Do White-Tailed Deer Avoid Red? An Evaluation of the Premise Underlying the Design of Swareflex Wildlife Reflectors

JAMES L. ZACKS

ABSTRACT

The increase in deer-vehicle accidents has created a demand for preventive measures. A red reflector system (Swareflex wildlife reflectors) that reflects vehicle headlights to the side of the road has been claimed to frighten deer from the highways because red is instinctively frightening to the deer. Using penned deer, this research examined the premise that red is instinctively frightening to the white-tailed deer by measuring the effectiveness of red reflectors in keeping deer from crossing a line defined by the reflectors. No evidence was found that the deer avoid the area marked by the reflectors, or that they exhibit any other behavior that suggests that red is instinctively frightening to them. The results are considered in the light of other reports that vary in the degree to which they suggest that the reflectors are effective on the highway. It is argued that, where they are effective, the reflectors may have influenced the behavior of the drivers rather than the behavior of the deer.

Because of the steady increase in deer-vehicle accidents in recent years, it has become desirable to find a means to keep the white-tailed deer off of the highways when vehicles are present. In 1971 a red reflector system was introduced that reflects vehicle headlights to the side of the road to frighten the deer away from the roadway until the vehicle has passed. The basis for the reflector system is the assumption that

> red light exerts a warning effect on deer. . . . The headlights of approaching vehicles strike the wildlife reflectors which are installed on both sides of the road. Unnoticeable to the driver, these reflect red lights into the adjoining terrain and an optical warning fence is produced. Any approaching wildlife is alerted and stops or returns to the safety of the countryside. (Unpublished data on Swareflex wildlife warning reflectors, manufactured by D. Swarovski and Company, Rock Island, Illinois.)

Although the Swareflex reflector system has been in use for a number of years, its effectiveness is still in question (1). Thus far, most of the attempts to evaluate the reflectors have involved installing them along a roadway and comparing the rate of vehicle-deer collisions with the collision rate when the reflectors are not in place. The present research focuses instead on the manufacturer's claim that the white-tailed deer are afraid of the illuminated red reflectors to the extent that they either stop or run away when the reflectors are illuminated. Although it has been shown previously that the white-tailed deer has sufficient color vision to discriminate a band of long wavelengths (which looks red to humans with normal color vision) from white, there have been no data to support the claim that red frightens the deer (2).

In this report an experiment is described that attempts to test the claim that the red reflectors are inherently frightening to the deer. This was accomplished by arranging several red reflectors in a line and illuminating them in a manner similar to that in which they would be illuminated on the highway. The behavior of the deer was then monitored to determine whether the presence of the red reflectors deterred the deer from crossing the line marked by the reflectors. It is shown in this paper that the results of the experiment provide no evidence that the white-tailed deer responds any differently to the presence of red Swareflex reflectors in a headlight beam than it does to white reflectors of the same geometry, or to the headlight beam with no reflectors. Other attempts to evaluate the effectiveness of the reflector system in the face of the research results are also discussed. The reported reduction in the number of deer killed in what appears to be the best highway study to date, is more likely a result of an increase in driver attentiveness than an effect of the reflectors on the behavior of deer.

The present experiment was specifically designed to evaluate the claim that an optical barrier of red reflectors would, when illuminated, frighten deer from crossing the barrier. The claim was evaluated under conditions that in some ways approximated those in which the reflectors might actually be used. A group of 10 white-tailed deer was housed in a large pen. They were encouraged to move about in the area where the reflector barrier was set up by providing

Department of Psychology, Michigan State University, East Lansing, Mich. 48824.

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the primary sources of water for the animals in that area.

Movement of the deer across a line defined by five sign posts was monitored under three different conditions. Red Swareflex reflectors, identical white Swareflex reflectors, or no reflectors at all were installed on the posts and illuminated by vehicle headlamps at night. If red Swareflex reflectors were frightening to the deer because of their color, then the deer would have been less likely to cross the illuminated reflector barrier than when no reflectors were present. White reflectors were used as a control condition to evaluate further the claim that an inherent fear of red is what makes the reflectors effective.

METHODS

Following is a description of the methods used in conducting the experiment.

Animals and the Site

Ten white-tailed deer (*Odocoileus virginianus*) were housed in a 3.5-acre pen (Figure 1). Three yearling bucks and seven yearling does were chosen to approximate the ratio of males to females in the Michigan deer herd during the fall before hunting season. All of the deer were bred at the facility. The does had previously participated in experiments in which the effects of trace elements in their diet were investigated.

