BEHAVIORAL RESPONSES OF CAPTIVE DEER TO VISUAL AND PHYSICAL

BARRIERS DESIGNED TO MINIMIZE DEER-VEHICLE COLLISIONS

by

DANIEL WILLIAM STULL

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

ABSTRACT

As white-tailed deer (*Odocoileus virginianus*) and human populations expand and overlap, deer-vehicle collisions become a common occurrence. Although a variety of mitigation techniques have been studied, one of the most effective is exclusion fencing. I evaluated efficacy of exclusion fencing for preventing deer crossing into roadways. Fences were grouped into 3 categories: woven-wire fencing (1.2-2.4-m), opaque fencing (1.2-1.8-m), and fencing with a 45° outrigger. No deer crossed 2.4-m woven-wire fencing. Outrigger fencing angled toward deer and 2.1-m woven-wire fence had similar efficacy and were the next most effective. Efficacy between woven-wire fencing and opaque fencing at similar heights was not different. Outrigger fencing was more effective angled toward deer than away. Outrigger fencing along roadways may act as a one-way crossing instead of potentially trapping deer like 2.4-m woven-wire fence. I also evaluated efficacy of Type III rip-rap as a tactile barrier. Rip-rap was unsuccessful at preventing deer crossings.

INDEX WORDS: Deer, Deer-vehicle collisions, Fence, White-tailed deer

BEHAVIORAL RESPONSES OF CAPTIVE DEER TO VISUAL AND PHYSICAL

BARRIERS DESIGNED TO MINIMIZE DEER-VEHICLE COLLISIONS

by

DANIEL WILLIAM STULL

B.S., Iowa State University, 2007

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2009

BEHAVIORAL RESPONSES OF CAPTIVE DEER TO VISUAL AND PHYSICAL

BARRIERS DESIGNED TO MINIMIZE DEER-VEHICLE COLLISIONS

by

DANIEL WILLIAM STULL

Major Professor:	Karl V. Miller	
	Robert J. Warren	
Committee:	John C. Maerz	
	Craig A. Miller	

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
December 2009

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Collisions with white-tailed deer (*Odocoileus virginianus*) present a significant hazard to

motorists in the United States. Dense deer populations, coupled with a growing human

population and concurrent expansion of the nation's roadway system, have increased the risk of

deer-vehicle collisions. State Farm Insurance Company (2009) estimated that 1.5 million drivers

are involved in deer-vehicle collisions each year, resulting in approximately 150 deaths and $1.1

billion in damage to personal property. Huijser et al. (2007) reported that the total number of

vehicle crashes in the United States, when considering all causes, had remained relatively

unchanged from 1990-2004. However, the proportion of wildlife-vehicle collisions in the annual

total for the period has increased steadily by 6,769 each year with deer-vehicle collisions

constituting 77% (5,212/yr) of the collisions with wildlife.

Many mitigation devices and strategies have been employed in an attempt to reduce the

frequency of deer-vehicle collisions, including animal detection systems, deer whistles, roadside

reflectors, roadway signage, population reduction, underpasses, overpasses, and fences. Animal

detection systems and other roadway signage can alert drivers when or where an animal is likely

to cross. However, roadway signage is often ignored by motorists as they become habituated to

it, even if accompanied with flashing warning lights (Putman et al. 2004). Research conducted

on white-tailed deer hearing and visual capabilities suggests deer whistles and roadside reflectors

are ineffective in altering deer behavior so that a deer-vehicle collision would be avoided

(D'Angelo et al. 2006, Valitzski et al. 2009). Although DeNicola and Williams (2008) were able

to reduce deer-vehicle collisions of three suburban areas by 49-78% by reducing deer populations along roadways, sharpshooting may not be a viable option in many areas due to location and public opinion. Underpasses and overpasses are effective at providing safe passage for wildlife when designed specifically for the site and when accompanied by fencing, decreasing deer mortality 42.3% along a 4-lane highway and 36.8% along a 2-lane highway (Lehnert and Bissonette 1997). However, high construction cost ($173,000/4-lane and $92,000/2-lane) limits extensive use of this option for minimizing deer-vehicle collisions (Lehnert and Bissonette 1997). Tactile barriers such as cattle guards are also effective at prohibiting movement of hoofed animals, such as red deer (*Cervus elaphus elaphus;* Reed et al. 1974, Belant et al. 1998a, Peterson et al. 2003, Sebesta et al. 2003). Although long expanses of cattle guards are likely infeasible, alternative tactile barriers such as rip-rap (i.e., large pieces of crushed rock) have not been evaluated for effectiveness. Additionally, the effectiveness of tactile-fence combinations has not been studied.

