day)</th>
<th>Duration (s)</th>
<th>Physical contact?</th>
<th>Approx. distance</th>
<th>Contact Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-captive adult male</td>
<td>12/9/2006</td>
<td>15:10:13</td>
<td>72</td>
<td>N</td>
<td>5-10m</td>
<td>AVED male approaches female deer outside of pen</td>
</tr>
<tr>
<td>Free-ranging adult female</td>
<td>11/30/2007</td>
<td>9:19:41</td>
<td>162</td>
<td>N</td>
<td>10-50m</td>
<td>Female deer seen foraging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9:46:30</td>
<td>45</td>
<td>N</td>
<td>30-50m</td>
<td>Female deer seen foraging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10:01:52</td>
<td>48</td>
<td>N</td>
<td>&lt;5m</td>
<td>Female deer seen foraging and defecating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16:29:48</td>
<td>12</td>
<td>N</td>
<td>5-10m</td>
<td>Female deer seen standing</td>
</tr>
<tr>
<td></td>
<td>12/3/2007</td>
<td>6:57:48</td>
<td>4</td>
<td>N</td>
<td>&lt;5m</td>
<td>Female deer seen standing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7:02:08</td>
<td>2</td>
<td>N</td>
<td>5-10m</td>
<td>Female deer seen foraging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7:24:24</td>
<td>336</td>
<td>N</td>
<td>20-30m</td>
<td>Female deer seen foraging and defecating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16:28:11</td>
<td>134</td>
<td>N</td>
<td>30-50m</td>
<td>Female deer seen foraging</td>
</tr>
<tr>
<td></td>
<td>12/4/2007</td>
<td>7:22:00</td>
<td>418</td>
<td>Y</td>
<td>&lt;5m</td>
<td>AVED female grooms foraging female deer</td>
</tr>
</tbody>
</table>
Table 1. continued.

<table>
<thead>
<tr>
<th>Study animal</th>
<th>Date</th>
<th>Contact start</th>
<th>Duration</th>
<th>contact?</th>
<th>distance</th>
<th>Contact Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free-ranging female</td>
<td>3/14/2008</td>
<td>18:57:44</td>
<td>134</td>
<td>N</td>
<td>5-10m</td>
<td>Fawn seen inspecting, avoiding AVED fawn</td>
</tr>
</tbody>
</table>
Remington James Moll was born on 12 April 1983 to Albert and Evelyn Moll in Menomonee Falls, Wisconsin. He graduated from Jenks High School in Jenks, Oklahoma in 2001. He received a Bachelor of Science in Fisheries and Wildlife Sciences from the University of Missouri in 2006. Following graduation, he began his Master’s research at the University of Missouri under Dr. Josh Millspaugh in the summer of 2006.

Rem met Valerie Ann Moll (formerly Lauver) during his undergraduate career at the University of Missouri. They competed on the University of Missouri’s track and field team together for 4 years and were wed on 17 December 2006 in Tulsa, Oklahoma.