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Evaluation of Wildlife Warning Reflectors for Altering White-Tailed Deer Behavior Along Roadways

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Abstract

*We evaluated the behavioral responses of white-tailed deer (*Odocoileus virginianus*) to 4 colors of wildlife warning reflectors (red, white, blue-green, and amber) that are purported to reduce the incidence of deer–vehicle collisions. We observed white-tailed deer behaviors relative to roads before and after installation of wildlife warning reflectors using a forward-looking infrared camera during 90 observation nights. We concluded that wildlife warning reflectors were ineffective in changing deer behavior such that deer–vehicle collisions might be prevented.* (WILDLIFE SOCIETY BULLETIN 34(4):1175–1183; 2006)

Key words

behavior, deer–vehicle collision, forward-looking infrared camera, Odocoileus virginianus*, road kill, white-tailed deer, wildlife warning reflectors.*

Deer (*Odocoileus* spp.)–vehicle collisions are a major concern throughout much of the United States, accounting for human injury and death, damage to vehicles, and waste of deer as a wildlife resource (Romin and Bissonette 1996). Most states attempt to minimize deer–vehicle collisions through a variety of techniques, including signage, modified speed limits, highway lighting, roadside fencing, over- or underpasses, warning whistles, habitat alteration, deer hazing, driver awareness programs, and reflective devices (Romin and Bissonette 1996). However, few studies have examined the efficacy of such techniques, and a distinct lack of information exists concerning deer behavior relative to mitigation efforts.

Strieter-Lite® (Strieter Corp., Rock Island, Illinois) wildlife warning reflectors are marketed as a proven and humane technique for reducing wildlife–vehicle collisions (www.strieter-lite.com). These reflectors are mounted on posts along roadsides and consist of a plastic housing with 2 reflective mirrors with plastic elements, which redirect light through colored lenses (Fig. 1). The manufacturer claims that the reflectors deter deer from attempting road-crossings by altering and distributing light from oncoming vehicle headlights across the road and into roadside corridors to "provide an optical warning fence to deer" (Strieter Corp., unpublished instruction manual:3).

Investigations of the effectiveness of wildlife warning reflectors have produced variable results for a variety of reflector models (Gilbert 1982, Armstrong 1992, Reeve and Anderson 1993, Pafko and Kovach 1996). However, these earlier studies often were limited by sample size and insufficient experimental design. Most studies used counts of deer carcasses along roadways to assess reflector effectiveness, and rarely used quality controls such as video surveillance of test sections or driver surveys to account for collisions that resulted in injured deer wandering from the roadside. Further, previous reflector studies provided little data on the behavioral reactions of free-ranging deer to reflector activation by the headlights of oncoming vehicles. This is a significant omission, given that these behavioral reactions constitute the very basis for the purported effectiveness of these reflectors.

Schafer and Penland (1985) documented a decrease in vehicle collisions with white-tailed deer (*O. virginianus*) and mule deer (*O. hemionus*) when Swareflex® reflectors (D. Swarovski & Co., Wattens, Austria) were used in an experiment that alternated covering and uncovering the devices. Alternatively, Reeve and Anderson (1993) used a similar study design and concluded that Swareflex reflectors were ineffective at reducing mule deer road kills in a migratory corridor. Waring et al. (1991) reported that Swareflex reflectors did not alter white-tailed deer crossing behavior; however, this conclusion was based on observations of only 14 attempted road crossings by deer in the presence of vehicles at night. Our objective was to determine the effect of 4 colors (red, white, blue-green, and amber) of Strieter-Lite reflectors in altering white-tailed deer roadway behavior in the presence of vehicles at night.

Study Area

We conducted our study at the Berry College Wildlife Refuge (BCWR) within the 11,340-ha Berry College Campus in northwestern Georgia, USA. The 1,215-ha BCWR, located in Floyd County, lies within the Ridge and Valley physiographic province (Hodler and Schretter 1986) with elevations ranging from 172 to 518 m. The BCWR is

