EVALUATION OF SOUND AS A DETERRENT FOR REDUCING

DEER-VEHICLE COLLISIONS

by

SHARON ANN VALITZSKI

(Under the Direction of Karl V. Miller and Robert J. Warren)

ABSTRACT

I evaluated the efficacy of sound as a deterrent for reducing deer-vehicle collisions by observing the behavioral response of captive and free-ranging white-tailed deer (*Odocoileus virginianus*) to a range of sound frequencies within their hearing range. Captive deer exhibited no behavioral response when exposed to any of 5 different pure-tone sound treatments. I then evaluated the effects of a moving automobile fitted with a sound-producing device and speakers on roadway behavior of free-ranging deer. My results indicated that deer within 10 m of roadways did not alter their behavior in response to any of the 5 pure-tone sound treatments tested in a manner that would prevent deer-vehicle collisions. Many commercially available wildlife-warning whistles (deer whistles) are purported to emit similar consistent, continuous pure-tone sounds; however, my data suggest that deer-whistles are likely not effective in altering deer behavior along roadways to help prevent deer-vehicle collisions.

INDEX WORDS: Auditory deterrent, Deer-vehicle collisions, Deer-whistle, Hearing, *Odocoileus virginianus,* Sound, White-tailed deer, Wildlife-warning whistle

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SHARON ANN VALITZSKI

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SHARON ANN VALITZSKI

Major Professors: Karl V. Miller
Robert J. Warren

Committee: Steven B. Castleberry
W. Dale Greene

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

DEDICATED TO MOLLY, ELSIE, RALLY, AND ELVIRA.

Though you were lost before this was finished, you made it fun while you were here. You will never be forgotten.

"The best fertilizer is the foot steps of the landowner."

"Find a job you love and you will never have to work a day in your life."

~Confucius

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Deer (*Odocoileus* spp.)-vehicle collisions are an increasingly important concern for the public and agencies charged with managing wildlife populations or highway safety. Increasing deer populations, coupled with expanding transportation systems, have led to a rise in the number of deer-vehicle collisions (Romin and Bissonette 1996). Annually, there are approximately 1.5 million deer-vehicle collisions at a cost of nearly $1 billion in damages (Sullivan and Messmer 2003). On average, 51,000 collisions are reported each year within the state of Georgia (J. Beardon, Georgia Department of Natural Resources Wildlife Resources Division, personal communication).

Despite public demand for more effective measures to keep deer off of roadways, few states have conducted scientific research on mitigation techniques before deployment (Romin and Bissonette 1996). Deer whistles are perhaps the most widely marketed and utilized mitigation technique available. Manufacturers of deer whistles state that the devices produce ultrasonic frequencies that should deter deer from roads by warning them of an approaching vehicle (Hornet Deer Whistle 2002, Deer Alert 2007, Save-A-Deer Whistle 2007). The manufacturers also claim that deer whistles emit consistent, continuous sounds when activated. Pure tones are defined as continuous sounds of equal intensity at a single frequency (Martin 1994), which can be produced using standard commercially available equipment. Scheifele et al.

(2003) tested the actual frequencies emitted from deer whistles, and found they produced pure tone sounds. Based on this study and other similarities between sounds elicited by deer whistles and pure tones, the objective of this research was to evaluate the efficacy of pure-tone sounds throughout the full range of deer hearing for altering the behavior of free-ranging deer along roadways.

LITERATURE REVIEW

There has been little scientific research conducted on the perception and behavioral response of white-tailed deer (*O. virginianus*) to sound. As a preliminary step towards developing an understanding of hearing abilities of deer, auditory brainstem response tests were conducted on captive deer at the University of Georgia's Whitehall Captive Deer Research Facility (D'Angelo et al. 2007). By recording the neurological responses of 13 sedated white-tailed deer to a range of sound frequencies at varying intensities, D'Angelo et al. (2007) determined that the range of white-tailed deer hearing included frequencies of sound from 0.25 kHz-30 kHz, with best hearing sensitivity from 4 kHz to 8 kHz. The upper limit of human hearing is approximately 20 kHz (Durrant and Lovrinic 1995), and any sound greater than this is considered ultrasonic. As deer could hear $\geq$20 kHz, these results suggest that ultrasonic sounds have potential for use as auditory deterrents for prevention of deer-vehicle collisions.

Measurements of the actual frequencies emitted from a selection of commercially sold deer-whistles showed that those whistles tested did not produce the ultrasonic sounds claimed by the manufacturer (Scheifele et al. 2003). Closed-end deer-whistles produced sound at 3.3 kHz, while open-end whistles produced sound at 12 kHz. Schildwachter et al. (1989) reported that deer-whistles did not emit recordable sounds at manufacturer-recommended vehicle speeds ($\leq$89 km/h), but when hand-blown, produced sound at 18-20 kHz accompanied by an audible whistle

(2 kHz). They also reported no behavioral responses of deer exposed to traveling vehicles equipped with whistles.

Bender (2003) found that the ROO-Guard, a sound device designed to deter kangaroos (*Macropus rufus*) by masking their ability to hear their natural predators, did not alter behavior of captive kangaroos and there was no reduction in free-ranging kangaroo density compared to control sites where the device was not used. She also found that the ROO-Guard sound comprised only a small component of ultrasonic frequencies and concluded that the ROO-Guard would be ineffective at reducing kangaroo damage to crops or deterring them from roadsides.