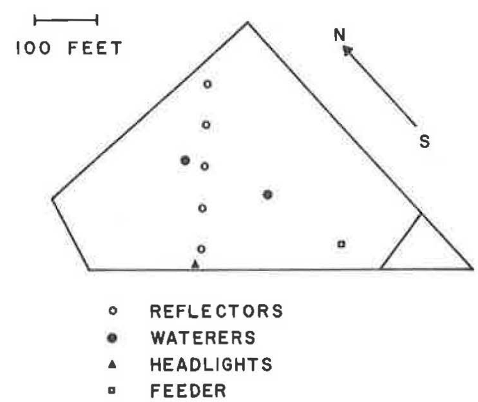

FIGURE 1 A map of the pen.

The deer were released into the pen on July 11, 1984 and final data collection occurred between August 20 and October 6, 1984. The deer were fed a commercially prepared exotic game feed that was continuously available from a hog feeder, which was refilled as needed. Water was available from two waterers separated by about 150 ft. Each waterer consisted of a covered reservoir from which water could be dropped into an aluminum pan. A toilet flush valve was used to release about 3 L of water with considerable splashing noise. A toilet float valve was used to control the refilling of the reservoir and the quantity of water per flush. The flush valve of each waterer was operated remotely by a radio-controlled servomotor.

To encourage a rapid response to the operation of a waterer, small holes were made in the bottoms of the aluminum watering pans. The water that was flushed into the pans drained out in about 1.5 min if it was not consumed by the deer. It was absorbed into the sandy soil very rapidly. During the period when data were being collected, the deer received most or all of their water during the course of the experiment, as described in the following paragraphs.

Experimental Procedure

Five sign posts were installed in a straight row across the pen and between the two waterers. They were spaced at intervals of 66 ft as recommended by the manufacturers of the reflectors. A bolt was installed on each post 42 in. above the ground. A reflector could be quickly installed or removed from the bolt. The terrain that was crossed by the reflector row was nearly flat, the difference between the heights of the highest and lowest posts being only 14 in. At one end of the line of reflectors, a pair of automobile headlamps was mounted in a position that simulated their location if they were actually installed in a vehicle that was driving down a road; the nearest headlamp was about 6 ft to the side of the reflector line. The headlamps were powered at 12 volts AC through a transformer.

From the west end of the reflector line, just outside of the pen and just behind the location of the headlights, the experimenter could view the deer, record data, and operate the waterers. Operation of a switch by the experimenter recorded the time and direction of each passage of a deer on a chart recorder. The definition of when a deer had crossed the line was arbitrary, but consistent across conditions. A crossing was recorded at the time that more than one-half of the animal's body was judged to have crossed the line. Because the animals often grazed in the area along the posts, they sometimes grazed right up the line, meandering onto it, and then back off it again. They similarly tended to walk up to the posts and lick them, sticking their heads up to or across the line, but often not crossing with the rest of their bodies. The most important fact is that the criterion for crossing the line was applied consistently and the behavior of the animals across the conditions did not differ in any way that would lead to a differential effect of the criterion under different conditions.

The author and two other people trained by the author served as the experimenter on separate occasions. A session was begun after sunset, when it was sufficiently dark so that automobiles that were driving under those conditions would have their headlights on. The passage of cars and trucks on a road that passed the pen was monitored to determine whether the passing vehicles had their headlights on. A session was never begun until a number of vehicles had passed, all having their headlights on.

On each night, each of the three conditions (no reflectors, white reflectors, and red reflectors) was tried. The order in which the conditions were run was varied according to a predetermined, counterbalanced order so that each possible order was run equally often. With three conditions, there are six different possible orders. Each order was repeated three times, for a total of 18 different sessions.

The basic procedure began with setting up the reflector condition. Then the headlights were turned on. For the next 15 min, every time that a deer crossed the line, the crossing and its direction were recorded. At the end of the first 5-min period, the waterer to the north of the line was operated once, loudly spilling about 3 L of water into the pan. At the end of the second 5-min period the waterer to the south of the line was operated. At the end of the next 5-min period (total of 15 min) the headlights were turned off. The experimenter then changed the reflectors to the next condition, using a flashlight if it was too dark to see without it. It usually took between 2-1/2 and 3-1/2 min to make the change. Five minutes after the headlights had been turned off, they were turned back on with the new reflector condition installed, and the procedure was then repeated. The deer were observed for 15 min, with each waterer operated once during this interval as in the first interval. Then the lights were turned off and the reflectors were changed again. After the third reflector condition was installed, a final 15-min observation interval was repeated. (See Figure 2.)

Early in the experiment, several cycles were run

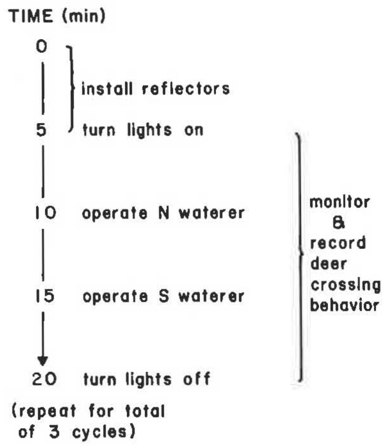

FIGURE 2 Diagram of the time course of a session.

each night, repeating the same pattern of alternation among the three reflector conditions two or three times. However, it was observed that the deer tended to be much more active during the first hour after the start of the session than later, when they often bedded down, so this practice was eliminated and each reflector condition was used only once per evening. The final data analysis is based only on the data from the first cycle through the three reflector conditions on any evening. Sessions in which the total number of crossings was less than 13 were repeated at a later time. Three sessions had to be repeated for this reason.