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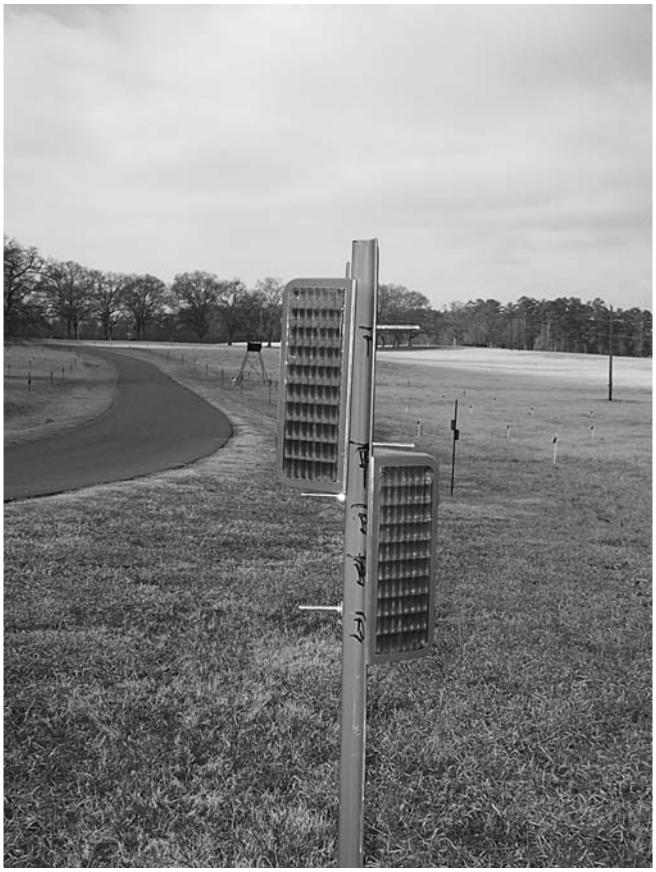

Figure 1. Wildlife warning reflectors mounted on a steel U-post within the area of influence, Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, during 2004–2005.

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.). Hunting is prohibited on BCWR and deer are abundant with an approximate density of 40 deer/km^2 (J. Beardon, Georgia Department of Natural Resources, personal communication). The BCWR contains approximately 24 km of 2-lane paved roads (M. Hopkins, Berry College Physical Plant, personal communication). In the past decade, 12–24 deer–vehicle collisions were reported annually on these roads (Berry College Police Department, unpublished data). The BCWR is open to public traffic during daylight hours. After dark, only vehicles with Berry College permits are allowed access through a gate staffed by campus police. Vehicle traffic at night is still a regular occurrence because approximately 1,600 students and staff reside on campus. Average traffic volume on BCWR roads was 28.8 (SE = 9.1) vehicles per hour for the 5-hour period after sunset during our study.

We selected 2 test areas on BCWR separated by >5 km. 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 (*Lolium arundinaceum*), 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

Test Area Establishment

The Strieter-Lite instruction manual indicates that the reflectors should emit light to linear distances of ≥38.1 m. Based on this information, physical characteristics of our study area, and equipment limitations, we defined an "area of influence" (Taylor and Knight 2003) centered on the sections of roadway we selected for reflector testing (Fig. 2). The area of influence extended 27.4 m perpendicular from the paved edges of the roadway and was 182.9 m in length centered on the midline of each test area. According to the manufacturer's claims, all deer within the area of influence should have detected light transmitted by reflectors. Within this area we also were able to accurately record specific deer behaviors and estimate deer movement distances.

We installed a 3-m-high elevated observation platform located 6 m from the roadway edge near the midline of each test area. We constructed 1.2-m-high plywood walls around the seating area of the observation platform to conceal the observer and equipment from the deer. We mounted a forward-looking infrared (FLIR) ThermaCAM B1 camera with a 12° lens (FLIR Systems, Inc., Boston, Massachusetts) to the safety rail of the observation platform. The observer was able to manipulate the FLIR in 360° rotation and ≥90° of vertical tilt. We connected the FLIR to a 33-cm black and white monitor to ease viewing, and placed the monitor on the floor of the observation platform in front of the observer. We powered the monitor with a 12-V deep-cycle marine battery and a 750-W direct-current to alternating-current electrical power inverter.