Information is limited regarding ungulate responses to auditory deterrents in actual roadway conditions. Romin and Dalton (1992) noted no differences in behavioral responses of 150 groups of mule deer (*O. hemionus*) exposed to either of two brands of deer whistles (brand not specified). They indicated that auditory deterrents may be ineffective at reducing deer-vehicle collisions and outlined the need for more research on the effects of sounds on behavior of ungulates along roadways.

The behavioral response of target animals to an auditory deterrent may depend on the type of sound emitted. Pure tones are single frequency, continuous sounds at equal intensity (Martin 1994). Complex sounds resemble sounds occurring in nature (i.e., deer vocalizations) and are composed of two or more pure tones of different frequencies that are generated simultaneously and repeated over time. Complex sounds are rapid-change stimuli, with fast neurological onset caused by simultaneous firing of the auditory nerve fibers (Hall 1992, Jacobson 1994).

In contrast to complex sounds, pure tones are considered prolonged-onset stimuli which produce a slower neurological response that lasts for the duration of the sound stimuli.

Therefore, if the purpose of sound is to produce a rapidly changing behavioral response, complex sounds may be more applicable than pure tones for management of wildlife damage. However, direct testing of complex sounds on deer feeding behavior has shown that these auditory deterrents either have no effect on deer behavior, do not produce the desired responses by deer, or the effectiveness of the devices diminishes after a short time interval of exposure. For example, sound devices such as propane exploders have proven ineffective at reducing deer damage to corn fields (Gilsdorf et al. 2004a). Bioacoustic frightening devices, which used distress and alarm calls from live-captured deer, were also shown to be ineffective, as track-count indices and use-areas of radio-collared deer did not differ among control plots and plots where the frightening device was active (Gilsdorf et al. 2004b). VerCauteren et al. (2005) found that elk (*Cervus elaphus*) and mule deer did not change their feeding behavior when the Critter Gitter™ acoustic frightening device was in place. The Critter Gitter device was designed to protect gardens and landscaping from wildlife damage by producing beeps that vary in pattern when the device is activated by the detection of an animal with passive-infared sensors. Likewise, Belant et al. (1998) tested motion-activated acoustic frightening devices, which also emit sound only when activated by the deer, and found that although these sound devices had an initial effect, deer quickly habituated to the sound and continued using corn fields at levels comparable to before the sound devices were put into use. When testing the effectiveness of the Yard-Guard, a regular-interval acoustic frightening device, Curtis et al. (1995) found no significant difference in apple consumption among test areas. Similarly, Ujvari et al. (2004) found that fallow deer (*Dama dama*) visiting a feeding station exhibited increasing indifference over time to pre-recorded sounds produced by acoustic road markings and concluded that the deer habituated to the acoustic stimulus.

The results of previous research suggest that auditory deterrents may be an unreliable method for altering deer behavior such that deer-vehicle collisions may be prevented. These studies looked primarily at commercially available devices. We investigated behavioral responses of deer to sounds within their known hearing range in a controlled field application. As sound stimuli must be neurologically significant to the animal to produce a behavioral response (Jacobson 1994), Belant et al. (1998) suggested that the lack of negative reinforcement associated with auditory deterrents prevents frightening devices from being effective deterrents for white-tailed deer. Thus, testing pure tones sounds to investiage the efficacy of sound deterrents is necessary to gauge if there is potential for these devices to reduce deer-human conflicts.

OBJECTIVES

1. Determine the behavioral responses of captive white-tailed deer to a range of sound frequencies within their hearing range.
2. Evaluate the effect of sounds on altering behavior of free-ranging deer along roadways.

Thesis Format

This thesis is written in manuscript format. Chapter 1 presents a literature review and background for this study. Chapter 2 is a manuscript that will be submitted to Journal of Wildlife Management describing my experiments evaluating the behavioral responses of white-tailed deer to a vehicle-mounted sound-production system. Chapter 3 summarizes and concludes the findings of my thesis research.

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CHAPTER 2

BEHAVIORAL RESPONSES OF WHITE-TAILED DEER TO A VEHICLE-MOUNTED SOUND PRODUCTION SYSTEM[1]

[1] Valitzski, S. A., G. J. D'Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller and R. J. Warren. To be submitted to *Journal of Wildlife Management*.

ABSTRACT

We evaluated the efficacy of sound as a deterrent for reducing deer (*Odocoileus* spp.)-vehicle collisions by observing the behavioral responses of captive and free-ranging white-tailed deer (*O. virginianus*) to pure-tone sounds within their documented range of hearing. The behavior of captive deer did not change when they were exposed to any of the 5 pure-tone sound treatments we tested. The behavior of free-ranging deer within 10 m of roadways was not altered in response to a moving automobile fitted with a sound-producing device and speakers that produced the same 5 sound treatments that we used in the trials with captive deer. Many commercially available, vehicle-mounted auditory deterrents (i.e., deer whistles) are purported to emit continuous pure-tone sounds similar to those we tested. However, our data suggest that deer whistles are likely not effective in altering deer behavior in a manner that would prevent deer-vehicle collisions.

