AN INVESTIGATION OF SWAREFLEX WILDLIFE WARNING REFLECTORS

by

James L. Zacks

In cooperation with:
the
U.S. Department of Transportation
Federal Highway Administration
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16. Abstract The rise in the number of vehicle-deer accidents has increased the need for an effective means of keeping deer off of roadways when vehicles are present. This project evaluates the effectiveness of Swareflex Warning Reflectors. These red reflectors are claimed to frighten deer from the highway when illuminated by headlights of a passing vehicle. They are effective, the manufacturer argues, because deer are innately afraid of red. The research was conducted in two Phases. In Phase I the spectral sensitivity of the white-tailed deer was evaluated. The purpose was to understand some basic aspects of color vision in the white-tailed deer, since the color of the reflector was argued to be the reason for its effectiveness. Phase I results suggest that the white-tailed deer is relatively more sensitive to light of shorter wavelengths than is the human, but revealed nothing special about their vision which might be the basis for a deterent system.

Phase II of the project examined the effectiveness of the reflectors in stopping deer from passing through a "barrier" of red Swareflex reflectors. This Phase was designed to determine whether there was any evidence that the white-tailed deer is innately afraid of red, and whether such an innate fear could be used to frighten them from the highways. No evidence was found in this situation for the assumed innate fear of red. The reflector barrier had no observable effect on the behavior of the deer.

The results are considered in the light of inconsistent reports from other states on the effectiveness of the Swareflex reflectors. It is argued that, where the accident rates may have decreased, the effects might be due to influence of the reflectors on the behavior of the drivers rather than on the behavior of the deer.

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Disclaimer

GENERAL INTRODUCTION

Due to the steady increase in deer-vehicle accidents in recent years, it has become desirable to find a means to keep the white-tailed deer (Odocoileus virginianus) off of the highways when vehicles are present. In 1971 a red reflector system, manufactured by D. Swarovski & Co. of Austria, was introduced which reflects vehicle headlights to the side of the road in order, it is claimed, to "frighten" the deer away from the roadway until the vehicle has passed. The basis for the reflector system is the claim 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." (From an advertising brochure for Swareflex wildlife warning reflectors, manufactured by D. Swarovski & Co. and distributed in the United States by the Strieter Corporation, Rock Island, Illinois.)

Although the Swareflex reflector system has been in use for a number of years, its effectiveness is still in question (Gilbert, 1982). Thus far, most of the attempts to evaluate the reflectors have involved installing the reflectors along a roadway and comparing the rate of vehicle-deer collisions to the collision rate when the reflectors are not in place. The present research focusses instead on the manufacturer's claim that the white-tailed deer is "afraid" of the illuminated red reflectors so that they either stop or run away when the reflectors are illuminated. Although we have previously shown (Zacks & Budde, 1983) 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.

The overall goal of this project was to evaluate the effectiveness of red, Swareflex wildlife reflectors. The project consisted of two phases. Phase I was designed to evaluate some properties of the visual system of the white-tailed deer. Prior research had suggested that white reflectors, which reflect vehicle headlight beams to the side of the road, are not effective in keeping deer from the highways (See Gilbert, 1982, for a review). Therefore, it was important to determine whether deer have color vision because, if they did not, there could be no special effect due to the color of the Swareflex reflectors. In an initial study (Zacks & Budde, 1983) we determined that the white-tailed deer has sufficient color vision to discriminate a band of long-wavelength light (which looks red to humans with normal color vision) from broad band illumination (which looks white to humans with normal color vision). This established the possibility that the color of the reflectors might be an important difference from those used previously. But it was not a direct test of the claim that the red reflectors would, because of their color, be frightening to the deer. Phase I of this project was designed to determine more about the basic color vision abilities of the white-tailed deer. The general goal was to determine whether there was any feature of their color vision which might be exploited in the design of a visual "repellent" system to keep them from the roadway in the presence of vehicles. Phase II of this project was designed to evaluate directly the assumption on which the design of Swareflex reflectors was based. Is red an innately frightening stimulus to the white-tailed deer? We examined the effects of red Swareflex reflectors on the movement of deer in a semi-natural setting.

The results of Phase I provide a description of the spectral sensitivity of a white-tailed deer. Under our test conditions the animal was sensitive to about the same range of wavelengths as two human observers tested under similar conditions. However this range may be shifted toward shorter wavelengths. No unique properties of her spectral sensitivity were uncovered which could be utilized to design a visual deterrent system which would keep deer off of the highways. Phase II provided no evidence that our white-tailed deer were innately afraid of red or responded to the presence of red Swareflex reflectors in any way.

PHASE I

An assessment of the spectral sensitivity of the white-tailed deer under light adapted conditions

One basic starting point in characterizing the color vision of an animal is to determine its spectral sensitivity (Jacobs, 1981). Spectral sensitivity is a measure of how effective light of different wavelengths is as a stimulus. The experiments of this phase of the project were designed to measure the spectral sensitivity of the white-tailed deer under the light-adapted conditions in which they had previously been shown to have some form of color vision. This would create the possibility of determining whether there is anything about their spectral sensitivity which might account for the effectiveness of red reflectors, if they are effective (although the report of Phase II, below, will show that they are not). Alternatively it might suggest other possibilities for capitalizing on some aspect of their color vision to design some other deterrent system.

MEASUREMENTS OF PHOTOPIC (LIGHT ADAPTED) SPECTRAL SENSITIVITY

The spectral sensitivity of a system is a measure of the efficiency with which it uses light of different wavelengths. To measure the spectral sensitivity of the visual system of a living organism we determine the amount of light required for the organism just to be able to see a test light and then repeat this measurement for test lights of a variety of different wavelengths. Many species have color vision under conditions of moderate to high illumination levels. When the light levels are very low there is not sufficient light to stimulate their cones. Instead they see with their rods, and have no color vision under those conditions. I chose to measure spectral sensitivity under conditions in which I knew the deer to have some kind of color vision. Thus I measured the ability of the deer to detect test stimuli against a white background of sufficient luminance so that humans would be seeing with their cones and not their rods. This was similar to the background level at which we had previously shown the deer to have color vision.

METHODS

THE BASIC PROCEDURE: The basic procedure for determining whether a deer could see the test stimulus was a simple variation of standard operant conditioning techniques. The deer were taught to lick on either of two tubes to receive water. The presence of water in either of the tubes was controlled by a remotely operated solenoid valve. About 19 inches beyond the lick tubes was a rear-projection screen, the front surface of which was illuminated by light from the room in which the deer was located. The test stimuli could be back-projected onto the screen directly in line with either of the two lick tubes. To measure the intensity required for the test stimuli to be just visible the deer were trained to lick on the tube behind which the test stimulus was projected. When the deer licked on the correct side they received a small amount of water on some of the licks on that side. The side on which the test stimulus appeared was changed randomly. I measured how accurately the deer restricted their licking to the tube on the same side on which the test stimulus was located. For each wavelength of the test stimulus I varied the intensity to find the intensity at which the animal could lick on the correct side just better than chance, and called that intensity the "threshold intensity".

APPARATUS: The basic experimental procedure was controlled by an Apple II microcomputer. It was interfaced to detect licks on either of two lick tubes and to control delivery of water to either of the tubes. In addition it was interfaced to a shutter, which turned the lights on and off, and a moveable vane, which determined whether an optical path to the right or left stimulus location was unblocked.

Each of the two lick tubes was mounted on a pivot so that licking on it caused the other end to push against a microswitch. In this way each lick could be detected by the computer. Solenoid valves in the water lines to each of the two lick tubes were controlled by the computer to deliver water reinforcement under program control.

An optical system (Fig. 1) was constructed using a tungsten-halogen source which was collimated, focussed on a shutter by a relay lens, recollimated, divided in two by a beam splitter cube, and directed at each of two locations on the rear projection screen by mirrors. Inconel-coated neutral density filters were used to control the stimulus luminances, and interference filters, placed in the collomated portion of the beam, controlled the spectral composition of the stimuli. The stimulus luminances were calibrated using a Pritchard photometer which was itself calibrated against a standard source. The interference filters were calibrated using a spectrophotometer to determine their spectral transmission properties. The luminances obtained when the interference filters were in the optical system were determined by measuring the stimulus spots in the apparatus with the Pritchard photometer, corrected to approximate the human photopic spectral sensitivity. These values were then corrected with the reciprocal of the human photopic spectral sensitivity in order to obtain the luminances of the stimuli.

The animals were housed in rooms with doors facing onto a hallway. The stimulus apparatus and the computer and control equipment could be wheeled up to an opening through the door that was normally covered by a removable panel. The lick tubes protruded through the opening, and the stimulus panel was visible at the end of an enclosure which occluded light except that which came through the opening in the door from the room in which the deer was located.

PROCEDURAL DETAILS: A daily session was divided into blocks of trials. Within a block the luminance of the stimulus was held constant. At the beginning of a block the experimenter positioned a neutral density filter to control the luminance of the test stimulus, (and, on trials with chromatic stimuli, an interference filter to control its wavelength). A trial began with the shutter closed, so that only the background field was visible to the deer. A moveable vane was positioned according to a random schedule so that the stimulus beam illuminated only one of the two sides. Then the shutter was opened. The computer established the number of correct licks required before another correct lick would be rewarded with a brief squirt of water. The criterion varied from a minimum of 2 to a maximum of 1Ø correct licks. Licks were then monitored. If the deer licked correctly the criterion number of times, it was rewarded and a new criterion was established. When water was delivered in response to a correct lick the shutter turned off the test stimulus, a brief squirt of water was delivered, and the stimulus was turned back on after a delay of 1 second. A trial continued for approximately 2.75 seconds, not including the time to deliver any reinforcements which were earned, and the brief time-out period following delivery of the water reinforcement. (NOTE: All timing was accomplished using loops in a BASIC computer program and was approximate.) At the end of a trial the shutter closed for Ø.8 seconds. During that time the computer again randomly determined the location of the test stimulus for the next trial, and the moveable vane was repositioned if a change in the stimulus location was called for. The shutter reopened, and the process was repeated for a total of 24 trials. The computer recorded the number of correct responses and errors separately for each side at the end of every 4 trials.