We developed distance markers to aid our estimation of distances and to delineate the area of influence within test areas. We designed the distance markers to collect and store heat during the day and subsequently radiate more heat than the surrounding environment at night, thus making the markers detectable in the FLIR. To create the distance markers, we filled 591-ml plastic drink bottles with automobile windshield washer fluid and coated the filled bottles with black rubberized automobile undercoating (Bondo Corp., Atlanta, Georgia). We used rot-resistant braided nylon twine (Wallace Cordage Co., Covington, Tennessee) to attach the bottles to 102-cm-long plastic fence posts with a steel shaft for step-in installation. On both sides of the road, we established 5 transects on each side of the midline of the test area at a spacing of 18.3-m. The transect length was perpendicular to the roadway with a starting point 9.1 m from the road edge. Along transects, we installed 5 distance markers spaced 4.6 m apart. We

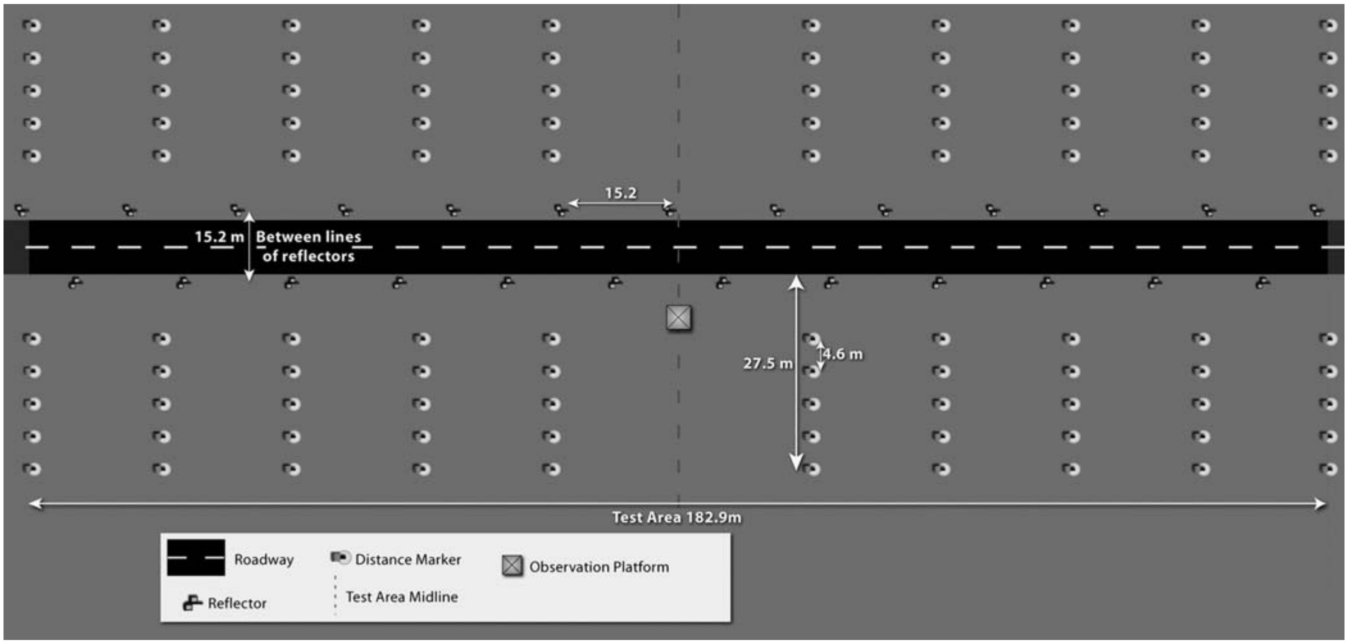

Figure 2. Experimental section of roadway established for evaluating the effect of wildlife warning reflectors on the behavior of white-tailed deer along roadways on Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, during 2004–2005.

determined our distance estimation error under normal observation conditions at night by estimating distances to random locations ($n = 60$) of coworkers standing within test areas. We pooled estimates from both test areas and calculated mean estimation errors for perpendicular distances from the road as 1.57 m (SE = 1.64 m) and 1.83 m (SE = 1.58 m) for lateral distances from the midline of the test areas.

At each test area, we installed 15 steel U-posts (Midwest Air Technologies Inc., Lincolnshire, Illinois) on each side of the roadway according to installation instructions for the Strieter-Lite Wild Animal Highway Warning Reflector System. Spacing between posts on the same side of the road was 15.2 m with a 15.2-m perpendicular distance between lines of posts on opposite sides of the road. We evenly staggered posts on opposite sides of the roadway in a diagonal fashion. This configuration ensured total reflector coverage of the area of influence because we installed reflectors 19 m beyond its endpoints. To facilitate deer accommodation to study-related objects in the test areas other than the reflectors, we installed the observation platforms, steel U-posts, and distance markers >2 weeks prior to the start of pretreatment observations. During pretreatment phases, no reflectors were present on the posts. We installed reflectors in daylight >8 hours prior to collecting the first observations for respective treatment phases. On each post, we directed an upper reflector toward the roadway and directed a lower reflector 180° opposite the roadway with the bottom of each reflector 61.0–76.2 cm above the crown of the road. We cleaned reflectors once per week using water and lens paper. A representative from Strieter Corporation inspected and approved our placement of reflectors on both test areas. Animal use procedures were approved by the Institutional Animal Care and Use Committees of the University of Georgia (IACUC No. A2004-10102-0) and Berry College (IACUC No. 2003/04–06).