Key words auditory deterrent, deer-vehicle collision, deer whistle, hearing, *Odocoileus virginianus*, sound, white-tailed deer.

INTRODUCTION

Deer (*Odocoileus* spp.)-vehicle collisions are an important highway safety issue throughout much of North America. Increasing deer populations, coupled with expanding transportation systems and vehicular volumes, have led to a rise in the number of deer-vehicle collisions (Romin and Bissonette 1996). Annually, there are approximately 1.5 million deer-vehicle collisions resulting in nearly $1 billion in damages (Sullivan and Messmer 2003). Most states in the U.S. employ mitigation techniques for reducing deer-vehicle collisions. However controlled scientific evaluations of these techniques generally are lacking (Romin and Bissonette 1996).

Vehicle-mounted auditory deterrents (i.e., deer whistles) are a widely accepted and commercially available device for prevention of deer-vehicle collisions. Deer whistles are purported to produce ultrasonic frequencies that deter deer from roads by warning them of an approaching vehicle (Hornet Deer Whistle 2002, Deer Alert 2007). These devices are advocated as humane, inexpensive, easy-to-use, and scientifically sound (Bomford and O'Brien 1990), but scientific evidence of their efficacy is lacking. Although several studies indicated that some commercially available deer whistles do not produce the ultrasonic frequencies as claimed (Schildwachter et al. 1989, Scheifele et al. 2003), many motorists rely solely on these products to prevent deer-vehicle collisions.

Previous research has evaluated the effects of auditory deterrents on white-tailed deer (*Odocoileus virginianus*) feeding behavior (Belant et al. 1998, Gilsdorf et al., 2004a, 2004b, VerCauteren et al. 2005). These studies concluded that auditory deterrents either have no effect on deer behavior, do not produce the desired responses by deer, or the effectiveness of the devices diminishes over a short time due to habituation. The effects of pure-tone sound on roadway behavior of free-ranging white-tailed deer has not been studied.

Recently, D'Angelo et al. (2007) conducted auditory brainstem response experiments to record the neurological responses of sedated white-tailed deer to a range of sound frequencies at varying intensities. They reported that the range of white-tailed deer hearing included frequencies from 0.25 kHz-30 kHz, with best hearing sensitivity between 4 kHz-8 kHz. Because the upper limit of human hearing is approximately 20 kHz (Durrant and Lovrinic 1995), ultrasonic sounds may have potential for use as auditory deterrents for resolving deer-human conflicts.

Deer whistles are claimed to emit consistent, continuous sounds when activated (Hornet Deer Whistle 2002, Deer Alert 2007). Pure tones are continuous sounds of equal intensity at a single frequency (Martin 1994), which may be produced using standard commercially available equipment. Scheifele et al. (2003) tested the actual frequencies emitted from deer whistles, and found they produced pure tone sounds. Based on this study and other similarities between sounds elicited by deer whistles and pure tones, the objective of this research was to test the effects of pure-tone sounds on white-tailed deer behavior. Our objective was to evaluate behavioral responses of captive deer to a range of pure tones and to test the efficacy of pure tones for altering the behavior of free-ranging white-tailed deer along roadways for prevention of deer-vehicle collisions.

STUDY AREA

We conducted experiments on the responses of captive deer to sounds at the Daniel B. Warnell School of Forestry and Natural Resources, Whitehall Deer Research Facility at the University of Georgia, Athens (herein, captive deer facility). The captive deer facility encompassed 2.4 ha, with 19 covered barn stalls, a rotunda with moveable internal walls to direct deer movements, 5 outside paddocks, and 3 outside holding/sorting pens. The captive deer facility houses 60-100 white-tailed deer annually.

We conducted the field portion of our study on the 1,215-ha Berry College Wildlife Refuge (BCWR), contained within the Berry College Campus in northwestern Georgia. BCWR is within the Ridge and Valley physiographic province (Hodler and Schretter 1986) with elevations ranging from 172-518 m. BCWR is characterized by campus-related buildings and facilities interspersed with pastures, woodlots, and larger forested tracts. Forested areas are dominated by oaks (*Quercus* spp.), hickories (*Carya* spp.), and pines (*Pinus* spp.).

BCWR had an abundant deer herd with an estimated 40 deer/km^2 (J. Beardon, Georgia Department of Natural Resources, personal communication). There were 12-24 deer-vehicle collisions reported annually on the approximately 24 km of paved roads (Berry College Police Department, unpublished data). BCWR roads were open to public traffic during daylight hours. After dark, only vehicles with Berry College permits were allowed access through a gate staffed by campus police. Average traffic volume was 26 cars/hr (24 hr average, SE = 4) during our study.

On BCWR, we observed free-ranging white-tailed deer on 2 test areas separated by >5 km: (1) main campus test area (280-m long segment of road) and (2) mountain campus test area (220-m long segment of road). The main campus test area was characterized as a campus-to-farm transition area. The test section of roadway separated a <2.5 cm high groomed lawn of orchard grass (*Dactylis glomerata*), fescue (*Festuca arundinacea*), and white clover (*Trifolium repens*) from a 6-m wide mowed roadside area of white clover, which transitioned into a Bermuda grass (*Cynodon dactylon*) field used for hay production. The mountain campus test area was composed of a groomed lawn similar in plant composition to that on the main campus test area and was interspersed with <20 hardwood and conifer trees. The mountain campus test area was bordered by several campus buildings, parking lots, and ponds.