At the end of a block of 24 trials the filters were changed to set up the conditions for the next block, and then it was begun.

At the beginning of a session several blocks were run with a "control" stimulus, a stimulus sufficiently above threshold so that it is easily detected. Blocks of the control stimulus were repeated until the deer licked correctly at least 90% of the time. Then a test stimulus was chosen according to a pre-determined list of test stimuli which were in scrambled order. As a control for the possibility that the apparatus might be delivering non-visual cues that the deer might be responding to, trials were run occassionally with the light source totally occluded. Following each block of trials with a test stimulus a block of trials with the clearly visible control stimulus was run. It was repeated until the deer again licked correctly at least 90% of the time. Usually it was necessary to run only one block of trials with the control stimulus after a block of trials with the test stimulus. However occassionally, especially after a block of trials with a test stimulus which was very nearly not detectable, it took more than one block of control stimuli before the animal resumed performing accurately.

A session consisted of up to 66 blocks of trials, ending when the deer quit working or when it was no longer performing at the criterion level on the control blocks.

ANIMALS: One doe, born approximately in 1981, was used as the experimental subject. In prior research with the same animal and a second doe, thresholds for white and long wavelength lights were found to be very similar. Both animals were able to discriminate a mixture of long wavelengths from a broad spectrum light on the basis of the difference in the spectral compositions of the two lights (Zacks & Budde, 1983). Thus, although only one animal was studied, there is some reason to believe that the data obtained from this animal can be generalized to apply to at least some other deer.

CONTROL EXPERIMENT WITH HUMAN OBSERVERS: One obvious way to assess the data obtained from the white-tailed deer is to compare its performance to that of a normal human observer. In order to be able to do this two human observers, the author and another person with normal color vision, were used as subjects in the same apparatus. A very simple method of adjustment was used to obtain thresholds for detecting lights of the same wavelengths as were used with the deer. The human subject observed the stimulus in one of the two positions used for the deer, and told the experimenter whether or not it was visible. If it was visible additional neutral density filters were added to reduce the light intensity. If it was not visible neutral density filters were removed to increase the light intensity. In this way the amount of light required just to be able to see the stimulus was determined.

RESULTS

The raw data for any specific wavelength can be described by plotting the percent of correct licks as a function of the stimulus luminance. The data obtained using a peak wavelength of 535 nanometers are plotted that way for illustration in Fig. 2. The accuracy increased with increased stimulus luminance from a level at the lowest luminances which was near chance to a level at which the animal performed with stimuli which were readily detectable.

The "chance" level must be determined empirically because each lick is not an independent event. If the deer licks randomly from side to side until it receives a reinforcement it is quite likely that additional time will remain before the trial is finished and the stimulus location is randomly chosen again. Thus a strategy the deer might follow is to lick randomly until it receives a reinforcement and then to lick continuously where it was reinforced until the shutter-closing signals the end of a trial. At that point it can begin to lick randomly again until it receives another reinforcement. For these reasons the chance level of performance was not 50%, as would be the case if each lick were an independent choice by the deer. Because the chance performance level cannot be predicted on simple theoretical grounds, it was determined empirically by presenting trials on which no stimulus was present at all. Across sessions she licked correctly 58% of the time on these trials. This "chance" level remained stable across more than a year of data collection. A horizontal line has been drawn in Fig. 2 at this level.

The level of best performance was based on her discrimination on the blocks of control stimuli of higher-luminance, white stimuli which were interspersed between the blocks of test stimuli. Over many sessions she licked correctly on 95% of the trials with the control stimuli. This has also been shown as by a horizontal line in Fig. 2.

Under some conditions the sensitivity to stimuli differing in wavelength can reasonably be described by monotonically increasing functions which are simply translated laterally along the logarithmic luminance abscissa. The data from this experiment can be described well by such a function. A smooth ogive was fit by eye to the data. This curve was then used as a template and fit to the data for each wavelength by shifting it laterally until the best fit was obtained. The threshold luminance was then determined by interpolating to find the luminance at which detection would have been half way between chance and best performance, 76.5% correct. This definition of threshold is quite analogous to the 75% correct point which is usually used when chance is 50% and perfect performance 100%. The curve which was fit in this manner is also shown in Fig. 2 along with the means by which the threshold luminance was estimated. The reciprocal of this value was then plotted as a function of wavelength to obtain the spectral sensitivity curve.

After the initial data collection was completed, preliminary analysis of the data suggested that it would be useful to extend the range of wavelengths at which the animal was tested. Because of the lack of time and the lack of sufficient light intensity from the apparatus each wavelength was tested only at one intensity in this part of the experiment. Fitting the ogive to a single point was less reliable than fitting it to multiple points, as was done for the data obtained earlier. None-the-less the replications of three wavelengths using this revised procedure produced very close agreement, supporting the general validity of the measurements.

In Fig. 3 the data obtained from the initial data collection are shown. For each wavelength the template is shown in the position judged by eye to provide the best fit. The data appear to be fit well by the template at most wavelengths. From the location of the template the luminance which would have produced 76.5% correct performance was determined at each wavelength. This was also done by fitting the templates to the single points obtained in the second part of this experiment. These luminances have been plotted in Fig. 4. The thresholds based on the initial experiment are plotted as diamonds and those based on the less sensitive procedure are plotted as squares. The data from the two parts of the experiment seem to agree quite well, making it reasonable to combine them. The data are shown relative to a textbook description of the photopic spectral sensitivity of a human observer.

Fig. 5 displays data obtained from the two human observers using the same apparatus along with the idealized spectral sensitivity of a human observer for comparison. It can be seen that the human data obtained in this apparatus compare reasonably well with the textbook data, peaking in the same vicinity. To facilitate comparison of the deer and human data they have been plotted together in Fig. 6. Comparison of the data reveals two conspicuous differences. The first is that the sensitivity advantage of the humans is greater at the longer wavelengths that it is at the shorter wavelengths. In other words, the deer appears to be relatively more sensitive at the shorter wavelengths than the human subjects tested. The second difference is that at 560 nm, the humans were more sensitive than the deer, by about 0.6 log units, and were generally more sensitive than the deer.

Because of the inaccuracies associated with the data from the deer for the shorter wavelengths, it is hard to be certain whether the peak which is well-defined in the vicinity of 540-550 nm is the real peak, with the higher points below 500 nm being abberant, or whether there is a genuine peak at the short wave-length end of the spectrum. Because those points are based on less data than the points in the mid-spectrum, they must be viewed with some caution. The lack of sufficient intensity in the apparatus precluded obtaining more extensive data in that region.

Throughout the course of the experiment the test animal was presented with a range of wavelengths of light. Although no special data were gathered to assess any other aspects of the animal's reaction to the test stimuli, there were no obvious signs that the animal was unwilling to approach the apparatus when any particular wavelength was present. This was consistent with our earlier failure to observe a special response even to long wavelength stimuli (which look red to human observers) of the kind that are reflected by the Swareflex reflectors (Zacks & Budde, 1983).

DISCUSSION

Our prior research has shown that the white-tailed deer has some kind of color vision, sufficient to discriminate red from white (Zacks & Budde, 1983). This phase of the research was designed to begin to look further at some basic aspects of their color vision. In particular it was designed to look for any unusual feature of their vision which might be exploited to keep them off of the roadways. The results suggest that there is a peak in the spectral sensitivity of the white-tailed deer in the area of 540-550 nm, and that there may be another, even higher peak below 500 nm, although the data in that area are less reliable. Whatever the exact shape of the spectral sensitivity curve it appears that in general the deer are relatively more sensitive toward the short wavelengths than are humans, and that they are relatively less sensitive toward the longer wavelengths, the wavelengths which are reflected by the Swareflex reflectors. Although there are suggestions of differences between the spectral sensitivity of the white-tailed deer and humans, there was nothing in the data which suggested an obvious feature on which we might capitalize in the design of a visual deterrent.

This phase of the research was conducted using a single animal. It is appropriate to consider whether results from a single animal can be generalized to the entire species. Caution is certainly urged. Although in our earlier research the animal which was tested in this experiment performed very nearly the same as a second doe which we tested, it is clearly possible that other individuals might be different. There are significant individual differences in human color vision, as well as in some other species (Jacobs, 1981).

PHASE II

An evaluation of Swareflex Wildlife Reflectors as frightening stimuli to the white-tailed deer

This phase of the research attempted to test the claim that red, Swareflex reflectors are inherently frightening to deer, and because of this will deter deer from crossing illuminated highways at night. In this experiment a line of red reflectors was illuminated similar to the way they would be illuminated if placed on the edge of a highway in the headlights of an approaching vehicle. The behavior of ten deer was monitored in order to determine whether the presence of the illuminated red reflectors prevented them from crossing the line of reflectors. The experiment provides no evidence that the white-tailed deer we used in this test respond any differently to the presence of red Swareflex reflectors in a stationary headlight beam in a pen situation than they do to white reflectors of the same geometry, or to the headlight beam with no reflectors. Because of this I will reject the claim that the white-tailed deer is inherently afraid of red. Then I will discuss the other attempts to evaluate the effectiveness of the reflector system in the face of my failure to find deer to be innately afraid of red light from these reflectors. I will argue that some reports of a reduction in number of deer killed in a real highway installation, while probably a real effect, are more likely due to some other factor, such as an increase in driver attentiveness, than to 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 because they are innately afraid of "red" light. The claim was evaluated under conditions which in some ways approximated those in which the reflectors might actually be utilized, although they differed significantly in a number of ways from a typical highway situation. These differences include the fact that the headlights were not moving, the reflectors were illuminated steadily for 15 minutes at a time, there was no vehicle noise associated with the headlights, there was no actual road, the interior of the pen was only a semi-natural environment, and the deer were pen-raised animals. However, I will argue that there is no reason to expect any of these factors to overcome the claimed innate fear of red.