Behavioral Observations

We observed deer–vehicle interactions for 4 hours per night beginning 30 minutes after sunset. The observer entered the observation platform >30 minutes prior to the start of recording observations to reduce disturbance to deer in the area. We cancelled observation nights during times of precipitation and heavy fog to reduce possible interference of light transmission by water particles in the air or on reflector lenses.

We conducted 15 nights of pretreatment observations in both test areas from 18 November 2004 to 25 January 2005. On the main campus test area, we installed the red reflectors on 26 January 2005 and conducted observations on 15 nights from 26 January to 10 March 2005. We removed the red reflectors on 11 March 2005. We installed the white reflectors on 24 March 2005 on the main campus test area and conducted observations on 15 nights from 24 March to 18 April 2005. On the mountain campus test area, we installed the blue-green reflectors on 8 February 2005 and conducted observations on 15 nights from 8 February to 18 March 2005. We removed the blue-green reflectors on 19 March 2005, installed the amber reflectors on 8 April 2005, and conducted observations on 15 nights from 8 April to 1 May 2005. Whereas seasonal variations in deer behavior related to breeding occur, this source of error likely would have had minimal effect on this experiment because we observed behavioral reactions of deer along our test sections of roadway after peak rutting season and before fawning season occurred.

Figure 3. Deer–vehicle interaction as captured using a forward-looking infrared camera (FLIR) on 19 Apr 2005 during the amber-colored wildlife warning reflector treatment phase on Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA.

For each deer–vehicle interaction observation, the observer selected a focal animal within the area of influence but outside of a 9-m buffer on both sides of the midline of the test area. We established this buffer to exclude animals from observation, which, because of their proximity, were most likely to be influenced by the presence of the observer. We chose focal animals to examine responses of individuals at different perpendicular and lateral distances within the area of influence and in different positions within groups of deer. We observed deer–vehicle interactions during normal traffic, which included small- to medium-sized passenger vehicles. We excluded observations, which included tractor trailers, buses, and other nonpassenger vehicles because travel by these types of vehicles was rare during the night on BCWR. When traffic was not available and deer were present in the area of influence, the observer used a 2-way radio to instruct a co-worker in a waiting vehicle to drive through the test area. We instructed the driver to maintain a continuous speed of about 48 km/hour and to use the vehicle's high-beam headlights unless other vehicles were in the test section of road. We set these conditions to simulate a typical vehicle traveling on BCWR (J. Baggett, Berry College Police Department, personal communication).

We grouped specific deer behaviors into 5 general categories, which were integral for assessment of deer–vehicle collision risk: 1) passive, 2) active toward the road, 3) active away from the road, 4) active parallel to the road, and 5) within the road (all behaviors within the paved surface of the road). At 2 periods during each observation, the observer classified the behavior of the focal animal and estimated the focal animal's perpendicular distance from the road edge and lateral distance from the midline of the test area. The observer recorded information for period 1 as the vehicle reached a point 50 m from the beginning of the area of influence. We selected this vehicle location for period 1 because curvatures of the test sections of roadway ensured that the headlights of the moving vehicle did not shine on the areas of influence until after that point. The observer recorded information for period 2 as the vehicle passed the focal animal or as the focal animal and vehicle interacted in the roadway (Fig. 3). We separated individual observations by ≥3 minutes.

Table 1. White-tailed deer behavior scores for wildlife warning reflector testing based on changes in deer behavior near roads from before a vehicle entered the test area (period 1) to as the vehicle passed the deer or interacted with the deer in the roadway (period 2) on the Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, during 2004–2005. Negative scores indicated increased risk of a deer–vehicle collision (DVC), neutral scores indicated no change in DVC risk, and positive scores indicated decreased DVC risk.