METHODS

Sound-emitting Equipment

We used a tone generator (Model 555, ACK Electronics, Atlanta, Georgia, USA) to produce pure-tone sound stimuli across a range of frequencies. We controlled sound intensity levels using a Madisound 5150 amplifier (Madisound Speaker Components, Madison, Wisconsin, USA), and a receiver (Model 2400, KLH Audio Systems, Sun Valley, California, USA). We transmitted sound to a 4-channel speaker selector with amplifier protection (Monster Cable SS4, Monster Cable Products, Inc., Brisbane, California, USA), which allowed us to select which speakers would emit the pure tones. We used Fostex 127E full-range speakers (Fostex America, a Division of Foster Electric, U.S.A., Inc., Gardena, California, USA) and Madisound high-frequency speakers (Madisound Speaker Components, Madison, Wisconsin, USA).

We calibrated the sound-emitting equipment to deliver the proper frequencies and levels of intensity. For calibration purposes, we recorded sample sound stimuli with a M30BX measurement microphone (free-field frequency response of 9 Hz-30 kHz; Earthworks Precision Audio, Milford, New Hampshire, USA) routed to an Edirol UA-25 USB sound card (Roland Corporation, Los Angeles, California, USA) connected to a laptop computer. We used RAVEN-Interactive Sound Analysis Software (Bioacoustics Research Program, Cornell Lab of Ornithology, Ithaca, New York, USA) to analyze sound stimuli. The same sound-emitting and calibration equipment was used for both the captive and field trials.

D'Angelo et al. (2007) concluded that ultrasonic pure tones (>20 kHz) had to be emitted between 45 and 60 db Sound Pressure Level (SPL) at the deer's ear to be heard reliably by the deer. To ensure that the sound treatments in our study were audible to deer, we set the minimum intensity at 70 db SPL at calibrated distances for all pure tones. Animal use procedures were approved by the Institutional Animal Care and Use Committees of the University of Georgia (IACUC # A2004-10102-0) and Berry College (IACUC # 2003/04-06).

Captive Trials

Based on D'Angelo et al. (2007) we selected pure-tone sound treatments within the hearing range of white-tailed deer. For all trials with captive deer, we observed behavioral responses of focal deer to 1 of 5 pure tone sound treatments: 0.28 kHz, 1 kHz, 8 kHz, 15 kHz, and 28 kHz. We assigned the treatments for each trial randomly. During each trial, we classified the behavior of the focal deer during 3 observation periods: 1) pre-treatment–15 sec, 2) treatment–5 sec of pure tone sound, and 3) post-treatment–15 sec, with a recovery period of 2 min between trials.

We classified the deer's behavioral responses as: 1) passive, 2) alert–head held high, movement of ears, 3) active–movement away from or towards speakers, or 4) flight–a swift movement away from the speakers. We recorded the position of the deer in relation to the speakers as away or towards for each observation period. One researcher made all observations to minimize observer bias.

During March-April 2006 at our captive deer facility, we housed 8 semi-tame, adult ($\geq$2.5 years) deer in an outside paddock (0.2 ha). We mounted speakers on evenly spaced posts along 2 sides of the perimeter of the paddock at 1.5-m above the ground. We placed 4 speakers serving each side of the paddock for a total of 8 speakers. From a blind near the midline of the paddock, the observer selected a focal animal randomly and recorded its behavior. During each trial, we set the speaker selector so that only speakers from 1 side of the paddock emitted sound stimuli. As calibrated, the sound was $\geq$70 db SPL at the midline of the paddock to ensure that sound was audible to the deer, but also allowed the deer a chance to respond and escape.

We also evaluated the behavioral responses of 5 adult deer housed individually in barn stalls (3 x 6-m) at our captive deer facility. We attached 1 speaker to the door of the barn stall and calibrated the sounds to ensure they were audible $\geq$70 dB SPL throughout the stall. We mounted video cameras (Panasonic pro-line WV-BP310, Panasonic Broadcast and Digital Systems Company, Secaucus, New Jersey, USA) in each stall that linked to a time lapse recorder (Panasonic AG-RT600P, Panasonic Broadcast and Digital Systems Company, Secaucus, New Jersey, USA), a color video monitor (Panasonic CT-1386YWD, Panasonic Broadcast and Digital Systems Company, Secaucus, New Jersey, USA), and a sequential switcher (Panasonic WJ-SQ208, Panasonic Broadcast and Digital Systems Company, Secaucus, New Jersey, USA) to observe behaviors of individual deer.

For each trial, we categorized changes in deer behavior between pre-treatment, treatment, and post-treatment observation periods. These changes were scored as: 1) negative reaction–focal deer moved towards the source of the sound, 2) positive reaction–focal deer moved away from the source of the sound, and 3) neutral reaction–no change in behavior of focal deer. We used a chi-square test of independence (Sokal and Rohlf 1995) allowing us to make comparisons of the independence of behavior score categories among all 5 sound treatments. We analyzed the behavioral responses of deer within a group and individual deer in barn stalls in independent analyses. We examined significance in shifts of deer behavior among the pure tone sound treatments using $\alpha = 0.05$.