Prohibitive fencing, often woven-wire fencing ≥2.4-m tall, effectively keeps deer out of roadways and reduces deer-vehicle collisions (Falk et al. 1978, Reed et al. 1980, Ludwig and Bremicker 1981, Clevenger et al. 2001, VerCauteren et al. 2006). Woven-wire prohibits deer from passing between individual wires. To be most effective at excluding deer from roadways, fencing should be installed on both sides of the road. However, even with effective exclusion fencing, deer may circumvent fence ends, enter the roadway at a new location (i.e., relocate the area of risk), and become trapped between the fences creating increased risk of a deer-vehicle collision (Conover 2002). To prevent a deer from circumventing fence ends, it may be necessary to extend the fence well beyond the targeted crossing site. However, long expanses of ≥2.4-m fence are expensive to build and maintain. To prevent deer from becoming trapped in the

roadway, the fence should allow one-way crossing away from the road.   Even with the cost of

fence construction and maintenance, and the need for innovative fencing designs, exclusion

fencing may be the most effective and practical method of reducing deer vehicle collisions

(Feldhamer et al. 1986). The objective of this research was to evaluate the effectiveness of

various heights and designs of fence and potential for rip-rap to slow deer movement.

LITERATURE REVIEW

Mitigation strategies for reducing deer-vehicle collisions have included altering deer

behavior away from the road, influencing driver behavior, or prohibiting deer access to the road.

Strategies involving altering behavior of either drivers (i.e., animal detection systems, reduced

speed limits, and roadway signage) or deer (i.e., deer whistles and roadside reflectors) have been

met with limited success (Huijser et al. 2007). Huijser et al. (2006) found that animal detection

systems accurately detected 87% of elk (*C. e. canadensis*) crossings on a highway in

Yellowstone National Park, Montana, USA. However, roadway signage and animal detection

systems are often ignored by motorists as they become habituated to it and therefore are

ineffective at mitigating wildlife-vehicle collisions (Putman et al. 2004, Meyer 2006). D'Angelo

(2007) examined the physiological and morphological characteristics of white-tailed deer visual

and auditory systems, and evaluated the effectiveness of Strieter-Lite® wildlife warning

reflectors at altering deer behavior away from roadways. In experimental trials, these reflectors

were ineffective at altering deer behavior in a manner that would reduce the incidence of deer-

vehicle collisions (D'Angelo et al. 2006). Mule deer (*O. hemionus*)-vehicle collisions were not

reduced in areas where Swareflex Reflectors were posted (Reeve and Anderson 1993). Ujvári et

al. (1998) reported that fallow deer (*Dama dama*) became habituated to WEGU wildlife warning

reflectors (Walter Dräbing KG, Kassel, Germany) over 17 nights. Most studies that report

reflectors as being effective base their evaluations on deer carcass counts (Schafer and Penland 1985, Pafko and Kovach 1996) before and after installment or reflectors are covered and uncovered. These methods fail to consider seasonal movements, traffic patterns, changes in deer densities, or altered driver behavior in the presence of reflectors (D'Angelo 2007).

White-tailed deer hearing has the greatest sensitivity between 4-kHz and 8-kHz (D'Angelo et al. 2007). Valitzski et al. (2009) evaluated pure tones within this range as a potential deterrent to prevent deer-vehicle collisions and found that they were unsuccessful at altering deer behavior away from the road.   Romin and Dalton (1992) reported mule deer were unaffected by Game Tracker or Sav-a-life wildlife warning whistles but did not determine if mule deer had the ability to hear the sound produced by either brand. Frightening devices such as motion-activated deer distress calls, propane exploders, and other electronic auditory devices have limited success reducing deer damage to crops (Belant et al. 1996, Belant et al. 1998b, Gilsdorf et al. 2006) and probably are not effective at reducing deer-vehicle collisions.