A group of ten white-tailed deer were housed in a large pen. They were encouraged to move about in the area where the reflector barrier was set up by providing the primary sources of water in different locations within that area. Movement of the deer across a line defined by five sign posts was monitored under three different conditions. Either red Swareflex reflectors, otherwise 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 are frightening to the deer they would be expected to cross the illuminated reflector barrier less than when no reflectors are present. White reflectors were also used as a control condition to evaluate further the claim that an inherent fear of red is what makes the reflectors effective, rather than some other feature.

METHODS

ANIMALS AND THE SITE: Ten white-tailed deer were housed in a 1.4 hectare pen (Fig.7). The fenced area was an old field grassland community which had been part of a former cattle ranch. It has undergone 25 to 30 years of succession. About five years prior to the study there was an underplanting of red pine. At one end of the pen there was a clump of jack pine. The surrounding area, of which the penned area is representative, supports from 8-12 deer per square kilometer in the fall.

Three yearling bucks and 7 yearling does were chosen to approximate the ratio of males to females in the Michigan deer herd during the fall, prior to 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. These animals are best described as wild deer which have adjusted to a range pen situation. They have learned to avoid running into a woven wire fence, to obtain water from buckets and to obtain food from feeders. However they are otherwise indistinguishable from wild deer. They are described by a Wildlife Biologist (Richard Earle, Michigan Dept. of Natural Resources, personal communication) as tolerant of the pen situation rather than tamed. The deer were released into the pen on July 11, 1984, and final data collection was between August 20, 1984 and October 6, 1984. They were fed a commercially-prepared exotic game feed which was continuously available from a hog feeder. It was refilled as needed. Water was available from two waterers separated by about 46 meters (See Fig.7.). 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 quarts 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. In order 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 which was flushed into the pans drained out in about one and one half minutes 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 in the course of the experiment, as described below.

EXERIMENTAL PROCEDURE: Five sign posts were installed in a straight row across the pen and between the two waterers. (See Fig.7.) They were spaced at intervals of 20 meters as recommended by the manufacturers of the reflectors. A bolt was installed on each post 107 centimeters above the ground. A reflector could be quickly installed or removed from the bolt. The terrain which was crossed by the reflector row was nearly flat, the difference between the heights of the highest and lowest posts being only 36 centimeters. At one end of the line of reflectors a pair of automobile headlamps (Westinghouse no. 4651) was mounted in a position that mimicked their location if they were actually installed in a vehicle that was driving down a road; the nearest headlamp was about six feet 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. We recorded a crossing at the time that more than 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. Similarly they also tended to walk up to the posts and lick them, sticking their head up to or across the line but often not crossing with the rest of their body. The most important fact is that the criterion 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 driving under those conditions would have their headlights on. The passage of cars and trucks on a road which passed the pen was monitored in order 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 minutes, every time that a deer crossed the line, the crossing (and its direction) were recorded. At the end of the first 5 minutes the waterer to the north of the line was operated once, loudly spilling about 3 liters of water into the pan. At the end of the second 5 minutes the waterer to the south of the line was operated. At the end of the next 5 minutes (total of 15 minutes) the headlights were extinguished. 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 minutes to make the change. Five minutes after having turned the headlights off they were turned back on, with the new reflector condition installed, and the procedure was repeated. The deer were observed for 15 minutes, with each waterer operated once during this interval as in the first interval. Then the lights were extinguished and the reflectors were changed again. After the third reflector condition was installed a final 15 minute observation interval was repeated. (See Fig. 8.) (Early in the experiment several cycles were run each night, repeating the same pattern of alternation between 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 upon the data from the first cycle through the three reflector conditions on any evening, except for one evening. On that occasion, because the deer were very active, two orders were run.) 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 sign-post line by an animal. In addition a log was kept noting the crossings, whether the animals were running, walking, grazing, etc. Any other salient events were noted. We were particularly careful to note the responses of the animals when the lights were first turned on, especially early in the experiment, in order to note 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 which might not have been captured by the crossing data.

RESULTS

THE MAIN EFFECT OF VARYING THE REFLECTORS: The principal question is whether or not the deer cross the reflector barrier less often when red Swareflex reflectors are installed than when there are either white reflectors or no reflectors at all. Of the total of 720 crossings which were observed in 18 sessions, the deer crossed 264 times when no reflectors were installed, 256 when red reflectors were installed, and 200 times when white reflectors were installed. (See Fig. 9.) 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 reducing 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 the deer's behavior, but the experimenters were especially alert for any other behavioral indications of whether or not 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 behavioral descriptions of the deer concur with the quantitative measure of their behavior in failing to reveal 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 approaching from the side to which the light was reflected would be deterred from crossing. In effect, as set up the reflectors were not a bi-directional barrier, but rather 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 1Ø. shows the data separated on the basis of the direction of movement through the barrier.

ORDER EFFECTS ON TRIALS WITHIN A SESSION: There are several additional aspects of the data which 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 1-3 hours. 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 Fig. 11, 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, $F(2,34)=5.84$, $p<.Ø1$). 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.

VARIATIONS IN THE NUMBER OF CROSSINGS PER SESSION: There was considerable variation in the number of crossing observed per session. Data from 3 out of a total of 21 sessions were discarded because we failed 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 as the experiment went on, but the effect was small compared to the overall day-to-day variability. The session-to-session variability in overall responding is shown in Fig. 12.

DISCUSSION

Within the context of this study the results fail to reveal any effect of red Swareflex reflectors in keeping the deer from crossing a boundary defined by a row of reflectors. We also failed to observe any other gross changes in their behavior in the presence of the red reflectors. The assumption that red was inherently frightening to the deer was the basis for using the reflectors alongside highways. This study provides no basis for expecting the reflectors to be effective under highway conditions.

There are several limitations to this experiment. First I will address issues related to the primary question of the research; namely, whether the white-tailed deer exhibits any "fear" of red, Swareflex reflectors.

In the experiment a limited number of deer (10) were tested repeatedly. The question arises as to whether they might have adapted to the conditions of the experiment and learned to ignore the reflectors. Nothing in the data supports this possibility. Even the first time that the red reflectors were presented there was no indication in the deer's behavior to suggest an avoidance response to the red reflectors. In addition the analyses of the crossing data give no indication of an effect of the reflectors in the early part of the experiment that disappeared as the experiment went on. Finally, responses which are described to be "innate" are behaviors which are genetically programmed to be "released" by specific stimuli, and which are very resistant to modification.

As the deer in this research were pen-reared it is possible that their behavior might not be completely representative of deer in the wild. The observations of the wildlife biologists who have worked with deer at this facility suggest otherwise. They believe that the effects of pen rearing are limited to circumscribed aspects of their behavior relating to their responses to the fence, waterers and feeders. (Richard Earle, Wildlife Biologist, Michigan Department of Natural Resources, personal communication.) Otherwise it is felt that their behavior does not differ significantly from that of completely wild deer. In other words it appears that the rearing conditions should not have influenced the deer's response to the reflectors.

In designing this experiment an attempt was made to incorporate some features of a typical highway installation of the reflectors. However there are several differences between the experimental situation and a highway situation. It is helpful to consider the extent to which these differences might limit out ability to generalize the results. In this consideration it is important to remember that the relevant question is whether the failure to observe the deer to exhibit a fear of red can be generalized from the experiment to highway conditions.

In this experiment the reflectors were illuminated by headlights positioned next to the reflectors as they might be on the highway. However, unlike on the highway the headlights were stationary, remaining on in the same place for fifteen minutes at a time. Although casual observation of deer suggests that they are very responsive to movement, it is unclear whether one would expect movement to enhance their responsiveness to red. It is impossible to determine that from this experiment. The setting was also different from a highway in that there was no clearly distinguishable roadway. It is unclear what effect this might have had. However, there is no theoretical reason to expect this to alter an innate fear.

The basic conclusion of this research is that white-tailed deer do not respond to the presence of red reflectors under the conditions of the experiment. Although the conditions differed from those along a typical highway the experiment provided no reason to expect the reflectors to work in a typical highway setting. For that reason it is interesting to examine the research which has been done in highway settings. The recent study by Shafer, Penland & Carr (1985) is especially interesting. They have installed red Swareflex reflectors on several stretches, totalling 3.7 kilometers, along SR 395 in the State of Washington. They have alternately covered and uncovered the reflectors for successive time intervals (one week intervals initially, and two week intervals subsequently). From a total of 58 deer killed at night in the test section since the beginning of the test in 1981, fifty two were killed when the reflectors were covered and 6 were killed with the reflectors uncovered. These results suggest that the reflectors are effective as installed on that highway.

However, another experiment, similar to that of Shafer et al, is underway in Colorado (Dale Reed, Wildlife Researcher, Colorado Division of Wildlife, personal communication). 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). This contrasts to Shafer et al, who observed a ratio of more than 8 to 1.

The fact that these apparently similar experiments appear to be yielding quite different results raises questions about the possible differences between the two situations. It is possible that the deer in these two different geographical locations respond differently to the reflectors. However there is an alternative explanation.