Field Trials

We used the same sound-emitting equipment as in the captive trials, altered for vehicle mounting (Figure 2.1). For all trials, we used a 1993 Buick station wagon with 4 high-frequency speakers (Madisound Speaker Components, Madison, Wisconsin, USA) mounted forward of the grill at an approximate height of 0.75 m above the road surface. Two speakers emitted sound directly in front of the vehicle (mounted 90^o from the grill) and 2 speakers emitted sound to the sides of the vehicle (mounted 45^o from the grill).

We conducted field trials during April and June 2006. We did not hold trials during May to avoid fawning and its possible influence on deer behavior. Within the 2 test areas on BCWR, we delineated an area of influence, which encompassed a 10-m buffer on both sides of the road for the entire length of the test area. Based on our calibrations of sound stimuli emitted from the test vehicle traveling through the test areas at 48 km/hr, we determined that sound stimuli was ≥70 dB SPL at 1.5 m above the ground within the 10-m buffer and ≥30 m ahead of the test vehicle. All sound treatments were ≥25 dB SPL above operating noise of the test vehicle at the calibrated distances.

To delineate the area of influence, we installed distance markers 10-m perpendicular to the road edge at 20-m intervals along the roadway segment of each test area (Figure 2.2). We observed deer behavior from a 3-m high elevated platform placed approximately 6 m from the road edge near the mid-line of each test area. We used a forward-looking infrared (FLIR) ThermaCAM B1 (FLIR Systems, Inc., Boston, Massachusetts, USA) with a 12 degree lens (360^o rotation and 90^o vertical tilt) mounted on the safety rail of the platform. The FLIR was connected to a 33-cm black and white monitor with a Video Cassette Recorder, powered by a 12-volt deep-cycle marine battery and a 750-watt power inverter. The distance markers delineating the area of influence were made to collect heat during the day and store and radiate more heat than the surrounding environment at night to be visible in the FLIR (D'Angelo et al. 2006). We established test areas 2 weeks before beginning our observations.

We recorded deer behavior during 2, 3-hr observation periods per day, from 0600-0900 hours and from 1900-2200 hours. We held 1 observation period per test area per day, alternating

AM and PM observation times. We concentrated our observations around dawn and dusk to maximize the number of deer in the test area. The observer entered the viewing platform 30 min before observations began to reduce disturbance to deer in close proximity to the test area. To minimize observer bias, the same researcher made all observations. The observer randomly selected a focal deer within the area of influence, and alerted a co-worker with a 2-way radio to drive through the area at 48 km/hr in the vehicle equipped with the sound-emitting equipment.

For each trial, we exposed the deer within the area of influence to 1 of 6 randomly assigned treatments. The 6 treatments consisted of a control (no sound stimuli from vehicle) and the 5 pure tones used in our experiments with captive deer: 0.28, 1, 8, 15, and 28 kHz. We did not conduct trials on days with heavy precipitation, fog, or high winds as these conditions would prevent sound from traveling at the calibrated intensities.

We characterized deer behavior into 1 of 5 categories: 1) passive, 2) alert–lifted head, movement of ears, 3) active–movement away or toward roadway, 4) flight–a swift movement away from the roadway and 5) within road–deer was within the roadway. Each trial consisted of recording focal deer behavior relative to each treatment at 2 observation periods: Period 1 (before the vehicle entered the test area), and Period 2 (during interaction between deer and vehicle). For each trial, we categorized changes in deer behavior between Periods 1 and 2. These changes were scored as: 1) a negative interaction–the behavior of the animal was more likely to cause a deer-vehicle collision, 2) a positive interaction–the deer was less likely to cause a deer-vehicle collision and 3) a neutral interaction–no change in risk of a deer-vehicle collision (Table 2.1). For example, if the behavior of the focal deer was passive during Period 1 (before the vehicle entered the test area), after which during Period 2 the focal deer was active towards the road (the interaction between the deer and vehicle) we would have categorized the trial as a negative interaction. We used a chi-square goodness of fit test (Sokal and Rohlf 1995), with $\alpha \leq 0.05$ indicating significance, to compare deer behavior when exposed to each pure-tone treatment to deer behavior when exposed to the control.

RESULTS

Captive Trials

During 15 days of observation from 22 March 2006-7 April 2006, we recorded 406 observations of the behavioral responses of captive deer to pure-tone sound treatments. For focal deer in a group, we held 30 trials per day for 8 days (n = 240 observations). For focal deer housed individually, we held ≤25 trials per day for 7 days (n = 166 observations).

The behavioral responses of focal deer were independent of the pure-tone sound treatments tested for all observations of captive deer within a group (Table 2.2; 0.28 kHz, χ_8^2 = 0.36, P = 0.999; 1 kHz, χ_8^2 = 2.54, P = 0.959; 8 kHz, χ_8^2 = 2.14, P = 0.976; 15 kHz, χ_8^2 = 6.02, P = 0.645; 28 kHz, χ_8^2 = 0.12, P = 0.999). For deer within a group, we scored ≥74 % of the observations in the neutral behavior category for all pure-tone sound treatments tested.