The standard fence used to prevent white-tailed deer damage is 2.4-m woven-wire fence. Ludwig and Bremicker (1981) evaluated 2.4-m fencing with one-way gates and reported that deer-vehicle collisions were reduced 60-93% over two fenced roadway segments. However, the length (4-km) of one the fences was considered too short and deer often circumvented the ends of the fence rather than using one-way gates. Falk et al. (1978) reported 2.3-m fencing was not high enough to prevent deer from crossing when startled by researchers.

Several studies have evaluated the efficacy of an array of alternate fencing designs (i.e., electric, woven-wire, barbed wire, and outrigger) to prevent deer damage, mostly in agricultural situations not associated with roadways. Electric fence designs are successful for preventing deer movement into exclosures (Tierson 1969, Palmer et al. 1985, Seamans and VerCauteren

2006). Tierson (1969) reported that deer behavior in response to making contact with the fence varied from appearing completely unaffected to reacting violently to the point of falling down. The addition of a 1.3-m, 5 stranded Electrobraid™ fence surrounding a preexisting 1.8-m snow fence reduced the number of deer gaining access to a corn feeder by 90% (Seamans and VerCauteren 2006). Webb et al. (2009) successfully prohibited deer movement with a 2.5-m, 15-strand high-tensile electric fence; however, white-tailed deer were still able to pass through water gaps and open places on uneven ground. Similarly, Leblond et al. (2007) reported that moose (*Alces alces*) roadway crossings were reduced by approximately 80% with the addition of a 1.5-m, 5 stranded Electrobraid™ in the Laurentides Wildlife Reserve, Quebec, Canada. Electrified fence requires continued maintenance to ensure the fence is working properly, limiting its applicability in many locations.

Fence designs with sections of overhanging fence, (i.e., outriggers) have also been tested. Goddard et al. (2001) reported equal success with a 0.9-m vertical fence with a 0.8-m, 90° outrigger and a 1.8-m vertical woven-wire fence at preventing crossings by red deer. Jones and Longhurst (1958) also reported that a 0.6-m vertical fence with an outrigger of 1.8-m angled at 25° and a 1.2-m vertical fence with 1.2-m outrigger angled at 45° were effective at prohibiting deer access to a Sudan grass pasture. A slanted fence design with a slope of 49° consisting of a 1.8-m roll of chicken wire also proved to be effective at restricting movement of mule deer and other ungulates (Jones and Longhurst 1958). Fenster (2006) reported that deer would enter an exclosure surrounded by a 45°, smooth-wire outrigger fence by climbing through the wires at the base, with the outrigger angled toward them, but would often jump over the top when the outrigger was angled away. Like electrified fence, 90° outrigger and slanted fences would

require a significant amount of maintenance in a roadside setting as debris could accumulate on top of the fence that would need to be removed and mowing would become more difficult.

Currently, the fence used by the Georgia Department of Transportation (GDOT) in areas with a high potential for deer-vehicle collisions is 2.7-m tall and constructed in three sections (GDOT, personal communication). The bottom section consists of 22.9-cm of woven-wire with 7.6-cm of vertical spacing between strands, and a strand of barbed wire running along the ground. The middle section is 2.2-m of woven-wire with 20.3-cm of vertical spacing between strands. The top section consists of two strands of barbed wire spaced 15.2-cm apart and located 15.2-cm above the middle section of woven-wire. Although this fence is effective, it is presumably more costly to construct than a standard 2.4-m woven-wire fence due to the additional barbed wire. Deer are more likely to become ensnared and killed crossing a fence with barbed wire than a fence without (Harrington and Conover 2006). If a more cost effective alternative to this fencing design were discovered, fence mitigation strategies could be used over more extensive areas and in additional locations.