The data thus gathered consisted of the times and directions of each crossing of the signpost line by an animal. In addition, a log was kept in which were noted the crossings and type of movement, such as whether the animals were running, walking, grazing, and so on. (Any other salient events were also noted.) The experimenters were particularly careful to note the responses of the animals when the lights were first turned on, especially early in the experiment. The purpose of this was to determine whether there was any behavioral evidence that the animals were or were not especially responsive to the red reflectors (or the other two conditions) in a way that might not have been captured by the crossing data. (Note: on one evening, because the deer were exceptionally active, two different sequences were run.)

RESULTS

The principal question is whether the deer cross the reflector barrier less often when red reflectors are installed than when there are either white reflectors or no reflectors at all. Following is a discussion of the experiment results.

The Main Effect of Varying the Reflectors

Of the 720 crossings that were observed in 18 sessions, the deer crossed the barrier line 264 times when no reflectors were installed, 256 times when red reflectors were installed, and 200 times when white reflectors were installed. (See Figure 3.) An analysis of variance found no statistically significant effect of the reflector condition ($F[2, 34] = 1.62$, $p > .10$). The only trend in the data, which did not approach statistical significance, was in the direction of the white reflectors; this reduced the crossing rate relative to both the red-reflector and no-reflector conditions.

In addition to the quantitative measures of barrier crossings, the experimenters wrote verbal descriptions of the animals' behavior. No systematic method was used to describe these other aspects of

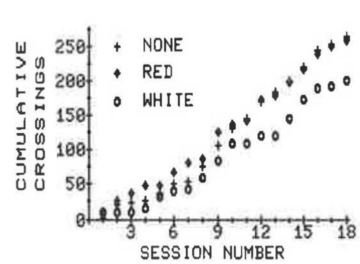

FIGURE 3 Total crossings in each session for each reflector condition.

the deer's behavior, but the experimenters were especially alert for any other behavioral indications of whether the animals reacted to the reflectors. There were none. From the very first time, the deer appeared not to respond in any observable way to the presence of the reflectors. Each of the three experimenters concurred that they would not be able to tell, from observing the behavior of the deer, which reflectors were installed. It was common to observe animals browsing in the area illuminated by the headlamps, and to see them browse slowly past the reflectors as though the reflectors were not present, even when they were oriented in the direction of the reflectors. Thus the informal behavior descriptions of the deer concur with the quantitative measure of their behavior in failing to reflect any effect of the presence of the illuminated red reflectors.

The reflectors were set up as though they were marking one side of a roadway. Because they are designed to reflect the headlights to only one side of the road, it would be expected that, even if deer are frightened by the reflected light, only those deer that approach from the side to which the light was reflected would be deterred from crossing. In effect, the reflectors were not set up as a bidirectional barrier, but rather as a one-way gate. For this reason, the effects of the barrier on crossings in each direction were analyzed separately. The analysis yielded the same result as was obtained from the analysis of the combined data.

There was no significant difference between the reflector conditions for movement south to north, where the deer would be facing the reflected light, or north to south, the case in which the manufacturers claim that the reflectors would not be visible. Figure 4 shows the data separated on the basis of the direction of movement through the barrier.

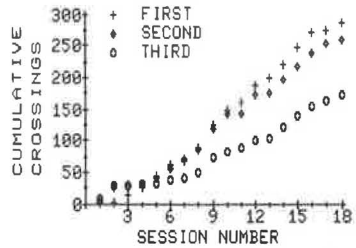

FIGURE 4 Total crossings in each session plotted separately for north-to-south and south-to-north with red reflectors.

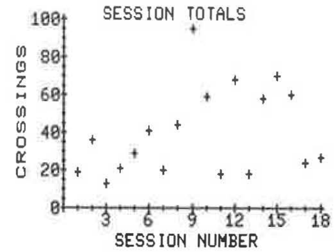

FIGURE 6 Total crossings in each session across reflector conditions.

Order Effects on Trials Within a Session

There are several additional aspects of the data that were examined. It was clear from observing the deer that they tended to become quite active somewhat before sundown and gradually to diminish their activity over the next 1 to 3 hr. For this reason an analysis of variance was performed on the effects of the order in which different reflectors were tried in a session. It can be seen in Figure 5, which summarizes the results, that there is a distinct tendency for the number of crossings to decrease over trials in a session. This decline was significant ($F[2, 34] = 5.84$, $p<.01$). Because the order in which the reflector conditions were run in different sessions was counterbalanced, with each of the six possible orders being replicated three times, this order effect was not the cause of the failure to find any differential effect of the reflector condition.