For focal deer housed individually, we detected no difference in the behavioral responses of deer among all 5 pure-tone sound treatments (Table 2.3; 0.28 kHz, χ_8^2 =2.69, P = 0.952; 1 kHz, χ_8^2 = 0.61, P = 0.999; 8 kHz, χ_8^2 = 1.74, P = 0.988; 15 kHz, χ_8^2 = 0.05, P =0.999; 28 kHz, χ_8^2 = 1.70, P = 0.989). We scored ≥69% of the observations as neutral behavior scores for deer housed individually.

At first exposure to sound, deer behavior was categorized as more alert, but reactions degraded to passive after multiple exposures to pure-tone sound treatments. We observed normal captive deer behavior of feeding, grooming, and laying down during all 3 observation periods. Deer behavior did not change with exposure to pure-tone sound treatments. We did not observe flight responses conducive to preventing deer-vehicle collisions.

Field Trials

During 26 observation periods from 10 April-26 April 2006 and 5 June-13 June 2006, we recorded 319 observations of focal deer relative to the test vehicle. All pure-tone sound treatments were used during both April and June observations. For all treatments, deer behavior did not change between Periods 1 and 2, as we classified $\geq$53% of the observations in the neutral category (Table 2.4). For the 0.28 kHz treatment versus the control, we observed a decrease in the proportion of neutral and positive responses by deer and an increase in the proportion of negative responses by deer ($\chi_2^2 = 7.58$, $P = 0.023$). For the other 4 pure-tone sound treatments, we observed no differences in the proportions of behavioral response categories between the treatment and the control (1 kHz, $\chi_2^2 = 0.13$, $P = 0.937$; 8 kHz, $\chi_2^2 = 3.44$, $P = 0.179$; 15 kHz, $\chi_2^2 = 0.89$, $P = 0.641$; 28 kHz, $\chi_2^2 = 4.54$, $P = 0.103$.)

In $\geq$35 % of trials with the control, deer responded in a positive manner (i.e., moved away from the road in a manner that a deer-vehicle collision might be prevented). Likewise, the proportion of positive responses by deer did not vary among the pure-tone sound treatments (0.28 kHz, 33%; 1 kHz, 37%; 8 kHz, 24%; 15 kHz, 33%; 28 kHz, 24%)

DISCUSSION

Our intent was to investigate responses of captive deer to pure-tone sound treatments to determine which were most applicable in a roadway setting (i.e., flight responses by deer away from the sound). Because the responses of captive deer did not differ among the sound treatments we tested, we elected to test all 5 pure tones in our field trials.

We found that the pure-tone sounds we tested did not alter the behavior of captive or free-ranging white-tailed deer in a manner that would prevent deer-vehicle collisions. Based on deer hearing abilities (D'Angelo et al. 2007) and our calibration of the sound treatments, all of the treatments we tested were audible to focal deer in the area of influence. However, only the 0.28 kHz pure tone elicited behavioral responses by deer and those deer were more likely to enter the roadway in the presence of the test vehicle. Given the general lack of response by deer to the sound treatments in our study, deer confronted with a vehicle and additional stimuli from auditory deterrents may: 1) have too little time to react as desired, 2) lack the neurological ability to process the alarm information efficiently to respond as desired, or 3) may not recognize the sounds we tested as threatening.

Pure tones are similar to the sounds deer-whistles are purported to emit. We tested pure tones at frequencies similar to manufacturer claims ($\geq$15 kHz, Hornet Deer Whistle 2002, Deer Alert Animal Warning Device 2007) as well as frequencies within the range that several designs of deer whistles have been shown to produce (Scheifele et al. 2003; 3-12 kHz). Therefore, our results suggest that deer whistles likely would not be effective for prevention of deer-vehicle collisions. Correspondingly, Romin and Dalton (1992) reported no differences in behavioral responses of mule deer (*O. hemionus*) exposed to either of 2 brands of deer whistles (brand not specified) compared to vehicles without whistles.

To effectively reduce the incidence of deer-vehicle interactions, auditory deterrents should be transmitted as far ahead and to the sides of the vehicle as possible to provide deer with ample time to react. For our field trials, we set minimum standards for pure tones being audible $\geq$70 db SPL within the 10-m area of influence and $\geq$30 m in front of the test vehicle traveling at 48 km/hr. Although our experiments were conducted under ideal conditions, with weather conditions conducive to sound transmission and few roadside obstructions, exceeding our minimum 10-m area of influence would be difficult, particularly at the higher frequencies. For example, we could not produce intensities for the ultrasonic treatment (28 kHz) greater than the minimum standards, or beyond the area of influence, without damaging the sound-producing equipment. Hearing safety of pedestrians also must be considered because they would be exposed to sounds within close proximity of passing vehicles. We limited intensities to $\leq$115 dB SPL at 1 m from the speakers based on standards set by the Occupational Safety and Health Administration (2006) for maximum permissible noise exposure for $\leq$0.25 hr/d.