Few studies have considered characteristics of deer vision when testing efficacy of exclusion fencing. Jones and Longhurst (1958) found that deer were more likely to attempt to go under a fence 1.3-m high and slanted towards them at 45° rather than jump over it. It was likely that this modified fence-crossing behavior occurred because deer perceived they could not successfully jump the fence. Gallagher et al. (2003) showed that a 1.7-m vertical fence composed of hanging burlap (i.e., 100% visual barrier) prevented the majority of deer from crossing. Although deer had the ability to cross underneath the burlap, as the lower end was not fixed, and deer had prior knowledge that corn was available on the other side, they did not cross. Wild ungulates, cattle, and horses are more likely to respect a solid barrier as opposed to a woven wire

6

barrier (Grandin 2007). Excited animals are more likely to run into a wire fence than a perceived solid barrier, which can be used to corral or move animals into a desired direction. A perceived solid barrier along roadways, such as existing fences retrofitted with an opaque covering, may minimize crossing attempts, although this has not been verified experimentally.

Barriers that exploit the anatomy of the ungulate hoof, hereafter referred to as tactile designs, have shown promise in preventing crossings. For example, grates of varying patterns (e.g., cattle guard) have been used in urban areas to successfully prohibit deer access (Reed et al. 1974, Belant et al. 1998a, Sebesta et al. 2003, Peterson et al. 2003). However, these barriers can still be breached if they are not spaced correctly or if the deer can reach the ground beneath the grate (Reed et al. 1974, Sebesta et al. 2003). Other tactile designs, such as the "slippery fence" design, also serve as effective barriers (Gallagher et al. 2005), but are not feasible for extensive use along roadways. Rip-rap (e.g., varying sized rock) has not been tested as a deer crossing barrier, although Austin and Garland (2001) and Cramer and Bissonette (2005) discuss how rip-rap was removed from wildlife underpasses and other passageways because it was prohibiting deer movement. Additionally, in 2004 a swath of rip-rap was used along the Christopher Creek Section of Arizona's State Route 260 as an alternative to ungulate fencing, however the results were not reported (Dodd et al. 2005).

A deer with previous success at crossing a barrier is more likely to attempt to cross it again. Therefore, it is important to understand a deer's perception of roadside barriers and characteristics of those that minimize crossing attempts. Animals make decisions by assessing external stimuli and determining the level of risk associated with their desired actions (Blumstein and Bouskila 1996). External stimuli for a deer might include access to food and water, escape from a predator, or actions of a conspecific, such as a rutting buck, a doe in estrus, or a calling

fawn. Behavioral patterns also vary among individuals. For example, white-tailed, black-tailed

(*O. h. columbianus*), and red deer male fawns are bolder than female fawns (Guinness et al.

1979, Jackson et al. 1972, and Taber and Dasmann 1954). It seems logical for deer with bold

personalities to be more prone to attempt risky behavior, such as crossing roadside fences.

Wilson et al. (1994) described the shyness-boldness continuum as an axis of behavioral variation

in a species. Animals living in groups often synchronize their behaviors in order to benefit from

a mutual, external stimulus (Dostálková and Špinka 2007). If the boldest deer perceived a

fencing design was "high risk", this likely would minimize crossing attempts by other members

of the group and limit positive reinforcement associated with successful attempts.

Most prior research has focused on the efficacy of fence ≥2.4-m on mitigating deer-

vehicle collisions. Few studies have actually evaluated fence height, fencing materials that limit

visibility, or alternate fence designs for roadway usage. Therefore, I evaluated woven-wire

fencing 1.2 to 2.4-m, opaque wove-wire fencing 1.2 to 1.8-m, and an outrigger style of fence

from both directions. I also evaluated the ability of a 6.1-m swath of Type III rip-rap as a

method of slowing deer movement.

OBJECTIVES

I compiled a list of barrier designs based on previous studies that have shown potential at

preventing deer crossings and may be applicable along roadways. I constructed test sections of

each barrier design within outdoor research paddocks at the Whitehall Deer Research Facility at

the University of Georgia to accomplish the following objectives:

1. Evaluate woven-wire fence heights including 1.2-m, 1.5-m, 2.1-m, and 2.4-m.

2. Evaluate woven-wire fence with a 100% opaque covering at heights including 1.2-m, 1.5-m and 1.8-m.

3. Evaluate 1.2-m woven-wire fence with a 50% opaque outrigger angled at 45° in the direction toward deer and away from deer.