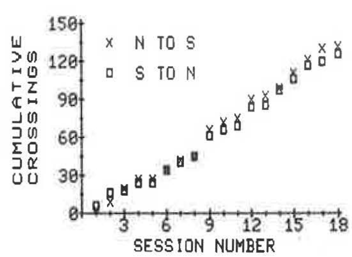

FIGURE 5 Total crossings in each session arranged in the order in which they were run.

Variations in the Number of Crossings Per Session

There was considerable variation in the number of crossings observed per session. Data from 3 out of 21 sessions were discarded because of a failure to observe a minimum of 13 crossings in each. Of the 18 sessions on which the main data analysis is based, a mean of 40 crossings was observed per session. However, the standard deviation was about 23, with a minimum of 13 crossings and a maximum of 95 crossings observed in different sessions. There was a slight increase in the number of crossings per session but the effect was small compared with the overall day-to-day variability. The session-to-session variability in overall responding is shown in Figure 6.

DISCUSSION OF RESULTS

The present study was designed to evaluate the assumption that red is an inherently frightening color to the white-tailed deer. Although the conditions for testing this assumption were chosen to be similar to the conditions under which the reflectors were designed to be used, there are admittedly several differences between the test situation and conditions along a real highway. For example, the headlights in the study were stationary rather than moving, the noise of a moving vehicle was lacking, and the deer became familiar with the testing situation. Although these differences might weaken the ability to generalize the results of the test to the general effectiveness of the reflectors in a highway situation, they bear less directly on the determination of whether red is inherently frightening to the deer, the question that the present research was designed to address.

The claim that red is an innately frightening color receives no support from the results of this research. The present study failed to reveal any effect of red Swareflex reflectors in keeping the deer from crossing a boundary that they defined. The study also failed to reveal any other gross changes in their behavior in the presence of the red reflectors. Because the assumption that red was inherently frightening to the deer was the basis for using the reflectors, it appears unlikely that they will affect the behavior of deer under highway conditions.

Although under highway conditions other factors are present, research with those factors that are present but with different reflectors showed no demonstrable effect of the reflectors (1). Thus, there is no basis for expecting wildlife reflectors to keep deer off the highways.

In view of these findings, the recent study by Schafer et al. (3) would appear to be problematic. They have installed red Swareflex reflectors on several stretches totaling 2.3 mi along SR 395 in Washington state and have alternately covered and uncovered the reflectors for successive time intervals (1-week intervals initially, and 2-week intervals subsequently). From a total of 58 deer killed at night in the test section since the beginning of the test in 1981, 52 were killed when the reflectors were covered and 6 were killed when the reflectors were uncovered. These results appear to provide a direct answer to the question this experiment attempted to address indirectly, and to have supported the opposite conclusion. There is, however, an alternative interpretation that eliminates the apparent inconsistency.

In the study by Schafer et al., Swareflex reflectors were installed on both sides of a highway at intervals of 66 ft on the straight sections and 33 ft on curves, as specified by the manufacturer. The reflectors were mounted as recommended by the manufacturer (and as mounted in the present study) so that the reflective surfaces were approximately at a 45-degree angle to the side of the road, thereby diverting the headlight beam away from the road along a line almost perpendicular to the edge of the road. The combination of a series of concave depressions in the highly reflective surface (which lies behind the red lens of the reflector) and the molded lenslets on the back of the red reflector lens causes the beam to be dispersed so that it can be viewed over a range of angles.

In the advertising literature the manufacturer suggests that the reflectors are "unnoticeable to the driver," and the illustrations show that all of the light is diverted to the side of the road. However, in the course of the current pen study, it became obvious to each of the experimenters that the color of the reflectors that had been installed was readily apparent from a vantage point behind the headlights that corresponded to the position from which the driver of a vehicle would view the scene. Thus a driver who enters a stretch of highway on which the reflector system is installed views a corridor of red reflectors that recede into the distance. In the study by Schafer et al. (3), this meant that as they covered and uncovered the reflectors, they were not only changing the conditions that the deer faced, they were also changing the conditions that the drivers faced. Because signing of a roadway with red markers on both sides of the road is unusual, and reserved for areas of extreme danger (such as proceeding the wrong way on a divided highway), it would appear plausible that the drivers would respond with increased alertness. Conventional signing for areas with high rates of automobile-deer accidents usually involves placing a small number of signs (often only one) warning of a deer crossing area. In the study by Schafer et al. (3), the warning signs are repeated every 66 ft (33 ft on curves) in the area that they protect. For this reason, it is ambiguous whether the behavior of the deer or the behavior of the drivers has been manipulated when the reflectors were covered and uncovered.