Sound stimuli must have neurological significance to the animal to produce a behavioral response (Jacobson 1994). Natural sounds (e.g., deer vocalizations) are complex, being composed of several pure tones of different frequencies generated simultaneously, repeating over time (Martin 1994). Complex sounds are rapid-change stimuli, with a relatively fast neurological onset caused by simultaneous firing of the auditory nerves (Hall 1992, Jacobson 1994). Pure tones are considered slow onset and long-duration stimuli producing slower neurological responses which last for the duration of the sound stimuli. To produce a rapid change in deer behavior, complex sounds may be more appropriate than pure tones. Nevertheless, research on auditory deterrents has shown that some types of complex sounds are ineffective for altering deer behavior. Gilsdorf et al. (2004b) found that distress and alarm calls recorded from live-captured deer used as a bio-acoustic frightening device did not deter deer from using agricultural fields. Similarly, elk (*Cervus elaphus*) and mule deer were not deterred from feeding sites by the Critter Gitter™, a deterrent device with an auditory alarm that "approached 120 dB in volume (manufacturer statement) and consisted of a repeated series of low and high pitched beeps that varied in pattern each time the device was activated"

(VerCauteren et al. 2005:1283). Other studies found no change in deer feeding behavior with motion-activated or regular-interval acoustic frightening devices (Curtis et al. 1997, Belant et al. 1998).

MANAGEMENT IMPLICATIONS

Considering the challenges of producing sound at appropriate intensities and distances from a moving vehicle, deer hearing capabilities, human safety concerns, and our observed lack of behavioral responses of deer to sound treatments, auditory deterrents do not appear to be appropriate for prevention of deer-vehicle collisions.

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Figure 2.1. Test vehicle equipped with sound-emitting equipment used for observations of behavior of free-ranging white-tailed deer in response to sound treatments at Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, 2006.

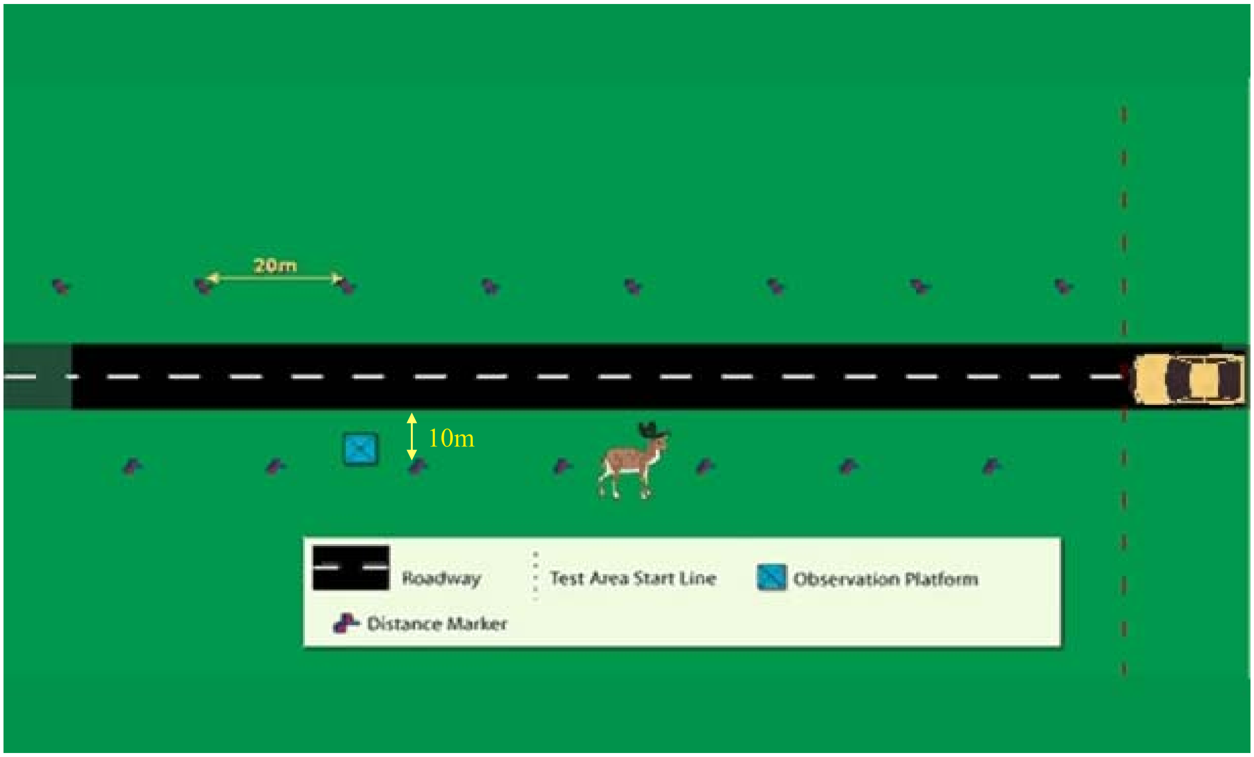

Figure 2.2. Depiction of an experimental roadway section established for testing vehicle-mounted sound deterrents on white-tailed deer roadway behavior on Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, 2006.

Table 2.1. Behavior score categories for white-tailed deer exposed to vehicle-emitted sound treatments based on changes in deer behavior along roadways, comparing periods before the deer was exposed to treatment to when the vehicle passed the deer or interacted with the deer on Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, 2006. Negative scores indicated a higher risk of a deer–vehicle collision (DVC), neutral scores indicated no change in DVC risk, and positive scores indicated a lower risk of a DVC.