Behavior score	Period 1	Period 2
−2	Passive	Within road
−2	Active toward road	Within road
−2	Active away from road	Within road
−2	Active parallel to road	Within road
−2	Within road	Within road
−1	Passive	Active toward road
−1	Active toward road	Active toward road
−1	Active away from road	Active toward road
−1	Active away from road	Active parallel to road
−1	Active parallel to road	Active toward road
0	Passive	Passive
0	Passive	Active parallel to road
0	Active away from road	Passive
0	Active parallel to road	Active parallel to road
+1	Passive	Active away from road
+1	Active toward road	Passive
+1	Active toward road	Active parallel to road
+1	Active away from road	Active away from road
+1	Active parallel to road	Passive
+1	Active parallel to road	Active away from road
+2	Active toward road	Active away from road
+2	Within road	Passive
+2	Within road	Active away from road
+2	Within road	Active parallel to road
+2	Within road	Active toward road

Data Analysis

We scored changes in general behavior categories (responses) from period 1 to period 2 for each focal animal observation. The scoring scale ranged from those responses that had a high likelihood of causing a deer–vehicle collision (negative responses) to those that lessened the risk of a deer–vehicle collision (positive responses; Table 1). We used chi-square tests (Sokal and Rohlf 1995) to make comparisons of behavior score categories among pretreatment and treatment phases within individual test areas. We calculated total distance moved and perpendicular distance moved from observation period 1 to observation period 2. We used paired *t*-tests (Sokal and Rohlf 1995) to determine differences in total and perpendicular distances moved within positive and negative response categories among pretreatment and treatment phases within individual test areas.

Results

From 18 November 2004 to 1 May 2005, we recorded 1,370 deer responses to vehicles during 90 nights of observations

Table 2. Proportions (%) of white-tailed deer behavioral response scores exhibited during each of the experimental phases of wildlife warning reflector testing on Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, during 2004–2005.

			Behavior score				
			Negative responses		Neutral	Positive responses	
Test area	**Experimental phase**	***n***	**−2**	**−1**	**0**	**+1**	**+2**
Main campus	Pretreatment	161	3.73	2.48	70.81	18.01	4.97
	Red reflectors	182	6.04*	7.14*	69.78	16.48*	0.55*
	White reflectors	295	7.12*	10.50*	51.10*	21.02*	10.20*
Mountain campus	Pretreatment	307	2.61	3.58	72.96	16.94	3.91
	Blue-green reflectors	226	3.09**	6.63**	80.00**	8.85**	1.33**
	Amber reflectors	199	9.04*	7.54*	54.77*	20.10*	8.54*

* $P \leq 0.001$ for differences observed in behavioral responses among pretreatment and treatment phases as determined by chi-square analysis.

** $P \leq 0.01$ for differences observed in behavioral responses among pretreatment and treatment phases as determined by chi-square analysis.

(4 hr each; Table 2). Irrespective of experimental phase or reflector color, we classified the largest proportion of behavioral responses as neutral. Changes in behavior were similar within the defined levels of positive and negative responses; thus, we present results as responses of the respective groups.

Main Campus Test Area

Behavioral responses.—Comparing the pretreatment to the red-reflector treatment, we observed a decrease in the proportion of positive behavioral responses and an increase in the proportion of negative responses (Table 2; $\chi^2_4 = 25.99$, $P \leq 0.001$). From pretreatment to the white reflector treatment, we observed a decrease in the proportion of neutral behavioral responses and an increase in the proportion of negative and positive responses ($\chi^2_4 = 42.65$, $P \leq 0.001$).

Distance moved.—The perpendicular distance of the focal animal from the roadway for period 1 was less during pretreatment than during the red reflector treatment (Table 3; $t = -5.77$, df = 341, $P \leq 0.001$). However, for deer demonstrating positive responses, we detected no differences in total distance moved ($t = -0.94$, df = 74, $P = 0.348$) or perpendicular distance moved from the roadway ($t = -1.31$, df = 74, $P = 0.193$). For deer demonstrating negative responses, total distance moved was greater during pretreatment than during the red reflector treatment ($t = 3.39$, df = 52, $P = 0.001$) and we detected no difference in perpendicular distance moved toward the roadway ($t = 1.90$, df = 52, $P = 0.063$).

The perpendicular distance of the focal animal from the roadway for period 1 was less during pretreatment than during the white reflector treatment (Table 3; $t = -2.12$, df = 454, $P = 0.035$). However, for deer demonstrating positive responses, we detected no difference in the total distance moved ($t = 0.180$, df = 81, $P = 0.858$) or perpendicular distance moved away from the roadway ($t = 0.055$, df = 79, $P = 0.956$). For negative responses, total distance moved ($t = 3.58$, df = 24, $P = 0.002$) and perpendicular distance moved toward the roadway ($t = 3.05$, df = 25, $P = 0.005$) were greater during pretreatment than during the white reflector treatment.