Another study, similar to that of Schafer et al., is under way in Colorado (personal communication with Dale Reed, wildlife biologist at the Colorado Department of Natural Resources). Although only 31 vehicle-deer accidents have been recorded of the 95 needed to have the desired statistical power, the number of deer killed when the reflectors were uncovered is thus far not statistically lower than when they were covered (12 killed when uncovered, 19 killed when covered), whereas Schafer et al. (3) observed a ratio of more than 8 to 1 in the number of accidents when the reflectors were covered compared with that when the reflectors were exposed. Although it is possible that there is a difference in the behavior of the deer populations in these two locales, it appears as likely that there may be significant differences in the drivers in the two studies. It would be important to determine whether there are differences such as the extent to which drivers on each of these stretches of road are local drivers who travel the roads frequently (and hence may have adapted to the presence of the reflectors) or whether they are drivers who tend to be on these stretches of roads infrequently and are confronting a novel highway signing condition. Such differences might explain differential effects of the reflectors on the behavior of the drivers in the two studies.

In summary, a plausible reconciliation of the data from the two highway studies and from this pen study is that the Swareflex reflectors do not deter the deer from moving onto the roadway, but that they cause drivers to be more alert. Further research to distinguish between these possibilities is important in determining whether it is more profitable to work toward changing the behavior of the deer or that of the drivers.

AUTHOR'S NOTE

Because this research has used Swareflex wildlife reflectors as an integral part of the research design, they have been referred to specifically rather than generically. Although the special property of these reflectors is supposed to be the color of the light reflected from them, the geometry of the lens, and so forth, are also salient features of the reflectors and would be virtually impossible to describe generically. In addition, this research was designed specifically to evaluate the Swareflex implementation of this kind of system.

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The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Michigan Department of Transportation or of the Federal Highway Administration.

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Discussion

JOHN R. STRIETER

The Swareflex Wildlife Warning Highway Reflector System has been shown by preponderance of evidence to reduce nighttime deer-vehicle collisions by 50 to 100 percent. Exhaustive tests were conducted in

Strieter Corporation, 2100 Eighteenth Ave., Rock Island, Ill. 61201.

Austria beginning in 1971, and testing begun in the United States and Canada in 1979 continues today.

Basically, objections are made to two conclusions in the paper. First, that white-tailed deer do not respond to the presence of red reflectors and second, that reflectors influence the behavior of the driver, rather than the behavior of the deer, in reducing roadkill.

The following aspects of Zacks' investigation and research project are analyzed:

1. Ten pen-raised yearling deer confined to a fenced area were used instead of wild deer in their native state.
2. Stationary headlight beams illuminating a single row of reflectors do not adequately simulate actual nighttime highway conditions of moving vehicles.
3. Drivers are generally unaware of reflectors along the roadways and do not become more alert when passing through a Swareflex reflectorized area.

The investigation does not take into account the designed function of Swareflex reflectors, namely, that as patterns of red optically moving lights progress ahead of vehicles they alarm the deer for a sufficient duration to permit vehicles to pass safely. Eyewitnesses have observed deer running toward, or standing beside, the reflectors suddenly turn and run away from the highway when the reflectors were lit up from a passing vehicle.

The methodology used and the conclusions drawn by James L. Zacks in the published report titled "An Investigation of Swareflex Wildlife Warning Reflectors" (1), and the paper in this Record titled "Do White-Tailed Deer Avoid Red?: An Evaluation of the Premise Underlying the Design of Swareflex Wildlife Reflectors" is the subject of this discussion.

In any test of a product it is reasonable to assume that the conditions used simulate true and actual conditions under which the product is intended to perform. However, the research and conclusions in Zacks' investigation are almost totally out of context with actual conditions under which Swareflex reflectors have been proven effective. For example, 10 white-tailed deer fenced within a 1.4 hectare area were used instead of wild deer in their natural state. Yearling bucks and does were bred at the facility, and the does had participated in other experiments.

For a total of 18 different sessions, two headlights were mounted on stationary posts and lighted for 15-min cycles. Stationary headlights in a fenced environment do not simulate vehicular headlights moving at high speeds with associated sounds and fumes. Nor do they simulate moving headlights striking reflectors along both sides of a highway, causing each reflector to light up progressively ahead of the approaching vehicle, with each reflector peaking in intensity.

Zacks' conclusion that red reflectors influence the behavior of drivers rather than the behavior of the deer is not substantiated. Highway safety personnel state that warning signs and devices lose their effect, if there is any, after drivers have observed them for 10 days. Furthermore, drivers are unaware of the presence or purpose of the red reflectors and therefore have no reason to decrease speed or to become more alert.