In both of the highway studies Swareflex reflectors were installed on both sides of a highway at intervals of 20 meters on the straightaways and 10 meters 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 at approximately 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 from the side of the road. The manufacturer suggests in their advertising literature that the reflectors are "unnoticeable to the driver", showing in their illustrations 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 this was inaccurate. The color of the reflectors which 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. Photographs taken from this position also clearly reveal the color of the reflectors. Thus a driver entering a stretch of highway on which the reflector system is installed views a corridor of red reflectors receding into the distance. In the study by Schafer et al this meant that, as they covered and uncovered the reflectors, they were changing more than the conditions which the deer faced. They were also changing the conditions which the drivers faced. Because signing of a roadway with red markers on both sides of the road is quite unusual, and reserved for areas of extreme danger (such as proceeding the wrong way on a divided highway), it would seem quite plausible that the drivers might respond with increased alertness. Conventional signing for areas with high rates of car-deer accidents usually involves putting a small number of signs (often only one) warning of a deer crossing area. In Shafer et al's study the warning "signs" are repeated every 20 meters (closer on curves) over the area which they protect. For this reason it is ambiguous whether the behavior of the deer or the behavior of the drivers was manipulated when the reflectors were covered and uncovered. It is plausible that the difference between the two highway studies described above has to do with differences between the populations of drivers and their responses to the reflectors rather than differences in responses of the deer to the reflectors. Perhaps there are significant differences in the extent to which drivers are familiar with these stretches of highway in the two studies, and therefore the extent to which the reflectors are novel and attention-getting.

Combining the disparity of findings in the highway studies with the results of this investigation of the responsiveness of deer to red suggests a possible reconciliation of all of the data. Perhaps Swareflex reflectors do not deter the deer from moving onto the roadway, but, under some conditions, they cause drivers to be more alert.

FUTURE RESEARCH

Additional experiments would make it possible to evaluate this interpretation. One approach would be to observe directly the behavior of the drivers under the two conditions (reflectors covered or uncovered). For example speeds could be monitored under those conditions, using an unobtrusive measurement system so as to be sure not to have an additional affect on the drivers. Ideally these measurements could be made in collaboration with the ongoing projects of Schafer et al and Reed and his coworkers so that their previous data would be relevant as a baseline for vehicle-deer accident rates under those conditions.

If there is an effect on vehicle speeds then the question would be answered unambiguously. On the other hand, it is possible that drivers might be more alert but that the additional alertness would not show up as a decrease in vehicle speed. If that were the case then some other procedure for evaluating alertness might be called for. For example, driver behavior might be monitored when a stuffed deer was placed on the side of the road, looking like it might possibly be moving onto the road. If drivers are more alert when the reflectors are uncovered, then the presence of the stuffed deer might reveal a difference in driver behavior that was not apparent from monitoring vehicle speeds in the absence of a deer.

If studies such as these reveal that the reflectors have had an effect on driver alertness then it would become important to consider the most effective means of selectively increasing driver alertness in areas of high risk of vehicle-deer collisions. Swareflex reflectors were special only in their alleged influence on the behavior of the deer. Very different considerations would apply to the effects on drivers.

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FIGURE CAPTIONS

FIGURE 1. Instrumentation Diagrams.

A. Light from a tungsten-halogen source (GE Q6.6A/T2 1/2/CL) was collimated by lens 1. Interference filters, when used, were placed in the collimated portion of the beam. Lens 2 focussed the beam onto a shutter. Neutral density filters controlled the luminance of the beam. Lens 3 recollimated the beam. A beam-splitting cube divided the beam, diverting one path to a front-surface mirror which in turn redirected the beam to one side of the rear-projection screen. The beam which passed straight through the cube was diverted to the side by a second front-surface mirror, and redirected toward the rear-projection screen by a third front-surface mirror. A motor-controlled vane, positioned just at the rear-projection screen, controlled the side of the screen which was illuminated.

The inset shows the animal's view of the stimulus display.

B. The block diagram illustrates the devices which could be controlled by the computer as well as the information which could be monitored by the computer.

FIGURE 2. An Illustration of the Curve-fitting Procedure Used to Estimate the Threshold Luminance.

The percentage of correct licks at each luminance (on an arbitrary scale) has been plotted (+) along with a template curve which was drawn to provide a good fit to most of the data and fit by eye to each set of data. The curve is asymptotic at a "chance" level which was estimated by determining how well the deer could do with the lights off, and a "best performance" level which was estimated by determining how well the deer could do with stimuli well above threshold. The dotted line illustrates how the luminance which would produce a performance of 76.5% correct, half way between the "chance" and "best performance" levels, was determined. The data shown here were obtained with a stimulus of 535 nm.

FIGURE 3. Psychophysical Functions for Each Wavelength Tested with Templates Fit by Eye.

Note that the template fits quite well at most wavelengths.

FIGURE 4. Spectral Sensitivity of the Deer.

The relative spectral sensivity of the deer is plotted with the sensitivity at the wavelength to which the deer was most sensitive arbitrarily set at one. A human, photopic spectral sensitivity curve has also been drawn with its peak normalized at one for comparison. Data which were derived from templates fit to several points are represented by diamonds. Those based on fitting the template to a single point are represented by rectangles.

FIGURE 5. Spectral Sensitivity of Two Human Subjects as Measured Using the Same Equipment.

The relative spectral sensitivity of two human observers is plotted on the same coordinates used to plot the results with the deer. A human, photopic spectral sensitivity curve has also been drawn similarly for comparison. Although there are discrepancies, the overall shapes agree well given the limits of the accuracy of the psychophysical method used to gather these data. Data from observer JZ are shown by X's. Data from observer DI are shown by +'s.

FIGURE 6. The Deer and Human Data Plotted Together.

The data of Figs. 4 and 5 have been combined. The same symbols have been used.

FIGURE 7. A Map of the Pen.

Five reflectors were arranged in a line at 66 foot (20 meter) intervals across the pen. To the N and S of the line were two remotely operated waterers. At the W end of the row of reflectors a pair of headlights was aimed parallel to the row. The experimenter sat directly behind the headlights and just outside of the pen.

FIGURE 8. Diagram of the Time Course of a Session.

For each reflector conditions (none, white, red) the reflectors were installed (or removed) and then the headlights were turned on for 15 minutes. At 5 and 10 minutes after turning on the headlights the N and S waterers respectively were " flushed". After 15 minutes the headlights were turned off and the next reflector condition called for by the random order was set up. The cycle was repeated so that 3 conditions were run in a 55 minute session.

FIGURE 9. Total Crossings in Each Session for Each Reflector Condition.

There is no statistically significant effect of varying the reflector condition. The only apparent (but non-significant) trend was for there to be fewer crossings in the presence of the white reflectors.

FIGURE 10. Total Crossings in Each Session Plotted Separately for N to S and S to N with Red Reflectors.

Because the red reflectors were oriented to be viewed from the S, they would be expected to deter S to N crossings more than N to S crossings. There is no statistically significant effect of the red reflectors on crossings in either direction.

FIGURE 11. Total Crossings in Each Session Arranged in the Order in which They Were Run.

The deer were generally more active at the beginning of the session than at the end. The number of crossings decreased significantly across the three conditions of the session.

FIGURE 12. Total Crossings In Each Session Summed Across Reflector Conditions.

There was considerable variability from session-to-session in the number of crossings recorded.

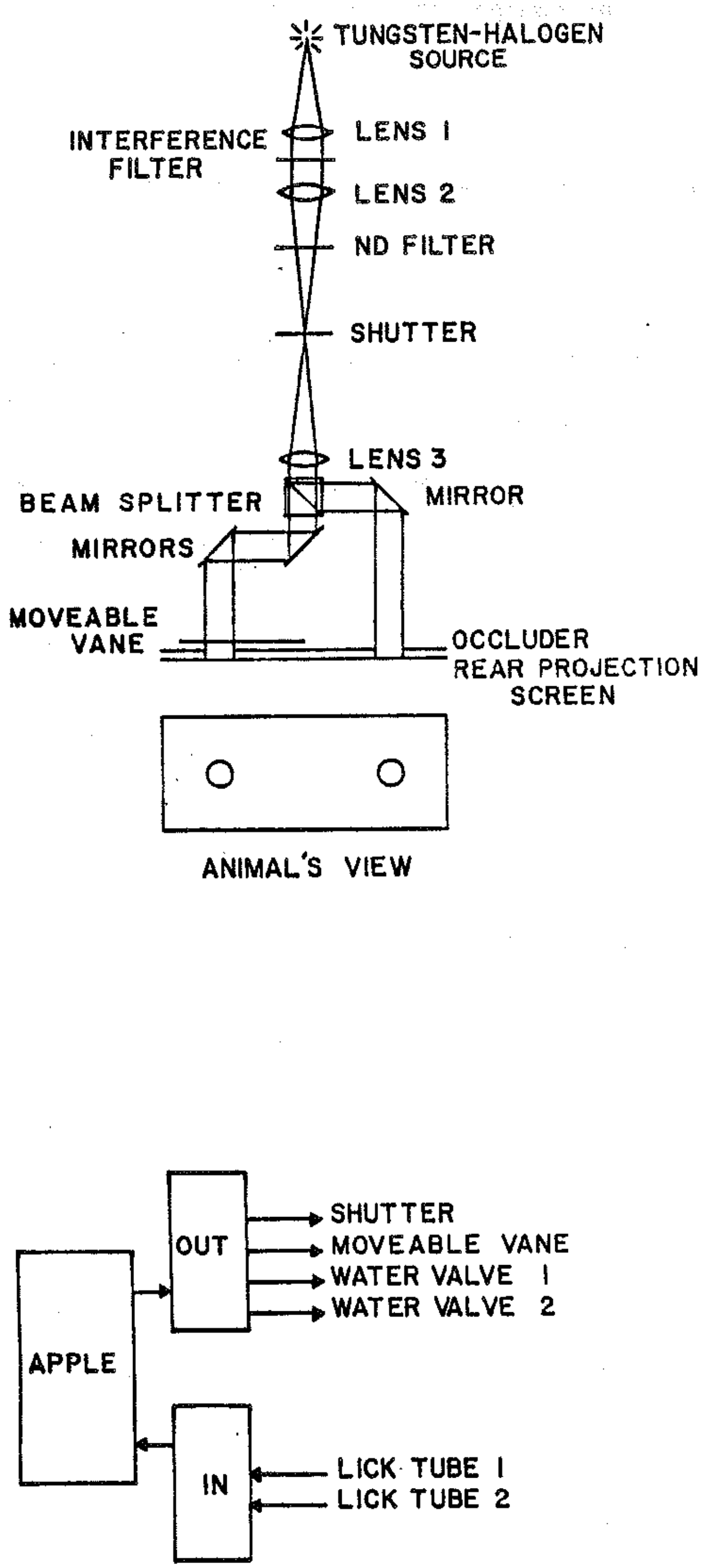
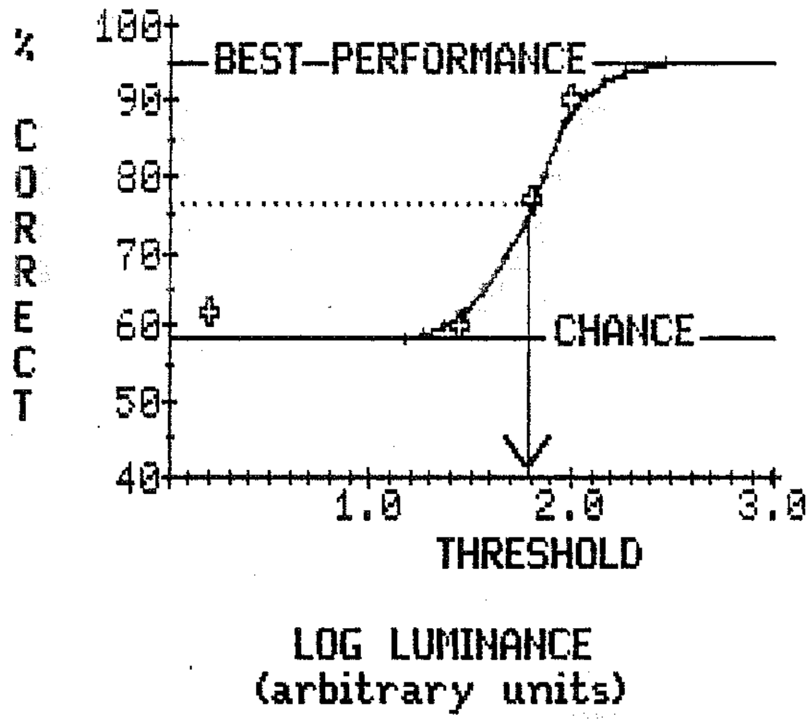