Mountain Campus Test Area

Behavioral responses.—From pretreatment to the blue-green reflector treatment, the proportion of behavioral

Table 3. Mean (SE) perpendicular distance of the focal animal from the road as the vehicle entered the test area (period 1), and mean (SE) perpendicular and total distances moved from period 1 to when the vehicle passed the deer or the deer and vehicle interacted in the roadway (period 2), for negative and positive behavioral responses of white-tailed deer during experimental phases of wildlife warning reflector testing on Berry College Campus and Wildlife Refuge, Mount Berry, Georgia, USA, during 2004–2005.

			Perpendicular distance	Perpendicular distance moved		Total distance moved	
Test area	**Experimental phase**	***n***	**Period 1**	**Negative responses**	**Positive responses**	**Negative responses**	**Positive responses**
Main campus	Pretreatment	161	10.4 (7.8)	8.9 (7.1)	4.8 (4.2)	13.1 (10.4)	5.6 (4.9)
	Red reflectors	182	15.5 (8.6)*	5.9 (4.4)	6.0 (3.8)	6.0 (4.6)*	6.4 (3.9)
	White reflectors	295	12.1 (8.0)**	4.2 (3.7)**	4.8 (3.4)	5.2 (4.3)**	5.5 (4.1)
Mountain campus	Pretreatment	307	13.6 (7.9)	4.7 (3.7)	6.4 (5.0)	9.3 (8.3)	7.8 (6.3)
	Blue-green reflectors	226	12.9 (7.8)	4.4 (3.0)	3.6 (2.4)*	6.7 (6.7)	4.9 (3.1)**
	Amber reflectors	199	11.9 (8.2)**	3.3 (2.9)**	3.6 (1.9)*	6.8 (10.8)	4.4 (2.9)*

* $P \leq 0.001$ for differences observed in perpendicular distances for period 1 and perpendicular and total distances moved among pretreatment and treatment phases as determined by chi-square analysis.

** $P \leq 0.05$ for differences observed in perpendicular distances for period 1 and perpendicular and total distances moved among pretreatment and treatment phases as determined by chi-square analysis.

responses increased in the neutral and negative behavior categories and correspondingly decreased in the positive response category (Table 2; $\chi^2_4 = 14.37$, $P = 0.006$). From pretreatment to the amber reflector treatment, we observed a decrease in the proportion of neutral behavioral responses and increases in the proportion of negative and positive responses (Table 2; $\chi^2_4 = 52.69$, $P \leq 0.001$).

Distance moved.—The perpendicular distance of the focal animal from the roadway for period 1 was similar ($t = 1.04$, df = 525, $P = 0.301$) during the pretreatment and blue-green reflector treatment (Table 3). For deer demonstrating positive responses, total distance moved ($t = 2.40$, df = 102, $P = 0.018$) and perpendicular distance moved from the roadway ($t = 1.66$, df = 100, $P \leq 0.001$) were greater during pretreatment than during the blue-green reflector treatment. For deer demonstrating negative responses, we detected no difference in total distance moved ($t = 1.48$, df = 80, $P = 0.143$) or perpendicular distance moved toward the roadway ($t = 0.417$, df = 80, $P = 0.678$) among the pretreatment and blue-green reflector treatment (Table 3). During the blue-green reflector treatment, we observed a deer–vehicle collision within the area of influence. The deer initially moved at a trot toward the roadway and stopped at a perpendicular distance of 10 m from the roadway before running into the path of the vehicle. The deer was struck in the hindquarters and moved >150 m from the roadway out of sight of the observer. The vehicle stopped immediately after the collision and then continued driving.

The perpendicular distance of the focal animal from the roadway for period 1 was less ($t = 2.23$, df = 500, $P = 0.026$) during the amber reflector treatment than during the pretreatment (Table 3). However, for deer demonstrating positive responses, the total distance moved ($t = 3.98$, df = 108, $P \leq 0.001$) and perpendicular distance moved from the roadway ($t = 4.29$, df = 98, $P \leq 0.001$) were greater during the pretreatment. For deer demonstrating negative responses, there was no difference in the total distance moved ($t = 1.28$, df = 107, $P = 0.203$) among the pretreatment and the amber reflector treatment. However, deer demonstrating negative responses during the pretreatment moved a greater perpendicular distance toward the roadway ($t = 2.21$, df = 107, $P = 0.029$).