The watering device, learned-response methodology for compelling deer to cross the reflector line, may override even the fear mechanisms that alert wild animals to possible dangers. In Zacks' experiment, deer are forced, through desire for water, to drastically alter their normal behavior patterns. It is suggested that a more scientific approach should have been used.

Comparison of data from an incomplete test conducted in Colorado with data from the completed test conducted in Washington state (2) was wholly inconclusive. The Colorado test required a total of 100 accidents, and only 31 vehicle-deer collisions were recorded at that time. Several empirical tests showing effective reflector results were not considered.

In evaluating the Zacks investigation, I sought unbiased appraisals from three biologists: Lee Gladfelter, Wildlife Research Station, Boone, Iowa; Bill Davidson, Idaho Fish and Game, Pocatello; and Erich Klinghammer, Purdue University, West Lafayette, Indiana. All have distinguished themselves in wildlife management and study.

The first objection is to the use of deer in a fenced area. Deer had become adjusted to a pen-reared environment and were conditioned to rapidly responding to a remote-controlled noisy watering device that emptied quickly if they did not rush to it. The reflectors were positioned to entice deer movement through the corridor in alternate cycles of five red and five white lights reflected from two stationary headlights mounted on posts.

Lee Gladfelter, Wildlife Research Biologist, wrote: "These captive animals may be . . . indistinguishable from wild deer in appearance or genetics, but certainly not in behavior, which is the main thrust of this project." (Personal communication, October 16, 1985.)

He stressed the great difference between captive and wild deer, noting that highway danger avoidance is learned from dams in the first year of life. The project tested yearlings, not adults, and none probably had been exposed to highway dangers; therefore, they would not respond in a manner typical of wild deer.

Bill Davidson, Regional Wildlife Biologist, stated: "There is always a danger when you try to anthropomorphize wild animals. Setting up the study on the basis of what a human might do and subjecting animals to the same sort of stimuli must carry some questions of applicability. Equally of concern is the use of yearling animals. Yearlings have a low experience level on survival mechanisms, and in pen-reared systems have rarely, if ever, been faced with life-threatening situations." (Personal communication, November 17, 1985.)

Zacks focused his research on the manufacturer's claim that white-tailed deer is afraid of the illuminated red reflectors.

Erich Klinghammer, Biologist, stated:

> This is not what the manufacturer has claimed. Zacks has taken an empirically tested warning system and formulated a limited, specific hypothesis, which is then tested under controlled conditions using captive deer which are used to humans, in an artificial situation which does not in essential features resemble the real situation along highways where a high number of deer kills are a problem. In my view, Phase I of the experiment is irrelevant to the basic question, 'Will the Swareflex Reflectors reduce roadkills by cars?' (Personal communication, November 29, 1985.)

Klinghammer also criticized segments of Phase II:

1. A relatively small number of deer was used in a familiar setting.
2. Stationary stimuli in a row illuminated by a constant light source do not simulate moving auto lights.
3. Humans that didn't elicit avoidance

response took active roles in the experiments.
4. Thirst motivation enticed deer to cross illuminated lines.
5. Missing is the essential control group: wild deer in the same setting, which would not work because they would not be tractable in this situation, or direct observation of deer in the wild.

Klinghammer indicated that he based his observations on his personal knowledge of white-tailed deer in the wild and of captive deer at Wolf Park, near Battleground, Indiana, where he kept such deer years ago.

For a total of 18 different sessions, the stationary headlights were illuminated for 15-min cycles, during which spilling water was released to entice the deer to cross in front of the lights. Humans entered the pen in the presence of the deer after each cycle to change or remove reflectors.

Gladfelter made these further observations:

> I do not feel that the stationary headlights' beams illuminating a row of five reflectors properly simulates the conditions encountered by deer on a reflectorized stretch of highway. Noise and movement associated with a vehicle moving down a highway at night are missing in the experiments. The changing angle and intensity of light on the reflectorized surface certainly would be more noticeable to an animal near the highway than the reflected light from stationary headlights. I personally feel that this is the single most important concept of reflectors.
>
> The color of the flickering light is not the question here, but how effective the reflector is at reducing highway mortality of deer. The 66-ft spacing of reflectors is designed for a moving vehicle. With this stationary project design, only the first two or three reflectors are obtaining good light intensity with the remaining reflectors too far from the light source to be properly illuminated. In a reflectorized portion of highway, a deer is exposed to danger for just a few seconds, but this test studies behavior during 15 minutes of continuous lighting. It does not, or could not, evaluate that fraction of a second decision a wild deer might make to avoid a highway crossing when confronted by a vehicle moving through a reflectorized section.