4. Evaluate Type III rip-rap as a prohibitive tactile barrier

5. Examine actions and behaviors associated with crossing barriers.

LITERATURE CITED

Austin, J.M. and L. Garland. 2001. Evaluation of a wildlife underpass on Vermont State Highway 289 in Essex, Vermont. Pages 616-624 *in* C.L. Irwin, P. Garrett, and K.P. McDermott, eds. Proceedings of the 2001 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Belant, J.L., T.W. Seamans, and C.P. Dwyer. 1996. Evaluation of propane exploders as white-tailed deer deterrents. Crop Protection 15:575-578.

Belant, J.L., T.W. Seamans, and C.P. Dwyer. 1998a. Cattle guards reduce white-tailed deer crossings through fence openings. Journal of Pest Management 44:247-249.

Belant, J.L., T.W. Seamans, and L.A. Tyson. 1998b. Evaluation of electronic frightening devices as white-tailed deer deterrents. Wildlife Society Bulletin 26:264-268.

Blumstein, D.T. and A. Bouskila. 1996. Assessment and decision making in animals: a mechanistic model underlying behavioral flexibility can prevent ambiguity. Oikos 77:569-576.

Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin 29:646-653.

Conover M.R. 2002. Threats to human safety. Pages 39-65 *in* M.R. Conover, ed. Resolving human-wildlife conflicts: The science of wildlife damage management. Lewis, Boca Raton, Florida, USA.

Cramer, P.C. and J.A. Bissonette. 2006. Wildlife crossings in North America: the state of the science and practice. Pages 442-447 *in* C.L. Irwin, P. Garrett, and K.P. McDermott, eds. Proceedings of the 2006 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

D'Angelo, G.J. 2007. Development and evaluation of devices designed to minimize deer-vehicle collisions. Ph.D. Dissertation, University of Georgia, Athens, USA.

D'Angelo, G.J., A.R. DeChiccis, D.A. Osborn, G.R. Gallagher, R.J. Warren, and K.V. Miller. 2007. Hearing range of white-tailed deer as determined by auditory brain stem response. Journal of Wildlife Management 71:1238-1242.

D'Angelo, G.J., J.G. D'Angelo, G.R. Gallagher, D.A. Osborn, K.V. Miller, and R.J. Warren. 2006. Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. Wildlife Society Bulletin 34:1175-1183.

DeNicola, A.J. and S.C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer-vehicle collisions. Human-Wildlife Conflicts 2:28-33.

Dodd, N.L., J.W. Gagnon, S. Boe, and R.E. Schweinsburg. 2005. Characteristics of elk-vehicle collisions and comparison to GPS-determined highway crossing patterns. Pages 461-477 *in* C.L. Irwin, P. Garrett, and K.P. McDermott, eds. Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Dostálková I., and M. Špinka. 2007. Synchronization of behaviour in pairs: the role of

   communication and consequences in timing. Animal Behaviour 74:1735-1742.

Falk, N.W., H.B. Graves, and E.D. Bellis. 1978. Highway right-of-way fences as deer

   deterrents.   Journal of Wildlife Management 42:646-650.

Feldhamer, G.A., J.E. Gates, D.M. Harman, A.J. Loranger, and K.R. Dixon. 1986. Effects of

   interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management

   50:497-503.

Fenster, R.L. 2006. Effectiveness of modifying existing fences to deter deer and elk from crops

   and high-value pastures. M.S. Thesis, Montana State University, Bozeman, USA.

Gallagher, G.R., H.A. Keen, and R.H. Prince. 2003. Effectiveness of a perceived solid barrier

   as an exclusion fence to prevent white-tailed deer damage. Proceedings of the Wildlife

   Damage Management Conference 10:23-29.

Gallagher, G.R., H.A. Keen, and R.H. Prince. 2005. Effectiveness of a white-tailed deer

   exclusion fence based on traction limitations of the hoof: the slippery fence.