TUNGSTEN-HALOGEN SOURCE
INTERFERENCE FILTER
LENS 1
LENS 2
ND FILTER
SHUTTER
LENS 3
BEAM SPLITTER
MIRROR
MIRRORS
MOVEABLE VANE
OCCLUDER
REAR PROJECTION SCREEN
ANIMAL'S VIEW
APPLE
OUT
SHUTTER
MOVEABLE VANE
WATER VALVE 1
WATER VALVE 2
IN
LICK TUBE 1
LICK TUBE 2

Figure 1.



% CORRECT
100
90
80
70
60
50
40
BEST—PERFORMANCE
CHANCE
1.0
2.0
3.0
THRESHOLD
LOG LUMINANCE
(arbitrary units)

Figure 2.

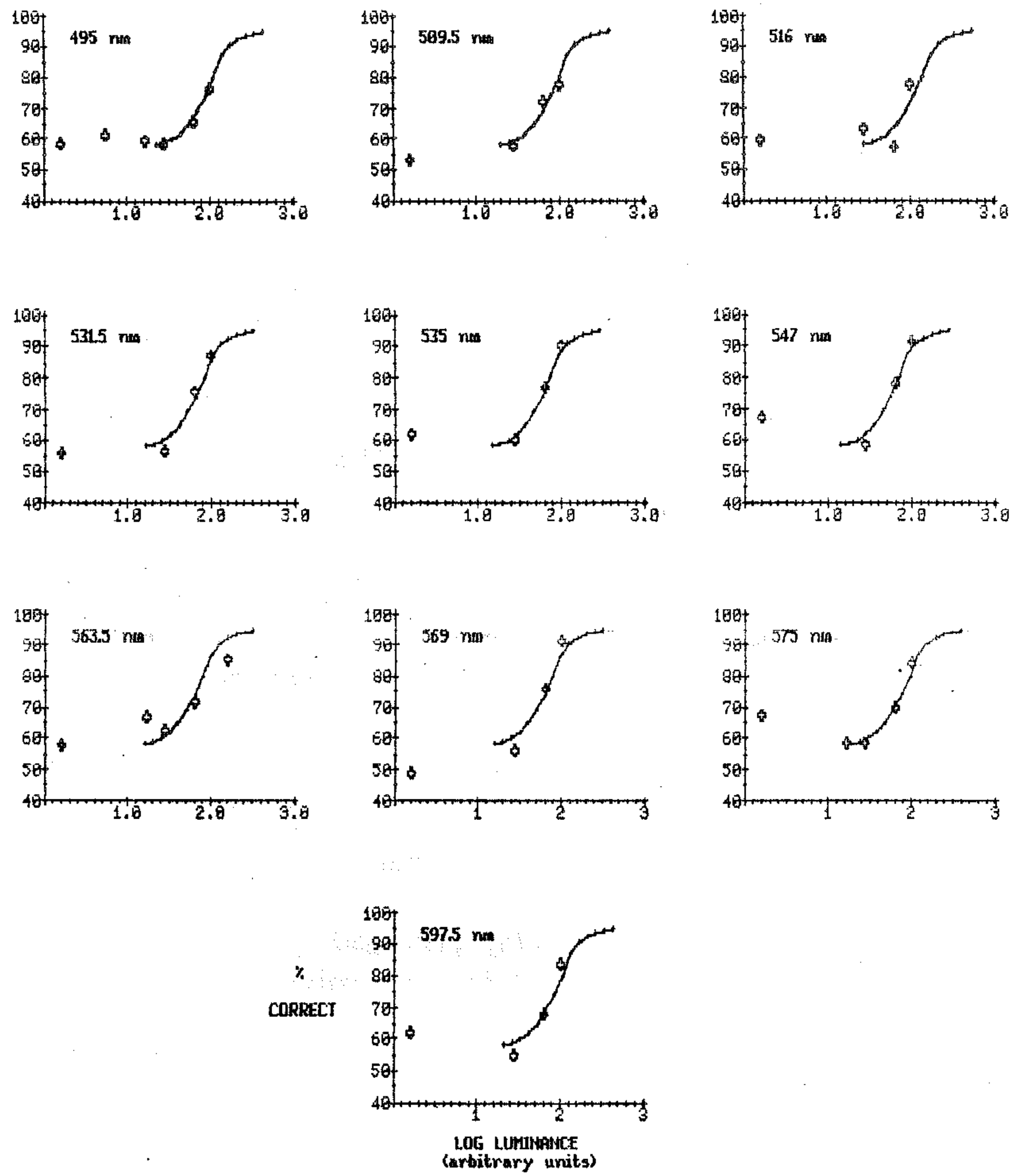

495 nm
509.5 nm
516 nm
531.5 nm
535 nm
547 nm
563.5 nm
569 nm
575 nm
597.5 nm
% CORRECT
LOG LUMINANCE
(arbitrary units)

Figure 3.

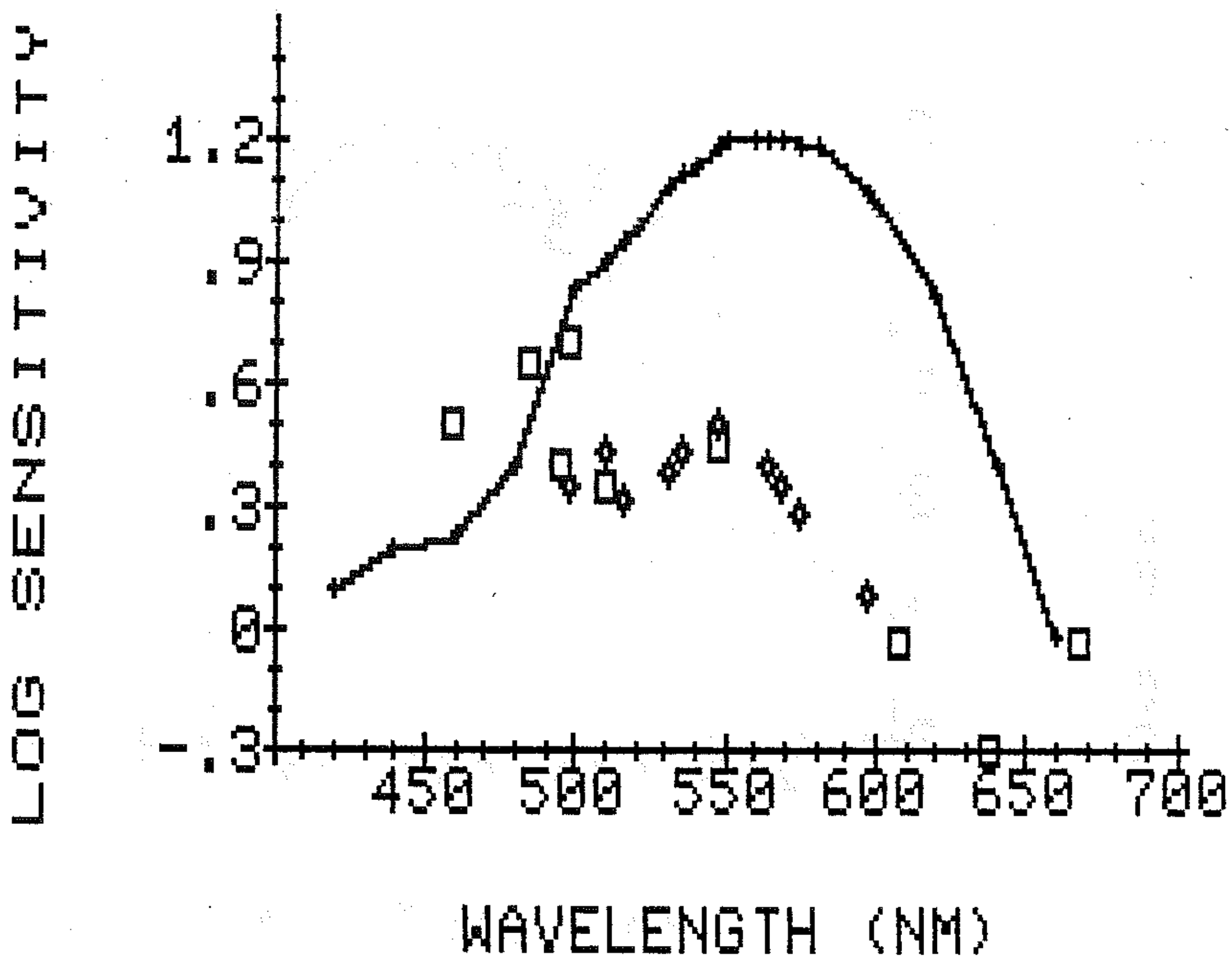

LOG SENSITIVITY
1.2
.9
.6
.3
0
-.3
450
500
550
600
650
700
WAVELENGTH (NM)

Figure 4.