The statistically valid results of the 90 percent reduction in nighttime roadkill in the Washington State Department of Transportation report were not considered in this investigation (2). The premise that drivers might see the reflectors and respond with increased alertness is disputed by monitors of actual Swareflex reflectors' tests. Reflectors in four approximately 1/4-mi locations were alternately covered and uncovered at 2-week intervals during the late fall to early spring from 1981 to 1984. Assuming drivers were more cautious when reflectors were uncovered, in the first 2-week period they would have slowed in the area where reflectors were uncovered, then sped up in the second area (no red lights) where they were covered, slowed again in the third uncovered area, and finally accelerated again in the fourth covered area. During the second week, they would have had to reverse driving habits when different areas were covered. However, this type of erratic speed up-slow down driving is not reflected in test results. Nor does it appear likely that any motorists would accept such traffic regimentation.

I believe that the field data collected since 1971, which indicate an average 80 percent reduction of nighttime roadkills by reflectors, is a far better analysis of the effectiveness of the Swareflex reflector system.

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Author's Closure

John R. Strieter, the U.S. distributor of Swareflex Wildlife Warning Reflectors, has raised a number of objections to the arguments advanced in my paper. These objections led him to challenge two of my conclusions:

1. He questioned whether I have demonstrated convincingly that white-tailed deer are, under natural conditions, not afraid of red reflectors, a conclusion that I drew from the results of experiments that I reported.

2. He disagreed with my proposed reinterpretation of the results of Schafer et al. (1). In their experiment they observed a reduction in the number of white-tailed deer killed when red Swareflex reflectors were installed beside a roadway and compared this reduction to the number of deer killed when the reflectors were not visible to the deer. Because in my research white-tailed deer showed no change in their behavior in the presence of illuminated red Swareflex reflectors, I was led to consider alternative explanations of the results reported by Schafer et al. I suggested that their results might have been due to an increase in driver awareness resulting from drivers seeing the red reflectors, rather than the result of any response of the deer to the reflectors.

I will review Strieter's objections and consider the extent to which they cast doubt on my conclusions.

Is there other evidence that suggests that Swareflex reflectors are effective? Strieter began his arguments with the claim, reiterated several times, that there is extensive evidence showing the reflectors to be effective in reducing deer-vehicle collisions. He suggested that my results are anomalous in that context. Although he claimed that there was a significant reduction in vehicle-deer collisions when Swareflex reflectors were used, few published sources of such data exist other than the report by Schafer et al. (1), which is discussed next.

There are two published reviews of the evidence on this issue. The first, by Gilbert (2), concluded that

> There is no statistically valid evidence that either the Van de Ree stainless steel

> mirrors or the Swareflex red reflectors reduce vehicle-deer collisions. The only statistically valid test with a minimally sufficient sample size concluded that the Swareflex reflector was ineffective [Woodard, et al. (3) 1973].

More recently Reed and Ward (4) have reached a similar conclusion about the effectiveness of wildlife reflectors, including the Swareflex reflector system. Thus, the published record does not support Strieter's suggestion that there are substantial data that demonstrate the effectiveness of Swareflex wildlife reflectors. In addition to the published research, Strieter alludes to anecdotal reports from customers who have installed the reflectors in varied settings. However, these reports are usually incomplete and involve few, if any, of the appropriate controls necessary to make evaluation of the reflector system's effectiveness possible. For this reason they must be viewed with extreme caution.

Has my research isolated the principles on which design of Swareflex reflectors is based? Strieter's arguments that my research has not took two forms. First, he argued that I failed to capture the key components of the reflector system design. He suggested that it is not simply the color, but rather the movement of the light along the line of reflectors, with each reflector peaking in intensity, that is important. Second, he argued that the research design did not simulate a real highway situation with the other stimuli associated with a moving vehicle (noise, movement, exhaust odors, etc.).

Consider first the criticism that the reflector system was designed to be effective when illuminated by a moving, not stationary, light. An understanding of the basis for the design of the reflectors must be gleaned from the advertising literature distributed by the manufacturer and its representatives. It was my reading of their claims, and the evidence that they offered to support them, that the reflectors were designed to attempt to capitalize on a presumed innate fear of red. I was not alone in this interpretation. In two different reports Schafer et al. (1) and Schafer and Penland (5) came to the same conclusion that I did. They stated that "the manufacturer of the Swareflex reflectors claim that the red color of the reflectors initiates an instinctive 'freezing' behavior in deer. Evidence for this functional response to red color has been given by Backhaus (6) and discussed by Koenig (7) and Weis (8), although Severinghaus and Cheatum (9) stated that deer are colorblind." Similarly, Reed and Ward (4) believed the reflector design to stem from the suggestions by Koenig (7) that predator eyes appear red to deer (although they challenged this "because the eyes of predators do not reflect light except from human sources").

Another reason that the succession of illuminated reflectors was not believed to be crucial was that the previous research with white reflectors, along real highways with moving vehicles, did involve their successive illumination, but the reflectors were judged not to be effective [Gilbert (2)]. Thus the red color was judged to be the significant difference in the Swareflex design.