   Proceedings of the Wildlife Damage Management Conference 11:233-241.

Gilsdorf, J.M., S.E. Hygnstrom, K.C. VerCauteren, G.M. Clements, E.E. Blankenship, and R.M.

   Engeman. 2004. Evaluation of a deer-activated bio-acoustic frightening device for

   reducing deer damage in cornfields. Wildlife Society Bulletin 32:515-523.

Goddard, P.J., R.W. Summers, A.J. Macdonald, C. Murray, and A.R. Fawcett. 2001.

   Behavioural responses of red deer to fences of five different designs. Applied Animal

   Behaviour Science 73:289-298.

Grandin, T. 2007. Behavioral principles of cattle handling under extensive conditions. Pages 44-64 *in* T. Grandin, ed. Livestock handling and transport 3rd edition. CAB International, Wallingford, UK.

Guinness, F.E., M.J. Hall, and R.A. Cockerill. 1979. Mother-offspring association in red deer (*Cervus elaphus* L.) on Rhum. Animal Behavior 27:536-544.

Harrington, J.L. and M.R. Conover. 2006. Characteristics of ungulate behavior and mortality associated with wire fences. Wildlife Society Bulletin 34:1295-1305.

Huijser, M.P., W. Camel, and A. Hardy. 2006. Reliability of the animal detection system along US Hwy 191 in Yellowstone National Park, Montana, USA. Pages 509-523 *in* C.L. Irwin, P. Garrett, K.P. McDermott, eds. Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and Environment, North Carolina State University, Raleigh, USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R. Ament. 2007. Wildlife-vehicle collision reduction study. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Jackson R.M., M. White, and F.F. Knowlton. 1972. Activity patterns of young white-tailed deer fawns in south Texas. Ecology 53:262-270.

Jones, M.B. and W.M. Longhurst. 1958. Overhanging deer fences. Journal of Wildlife Management 22:325-326.

Leblond, M., C. Dussault, J. Ouellet, M. Poulin, R. Courtois, and J. Fortin. 2007. Electric fencing as a measure to reduce moose-vehicle collisions. Journal of Wildlife Management 71:1695-1703.

Lehnert M.E. and J.A. Bissonette. 1997. Effectiveness of highway crosswalk structures at

reducing deer-vehicle collisions. Wildlife Society Bulletin 25:809-818.

Ludwig, J. and T. Bremicker. 1981. Evaluation of 2.4-meter fences and one-way gates for

reducing deer-vehicle collisions. Minnesota Wildlife Resources Quarterly 41:77-88.

Meyer, E. 2006. Assessing the effectiveness of deer warning signs. Final Report K-TRAN:KU

03-6. The University of Kansas, Lawrence, USA.

Pafko, F., and B. Kovach. 1996. Minnesota experience with deer reflectors. Pages 130-139 *in*

G.L. Evink, P. Garrett, D. Zeigler, and J. Berry, editors. Proceedings of the International

Conference on Ecology and Transportation. Center for Transportation and the

Environment, North Carolina State University, Raleigh, USA.

Palmer, W.L., J.M. Payne, R.G. Wingard, and J.L. George. 1985. A practical fence to reduce

deer damage. Wildlife Society Bulletin 13:240-245.

Peterson, M.N., R.R. Lopez, N.J. Silvy, C.B. Owen, P.A. Frank, and A.W. Braden. 2003.

Evaluation of deer-exclusion grates in urban areas. Wildlife Society Bulletin 31:1198-

1204.

Putman, R.J., J. Langbein, and B.W. Staines. 2004. Deer and road traffic accidents: a review of

mitigation measures: costs and cost-effectiveness. Report for the Deer Commission for

Scotland. Contract RP23A, UK.

Reed, D.F., T.M. Pojar, and T.N. Woodward. 1974. Mule deer responses to deer guards.

Journal of Range Management 27:111-113.

Reed, D.F., T.N. Woodward, and T.D.I. Beck. 1980. Regional deer-vehicle accident research.

U.S. Department of Transportation Federal Highway Administration Report No. FHWA-

RD-79-11. National Technical Information Service, Springfield, Virginia. USA, 61 pp.