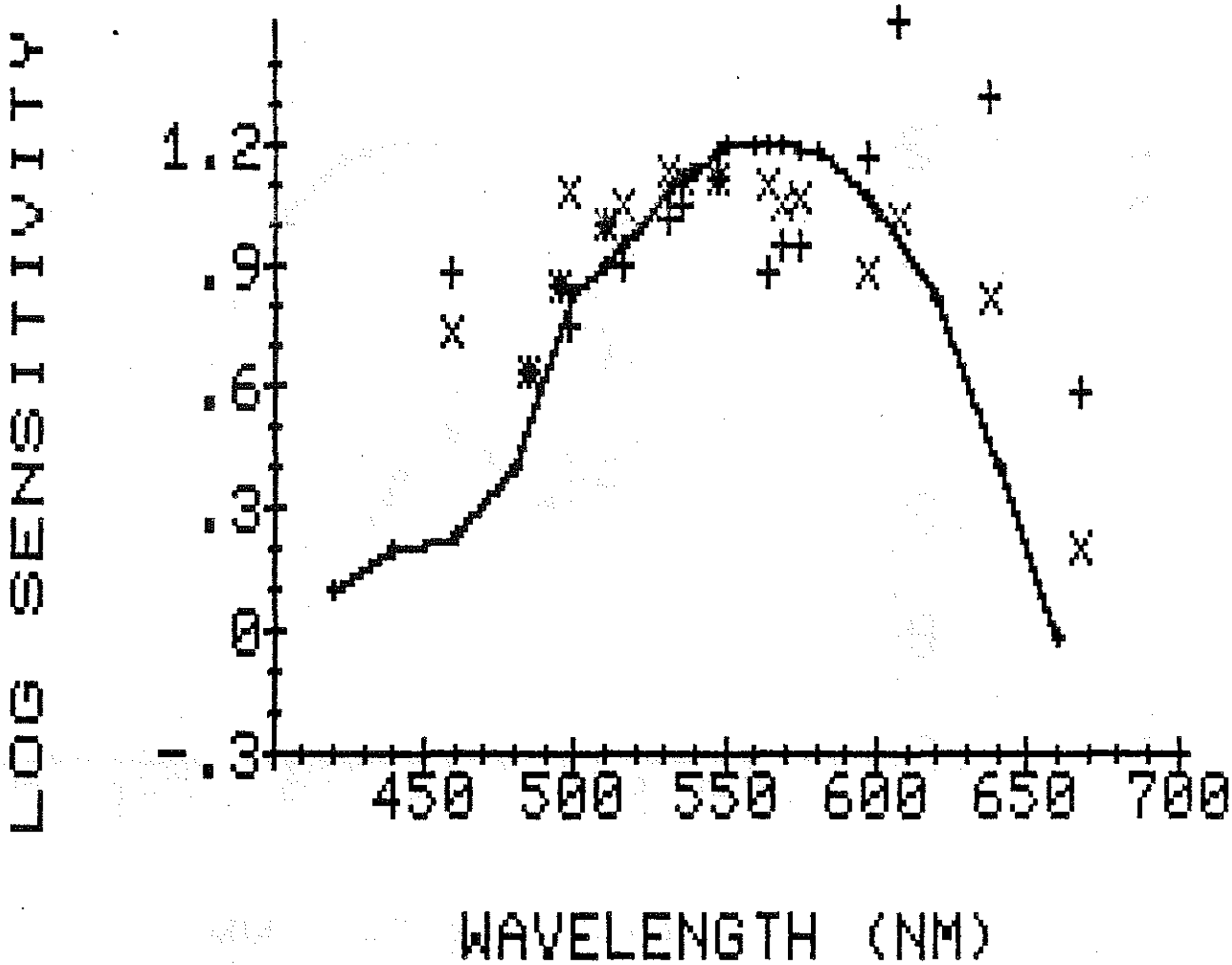

LOG SENSITIVITY
1.2
.9
.6
.3
0
-.3
450
500
550
600
650
700
WAVELENGTH (NM)

Figure 5.

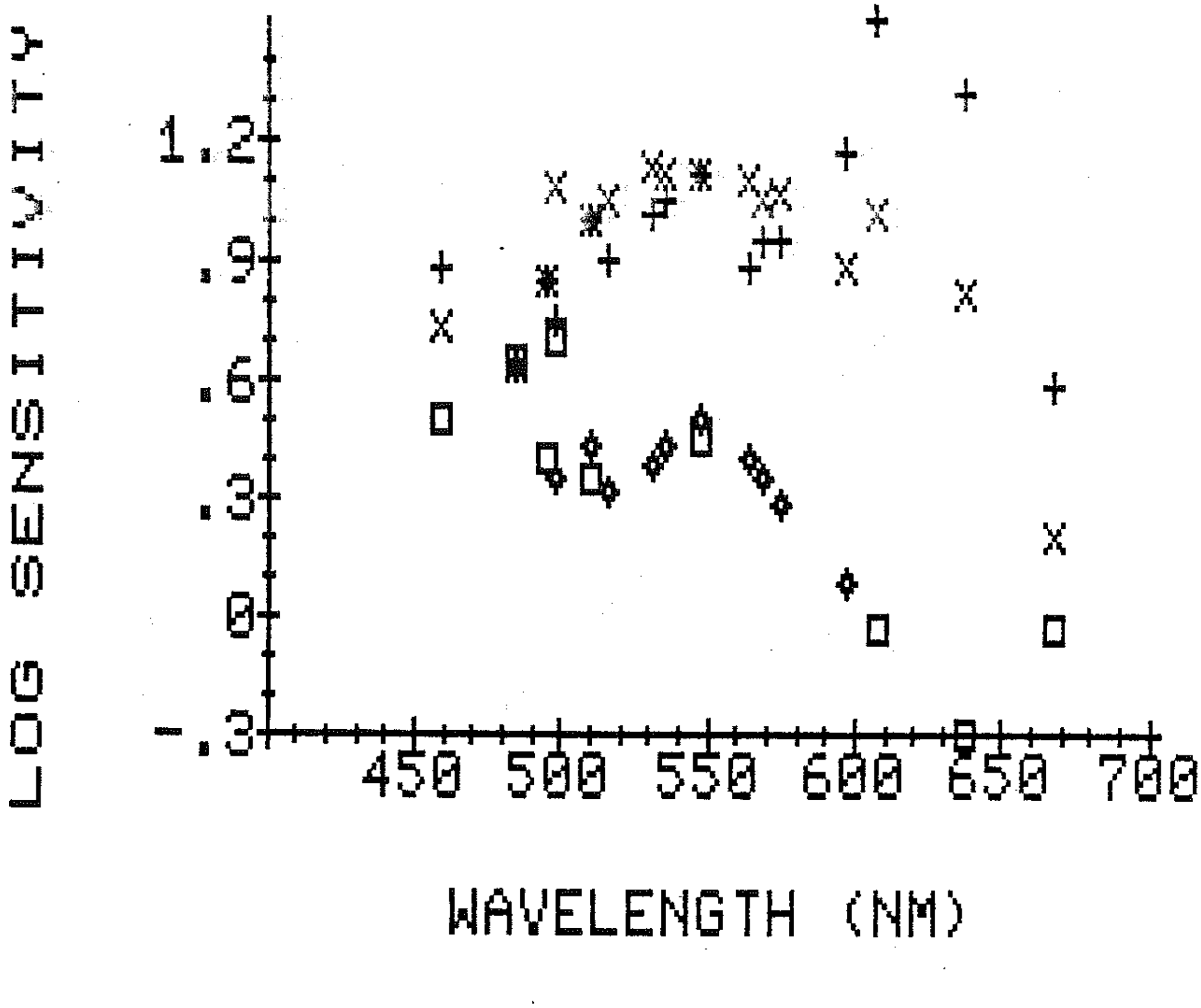

LOG SENSITIVITY
1.2
.9
.6
.3
0
-.3
450
500
550
600
650
700
WAVELENGTH (NM)

Figure 6.