	Observation period	
Behavior Score	**Before**	**During**
Negative	Passive	Within road
Negative	Passive	Active toward road
Negative	Alert toward road	Within road
Negative	Alert toward road	Active toward road
Negative	Alert away from road	Within road
Negative	Alert away from road	Active toward road
Negative	Active toward road	Within road
Negative	Active toward road	Active toward road
Negative	Active away from road	Within road
Negative	Active away from road	Active toward road
Negative	Flight away from road	Flight towards road
Negative	Within road	Within road
Neutral	Passive	Passive
Neutral	Passive	Alert toward road
Neutral	Passive	Alert away from road

Neutral	Alert toward road	Alert toward road
Neutral	Alert toward road	Passive
Neutral	Alert toward road	Alert away from road
Neutral	Alert away from road	Alert away from road
Neutral	Active toward road	Active toward road
Neutral	Active toward road	Active parallel to road
Neutral	Active away from road	Alert toward road
Neutral	Active away from road	Active away from road
Neutral	Active parallel to road	Active parallel to road
Positive	Passive	Active away from road
Positive	Passive	Flight away from road
Positive	Alert toward road	Flight away from road
Positive	Alert toward road	Active away from road
Positive	Alert away from road	Active away from road
Positive	Active towards road	Active away from road
Positive	Active away from road	Flight away from road
Positive	Within road	Active away from road

Table 2.2. Percent change of white-tailed deer behavioral response scores exhibited by captive deer within a group, compared using a Chi-Square Test of Independence, during pure-tone sound trials at the University of Georgia Captive Deer Research Facility, Athens, Georgia, USA, 2006.

		Behavior change categories (%)				
Treatment	***N***	**Negative**	**Neutral**	**Positive**	χ^2	***P***
0.28 kHz	50	10.00	74.00	16.00	0.36	0.9999
1 kHz	48	4.17	75.00	20.83	2.54	0.9598
8 kHz	44	2.27	81.81	15.91	2.14	0.9764
15 kHz	43	16.28	79.07	4.65	6.02	0.6450
28 kHz	55	9.09	78.18	12.73	0.12	0.9999

Table 2.3. Percent change of white-tailed deer behavioral response scores exhibited by captive deer housed individually, compared using a Chi-Square Test of Independence, during pure-tone sound trials at the University of Georgia Captive Deer Research Facility, Athens, Georgia, USA, 2006.

		Behavior change categories (%)				
Treatment	***N***	**Negative**	**Neutral**	**Positive**	χ^2	***P***
0.28 kHz	36	2.78	69.44	27.78	2.69	0.9523
1 kHz	24	8.33	79.17	12.50	0.61	0.9997
8 kHz	27	3.70	85.19	11.11	1.74	0.9880
15 kHz	37	8.11	72.97	18.92	0.05	0.9999
28 kHz	42	11.90	73.81	14.29	1.70	0.9889

Table 2.4. Percent change of white-tailed deer behavioral response scores for free-ranging deer exposed to vehicle-mounted sound-producing devices, compared using a Chi-Square Goodness of Fit Test, on Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, 2006.

		Behavior change categories (%)				
Treatment	***N***	**Negative**	**Neutral**	**Positive**	χ^2	***P***
Control	59	5.08	59.32	35.59		
0.28 kHz	52	13.46	53.85	32.69	7.58	0.0226
1 kHz	51	5.88	56.86	37.25	0.13	0.9371
8 kHz	51	5.88	70.59	23.53	3.44	0.1791
15 kHz	51	7.84	58.82	33.33	0.89	0.6408
28 kHz	55	9.09	67.27	23.64	4.54	0.1033

CHAPTER 3

SUMMARY AND CONCLUSIONS

As public concern over deer-vehicle collisions increases, agencies charged with managing wildlife populations or highway safety are interested in the effectiveness of mitigation techniques, such as deer whistles. Little scientific research has been conducted on the perception and behavioral response of white-tailed deer to sound. Results of previous research on other types of auditory deterrents suggest that sound deterrents may not be a reliable method for altering deer behavior such that deer-vehicle collisions may be prevented. There are similarities between sounds produced by deer whistles and pure tones. Therefore, I evaluated the efficacy of pure-tone sounds throughout the full range of deer hearing for altering the behavior of free-ranging deer along roadways.

I first investigated responses of captive deer , looking for a flight response by deer away from the sound, to pure-tone sound treatments to determine which were most applicable in a roadway setting. Because the responses of captive deer did not differ among the sound treatments I tested, I elected to test all 5 pure tones in our field trials. I found that the pure-tone sounds I tested did not alter the behavior of free-ranging white-tailed deer in a manner that would prevent deer-vehicle collisions. Free-ranging white-tailed deer within 10 m of roadways did not change their behavior relative to 4 of the 5 pure tone sound treatments. The 0.28 kHz pure tone sound treatment elicited negative responses from deer in our field trials (i.e., deer were more likely to move towards the roadway and create a dangerous situation along the road edge).

Based on the lack of behavioral responses of deer to any of the sound treatments, deer confronted with a vehicle and additional stimuli from auditory deterrents may: 1) have too little time to react as desired, 2) lack the neurological ability to process the alarm information efficiently to respond as desired, or 3) may not recognize the sounds I tested as threatening. Considering the challenges of producing sound at appropriate intensities and distances from a moving vehicle, deer hearing capabilities, human safety concerns, and my observed lack of behavioral responses of deer to sound treatments, auditory deterrents appear to lack applicability for prevention of deer-vehicle collisions.