Strieter's second argument with the design of the experiment was that I did not simulate highway conditions. This argument ignored the fact that the research was designed to isolate and assess the premise on which the design of the reflector system was based. If a response of deer to reflectors is the result of "an instinctive freezing behavior" in the presence of the reflected red light, then the other features of the highway situation would not be relevant. Similarly, I would argue that the use of penned deer rather than wild deer was not as significant as Strieter suggests. It is part of what we mean by calling a behavior innate that it is extremely stereotypical of the species and very resistant to change. Students of animal learning who sought to find species-independent laws of learning found that it was extremely difficult to make major changes in innate behavior even when they brought to bear all that had been learned about animal learning from many years of research [Breland and Breland (10)].

Still another feature of the conditions of my experiment that Strieter challenged was the procedure for attracting the deer to the reflectorized area of the pen. I used remotely controlled waterers to splash water into a metal pan. He suggested that the deer's normal fear responses to the reflectors may have been overridden because of extreme thirst. In the absence of additional information that suggestion is plausible. However, additional data argue against that suggestion. Although they were not reported, observations were made not only of the time and direction of a crossing, but also of the approximate location, and whether the animals were walking or running. If most of the crossings occurred as the deer ran to the waterers, Strieter's suggestion would be plausible. However, only a small number of the crossings were of that type. More typically, animals that may have come into the area initially, at the flush of a waterer, were observed to be remaining in the general vicinity, browsing on vegetation, wandering about, and generally walking slowly rather than running, often moving through the line of reflectors. There was nothing in the behavior we observed that would have suggested that the deer were blindly responding to the water, letting excessive thirst override their normal instinctive reactions.

Do Swareflex reflectors affect the behavior of the deer or the behavior of the drivers? The report of Schafer et al. (1) is the one, apparently well-controlled experiment that suggests that the Swareflex reflectors are effective. Although I do not dispute the statistical significance of these findings, I have suggested that there is an interpretation that is quite different from the one Schafer et al. offered. They suggested that the reflectors were effective because they kept the deer from the roadways during the time that the reflectors were illuminated by the headlamps of a passing vehicle. I have outlined the suggestion that the reflectors may have influenced the behavior of the drivers, rather than that of the deer. Strieter argued that this interpretation is unlikely because the drivers would have been observed to slow down in sections in which the reflectors were exposed, and to speed up in sections in which they were covered. He suggested that "this type of erratic speed up-slow down driving is not reflected in the test results."

Unfortunately, no systematic observations of the drivers were reported in this experiment. In addition, although slowing down in the presence of the signs would indicate a response to the signs, failure to slow down would not necessarily be evidence against an increase in attentiveness. Often, to demonstrate such a response, it is necessary to tax the limits of drivers' attention in order to show that they are paying increased attention. This might be done by observing drivers' responses to an attention-demanding situation. For example, even though the drivers in an area with reflectors might not be observed to slow down when they approach the reflectors, they might still be more attentive so that, when deer are present, they are quicker to notice them and slow down.

Only through additional research will it be possible to determine the correct interpretation of the results by Schafer et al. (1). The thrust of my alternative interpretation of the research of Schafer et al. was to suggest the direction in which additional research might go in order to determine the reason that they found the reflectors to be effective.

Because the problem of vehicle-deer collisions is serious in some areas, it might be argued that it does not matter why the reflectors worked in the experiment by Schafer et al., only that they did work. That argument is unsatisfying. For example, if my suggestion that the reflectors worked because of their effect on drivers is correct, then it raises other serious issues. Highway engineers have traditionally been opposed to using red to mean anything other than Stop. In the installation of the reflectors in my experiment, photographs verified that the reflectors were visible from a vantage point that simulated a driver in a highway situation. For this reason use of the reflectors might be unacceptable. If the reflectors have an effect on driver behavior, then additional evidence will be required to determine whether their effectiveness persists as drivers become more familiar with the reflector installations.

As illustrated in the preceding paragraph, it is important to understand the reasons for any present success in order to guide the direction of future attempts to refine and improve the use of measures to keep wildlife from the highways when vehicles are present.

In conclusion, Strieter's comments notwithstanding, certain points remain clear. First, there is no direct evidence that white-tailed deer are innately afraid of red light. Nor is there direct evidence that the behavior of white-tailed deer is influenced by Swareflex wildlife reflectors, installed beside a real highway, when illuminated by the headlamps of a vehicle moving past. The majority of published research suggests it is not.

Finally, there are plausible alternative interpretations of the one report of an experiment in which the installation of wildlife reflectors led to a reduction in vehicle-deer collisions. For these reasons it would appear prudent to refrain from the expense of installing the reflectors except where they are part of a well-designed experiment that will make evaluation of their effectiveness possible, and will provide insight into the reason for the effectiveness if it is found to exist.

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