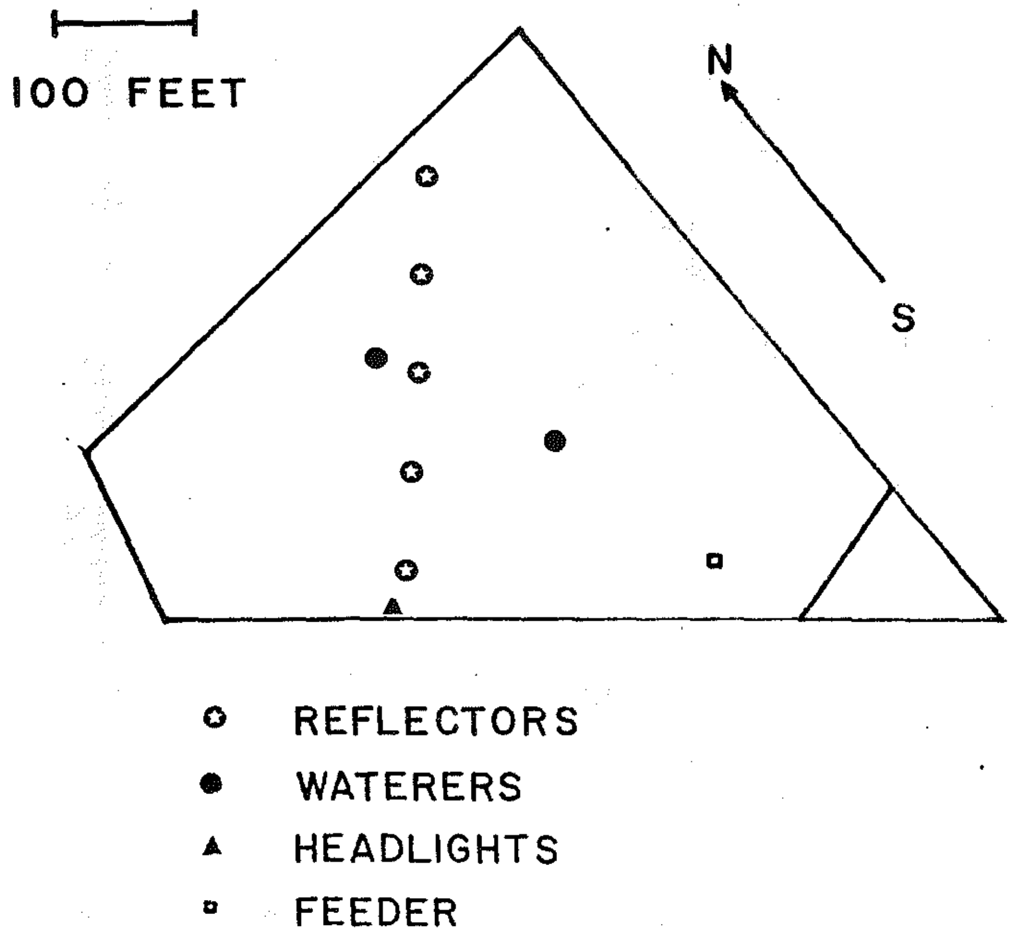


Figure 7.

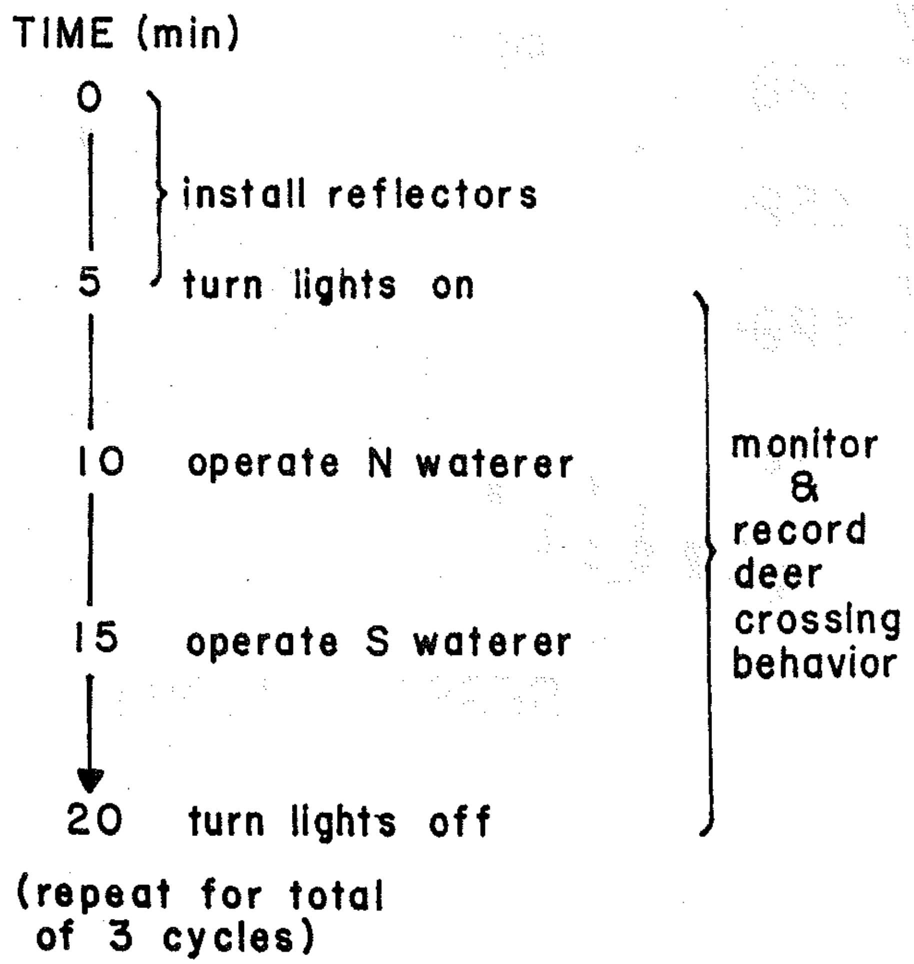
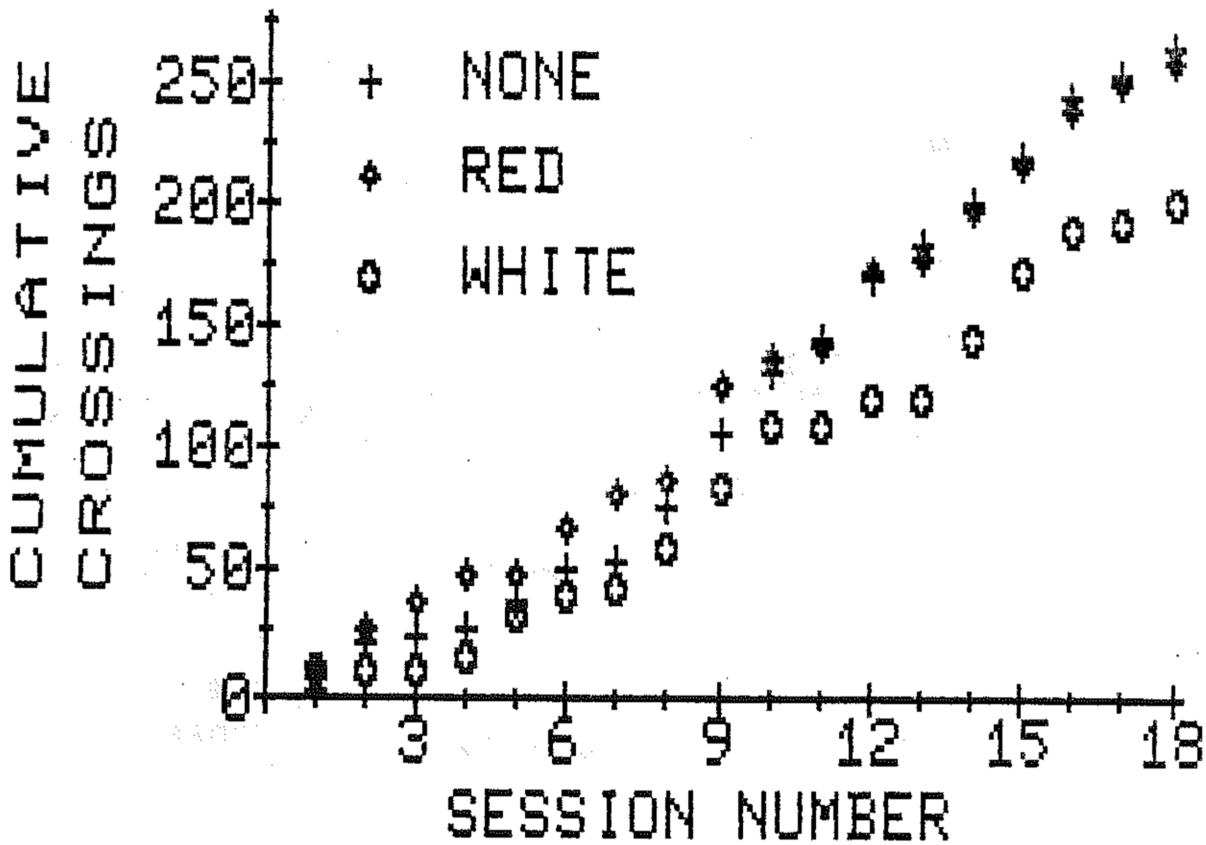
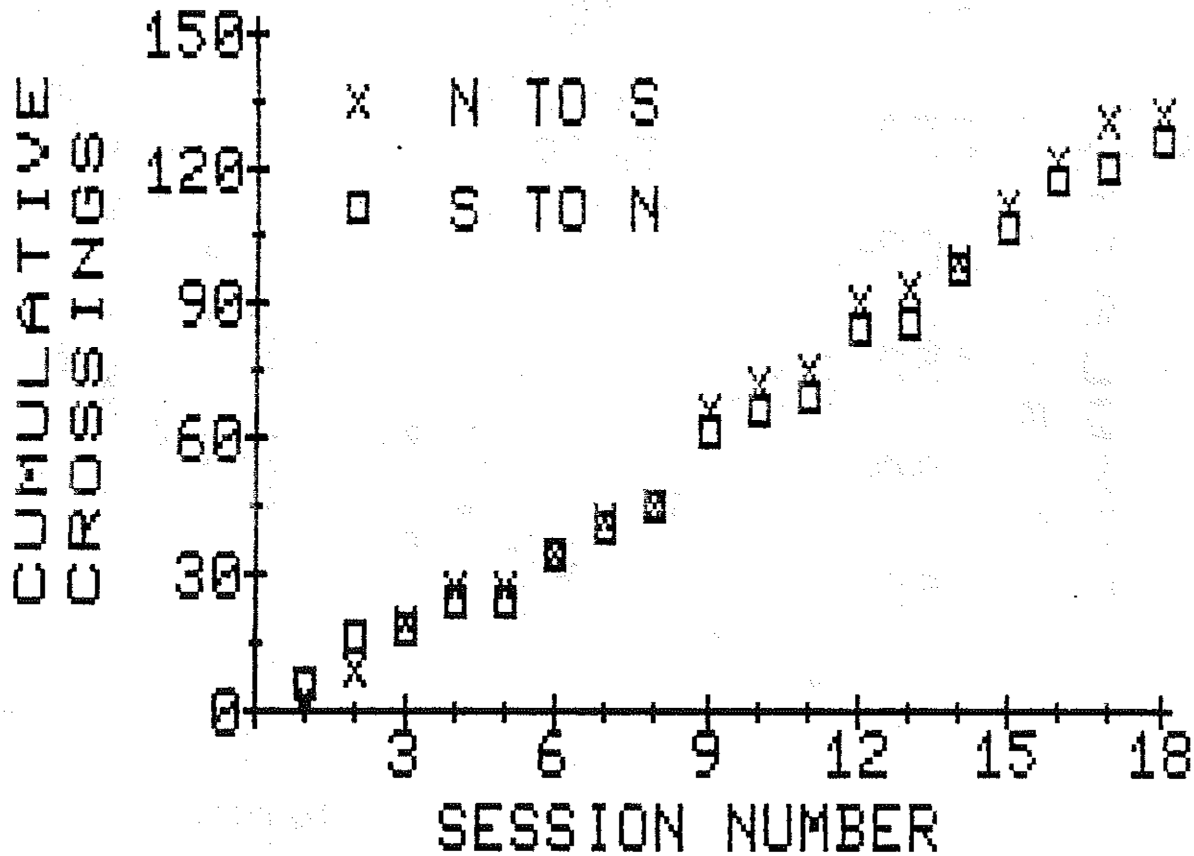