Effect on Moving Animals

To further assess the potential efficacy of wildlife warning reflectors in reducing deer–vehicle collisions, we separately analyzed a subset of 221 observations where the focal animals were actively moving (i.e., walking or running) toward the road before the vehicle entered the test area. These observations represent those most likely to have resulted in a deer–vehicle collision. During the pretreatment phase when no reflectors were in place, the focal animal reacted in a positive manner and stopped moving toward the road in 64% of the observations ($n = 36$, pooled for both test areas). In contrast, the proportion of positive behavioral responses was lower for all reflector treatments than for the pretreatments (red reflector treatment = 13%, $n = 24$, $\chi^2_1 = 25.60$, $P \leq 0.001$; white reflector treatment = 55%, $n = 92$, $\chi^2_1 = 3.02$, $P = 0.082$; blue-green reflector treatment = 14%, $n = 21$, $\chi^2_1 = 12.50$, $P \leq 0.001$; amber reflector treatment = 50%, $n = 48$, $\chi^2_1 = 4.46$, $P = 0.035$).

Discussion

Descriptions of deer behavior relative to roadways are limited in the literature. Our pretreatment observations of deer responses to vehicles indicated that deer tend to avoid crossing roads in the presence of vehicles. Our data were consistent with observations by Waring et al. (1991) of white-tailed deer road-crossing behavior in Crab Orchard National Wildlife Refuge, Illinois. Before Swareflex reflectors were installed, Waring et al. (1991) observed that 71.4% ($n = 89$) of crossings by white-tailed deer were completed without a deer–vehicle interaction on a 2-lane highway, which experienced heavy traffic. Although deer–vehicle collisions are common and problematic (Sullivan and Messmer 2003), when considering the abundance of deer and the density of roads throughout their range (Federal Highway Administration 1998), deer–vehicle collisions likely are rare compared to the frequency of crossings attempted by deer. However, the road-crossing success of deer in localized areas may be impacted by factors including vehicle speed, traffic volume and patterns, vehicle types, motorist awareness of deer, weather conditions, ambient and vehicle-produced light levels, characteristics of the habitat–roadway interface, and mitigation strategies.

Our study contradicted claims that wildlife warning reflectors "deter deer from crossing the highway when reflecting vehicle headlights" (Strieter Corp., unpublished instruction manual:27). Our results demonstrated that deer exposed to each of the 4 colors of reflectors we tested were more likely to be involved in negative deer–vehicle interactions than without the devices present. Further, any increase in the proportion of positive behavioral responses was coincident with an equal or greater increase in the proportion of negative responses within a given treatment phase. Likewise, when we observed an increase in neutral responses, similar decreases in positive and negative responses were evident. Our analysis focusing only on deer moving toward the roadway indicated that the wildlife warning reflectors appeared to provide no reduction in the potential of a negative deer–vehicle interaction.

Although group size may affect flight response in deer (LaGory 1987) and road-crossing behavior, we chose not to evaluate its effect on deer in our study because highway departments that use reflectors have no control over whether deer attempt road crossings singly or as a member of a group. Determining age and sex of focal animals was not always possible using FLIR, so we did not consider the effects of these variables in our analyses. However, >90% of the deer we observed probably were female.

In the only previous study of deer behavior near roads, Waring et al. (1991) also reported that roadside reflectors (Swareflex) had no impact on the crossing behavior of white-tailed deer or the incidence of road kills. Ujvári et al. (1998) examined the habituation of fallow deer (*Dama*

dama) to repeatedly occurring light reflections from a red WEGU reflector (Walter Dräbing KG, Kassel, Germany) placed directly in front of a bait site. During the first experimental night, fallow deer fled from the stimulus in 99% of cases, but over the remaining 16 experimental nights, deer exhibited increasing indifference to reflections, which was explained by habituation to the stimulus. To examine for possible acclimatization, we made comparisons of behavior score categories among entire pretreatment phases and successive 5-night blocks of each treatment phase (i.e., nights 1–5, 5–10, and 10–15) within individual test areas (G. J. D'Angelo, unpublished data). Generally, during our treatment phases, we observed the greatest differences in behavioral responses from pretreatment to treatment nights 1–5, but these differences were not indicative of flight and alarm as in Ujvári et al. (1998). Rather, we observed similar changes in positive and negative responses, which corresponded to an opposite shift in neutral responses. We detected the greatest shifts in behavioral responses from pretreatment levels during the white and amber reflector treatments. Since we tested these reflector treatments during spring versus autumn and winter when the red and blue-green reflectors were tested, it is possible that deer responses to reflectors may be influenced by seasonal differences.