TIME (min)
0
install reflectors
5
turn lights on
10
operate N waterer
15
operate S waterer
20
turn lights off
(repeat for total of 3 cycles)
monitor & record deer crossing behavior

Figure 8.



CUMULATIVE CROSSINGS
250
200
150
100
50
0
+ NONE
RED
WHITE
3
6
9
12
15
18
SESSION NUMBER

Figure 9.



150
120
90
60
30
0
CUMULATIVE CROSSINGS
x N TO S
□ S TO N
3
6
9
12
15
18
SESSION NUMBER

Figure 10.

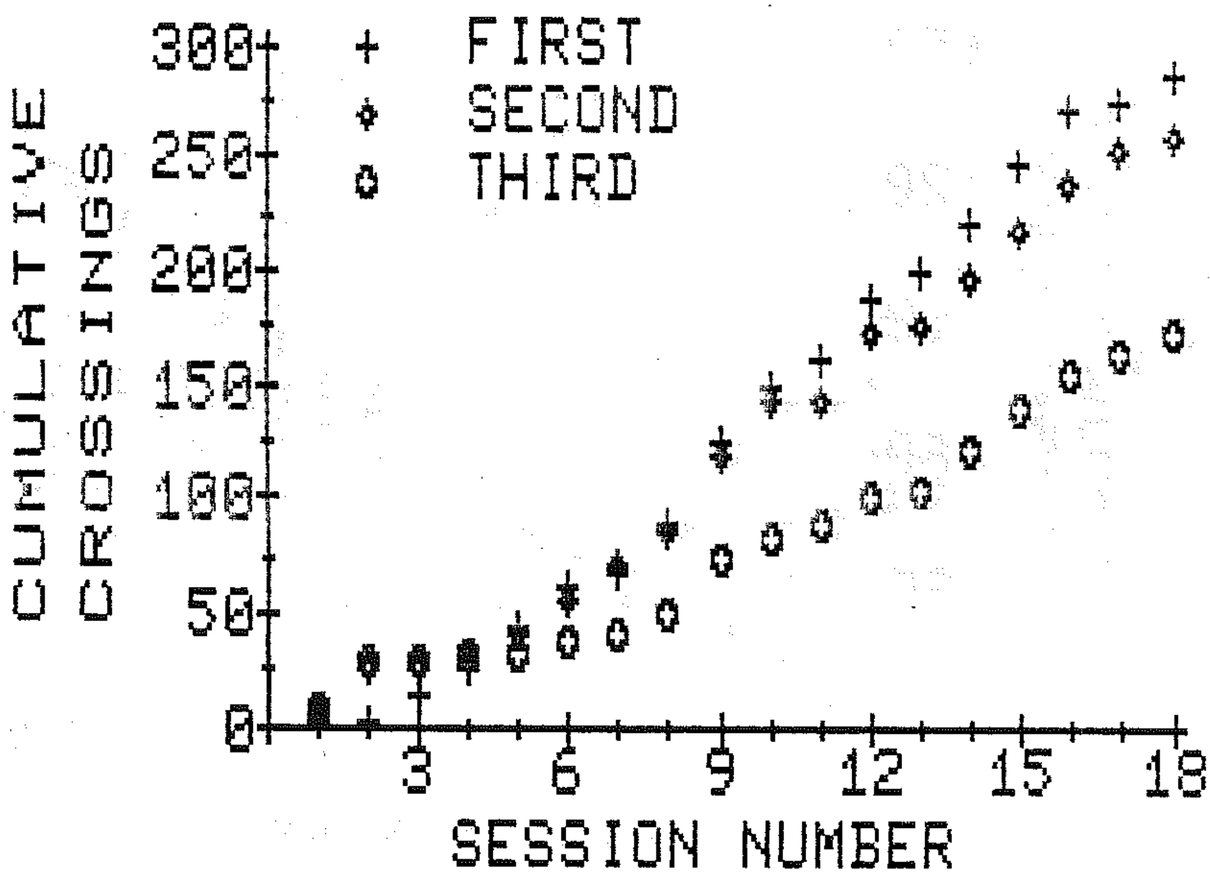

CUMULATIVE CROSSINGS
300
250
200
150
100
50
0
+ FIRST
SECOND
THIRD
3
6
9
12
15
18
SESSION NUMBER

Figure 11.

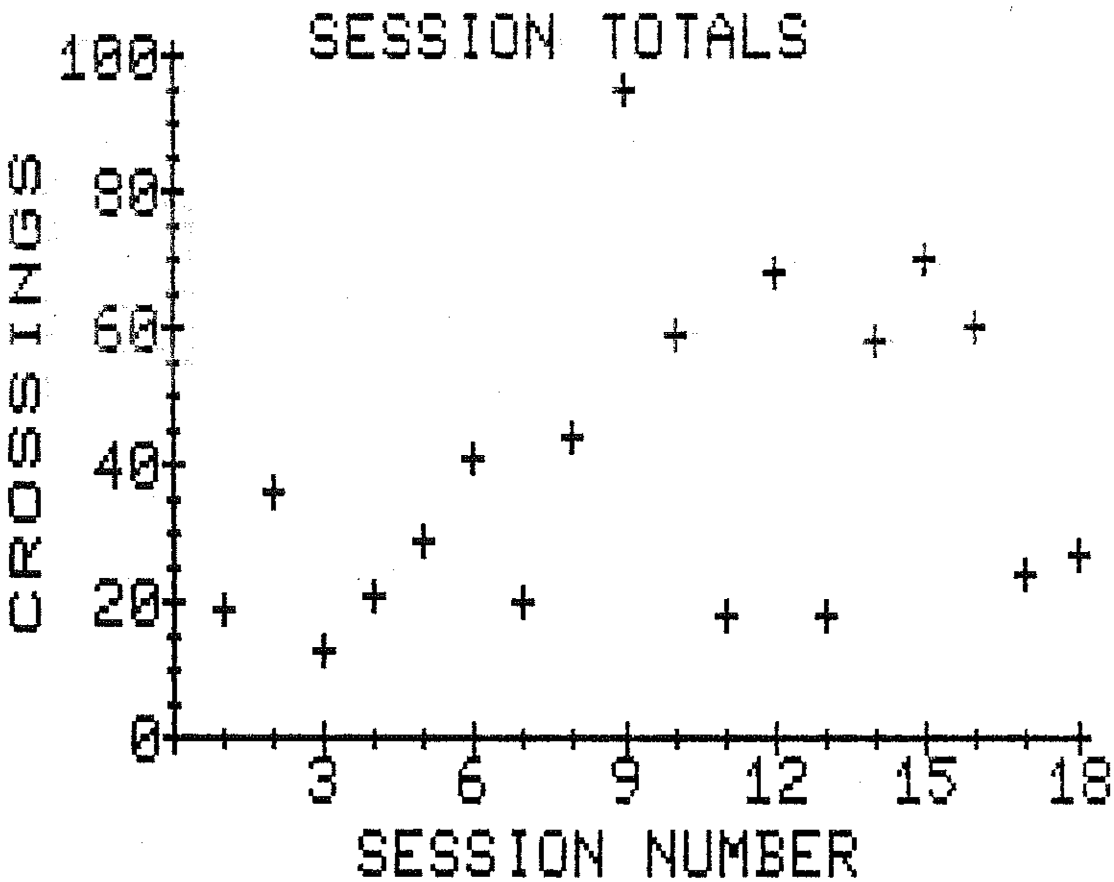

SESSION TOTALS
CROSSINGS
100
80
60
40
20
0
3
6
9
12
15
18
SESSION NUMBER

Figure 12.