Electrophysical measurements of the spectral mechanisms in white-tailed deer have shown that peak sensitivity of deer color-vision is well below the long wavelength of red (Jacobs et al. 1994), which is the most commonly marketed color of wildlife warning reflectors. VerCauteren et al. (2003) concluded that deer were not frightened by 2 models of red laser beams because deer could not detect the red color or the intense brightness of the lasers. Based on characteristics of deer color-vision (Jacobs et al. 1994) and the assumption that reflectors would be effective, we hypothesized that the ranked order of effectiveness in deer–vehicle collision risk prevention would follow a gradient with short-wavelength reflector-lens colors being most effective and long-wavelength lens colors being least effective: 1) blue-green reflectors (short wavelengths), 2) white reflectors (short, medium, and long wavelengths), 3) amber reflectors (medium and long wavelengths), and 4) red reflectors (long wavelengths), and 5) pretreatment (no wavelengths reflected). Our experiments demonstrated nearly opposite results with individual reflector treatments apparently increasing deer–vehicle collision risk from pretreatment levels. We observed the highest level of deer–vehicle collision risk during the blue-green reflector treatment phase with slightly lower levels of risk during the amber, red, and white reflector phases in respective order of decreased risk. This suggests that negative responses by deer may directly increase with greater perception of light from the reflectors.

Evidence for nocturnal mammals with visual systems comparable to white-tailed deer (i.e., tapetum lucidum, retina dominated by rod photoreceptors, and oval-shaped pupil with a large opening) suggested that the rapidity of their visual adaptation from darkness to abrupt increases in light (e.g., vehicle headlights) may be considerably slower than that of diurnal species like humans (Ali and Klyne 1985). A possible explanation for the increase in negative deer–vehicle interactions from pretreatment levels during each of the reflector treatments in our study may be that light from reflectors in combination with vehicle headlights overwhelmed the deer visual system. However, Sielecki (2001) reported that the primary reflected light intensity of Swareflex and Strieter-Lite reflectors was minimal. Sielecki (2001) found that all models, regardless of lens color, reflected <0.1 lux at a distance of 2 m, which is an illumination level less than that of a full Moon on a clear night (0.1 lux). Alternatively, Sielecki (2001) also observed a more intense white surface reflection from the external lens surface of the Swareflex and Strieter-Lite reflectors, which had a luminance value "several times to several hundred times higher than that of coloured light from the coloured lenses" (Sielecki 2001:484). During our trials, we also observed the white surface reflection described by Sielecki (2001). However, this reflection occurred as the vehicle passed an individual reflector, which logically is too late to prevent deer from entering the path of an oncoming vehicle. In our observations the white surface reflection transmitted no detectable light to diagonally or laterally adjacent reflectors.

Management Implications

We concluded that the wildlife warning reflectors we tested did not alter deer behavior such that deer–vehicle collisions might be prevented. Our data indicated that deer exhibit an increase in negative behavioral responses toward vehicles in the presence of reflectors. We suggest that until further research on deer–vehicle collision reduction strategies becomes available, management efforts should focus on: 1) implementing proper deer-herd management programs, 2) controlling roadside vegetation to minimize its attraction for deer and maximize visibility for motorists, 3) increasing motorist awareness of the danger associated with deer–vehicle collisions, 4) thoroughly monitoring deer–vehicle collision rates, and 5) encouraging communication and cooperation among governments, wildlife researchers, highway managers, motorists, and others involved in issues of deer–human conflict.

Although many aspects of deer biology are well studied, we lack basic knowledge of anatomy and physiology related to the sensory capabilities of deer. Advancing this information may prove integral to the development of effective and economically feasible strategies to minimize deer–vehicle collisions. Further, our understanding of deer behavior related to most mitigation strategies is inadequate. Future development of deer-deterrent devices and strategies should be guided by knowledge of deer senses and behavior. Prior to extensive deployment of mitigation strategies in the field, researchers should empirically test their effectiveness in altering deer road-crossing behavior and ultimately the potential of such techniques for preventing deer–vehicle collisions.

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