Reeve, A.F., and S.H. Anderson. 1993. Ineffectiveness of Swareflex Reflectors at reducing deer-vehicle collisions. Wildlife Society Bulletin 21:127-132.

Romin, L.A. and L.B. Dalton. 1992. Lack of response by mule deer to wildlife warning whistles. Wildlife Society Bulletin 20:382-384.

Schafer, J.A. and S.T. Penland. 1985. Effectiveness of Swareflex Reflectors in reducing deer-vehicle accidents. Journal of Wildlife Management 49:774-776.

Seamans, T.W. and K.C. VerCauteren. 2006. Evaluation of Electrobraid^{TM} Fencing as a white-tailed deer barrier. Wildlife Society Bulletin 34:8-15.

Sebesta J.D., S.W. Whisenant, R.R. Lopez, and N.J. Silvy. 2003. Development of a deer guard prototype for Florida Key deer. Proceedings of the Annual Conference of the Southeastern Associations of Fish and Wildlife Agencies 57:337-347.

State Farm Insurance Company. 2009. <http://www.statefarm.com/>. Accessed October 7, 2009.

Taber, R.D. and R.F. Dasmann. 1954. A sex difference in mortality in young Columbian black-tailed deer. Journal of Wildlife Management 18:309-315.

Tierson, W.C. 1969. Controlling deer use of forest vegetation with electric fences. Journal of Wildlife Management 33:922-926.

Ujvári, M., H.J. Baagøe, and A.B. Madsen. 1998. Effectiveness of wildlife warning reflectors in reducing deer-vehicle collisions: a behavioral study. Journal of Wildlife Management 62:1094-1099.

Valitzski, S.A., G.J. D'Angelo, G.R. Gallagher, D.A. Osborn, K.V. Miller, and R.J. Warren. 2009. Deer responses to sounds from a vehicle-mounted sound-production system. Journal of Wildlife Management 73:1072-1076.

VerCauteren K.C., M.J. Lavelle, and S. Hygnstrom. 2006. Fences and deer-damage

    management: a review of designs and efficacy. Wildlife Society Bulletin 34:191-200.

Webb, S.L., K.L. Gee, S. Demarais, B.K. Strickland, and R.W. DeYoung. 2009. Efficacy of a

    15-strand high-tensile electric fence to control white-tailed deer movements. Wildlife

    Biology in Practice 5:45-57.

Wilson, D.S., A.B. Clark, K. Coleman, and T. Dearstyne. 1994. Shyness and boldness in

    humans and other animals. Trends in Ecology and Evolution 9:442-446.

CHAPTER 2

BEHAVIORAL RESPONSES OF CAPTIVE DEER TO VISUAL AND PHYSICAL

BARRIERS DESIGNED TO MINIMIZE DEER-VEHICLE COLLISIONS

ABSTRACT

We evaluated the efficacy of a variety of fencing designs for the prevention of deer

crossing including woven-wire fencing (1.2-m, 1.5-m, 1.8-m, 2.1-m, and 2.4-m), opaque fencing

(1.2-m, 1.5-m, and 1.8-m), and a 0.6-m outrigger fencing installed at a 45° angle above a 1.2-m

wire fence (towards and away from the deer). We recorded attempted crossings and successful

crossings of fence barriers by captive deer to access a known feed source. No deer crossed the

2.4-m high woven-wire fence, whereas all deer successfully crossed the 1.2-m woven-wire fence.

We observed no differences in successful crossings between the woven-wire fence and the

opaque fencing. Outrigger fencing was more effective when the outrigger was angled towards

the deer than away from the deer. The outrigger fencing angled towards the deer and the 2.1-m

woven-wire fence had similar efficacy. Because orientation of the outrigger fence influenced

effectiveness, this design may be useful along roadways because it may act as a one-way

crossing to enable deer to exit the roadway unlike the 2.4-m fence.

INTRODUCTION

The frequency of deer-vehicle collisions in the United States has increased over recent

decades. Increasing populations of white-tailed deer (*Odocoileus virginanus*), particularly in

suburban and exurban areas, combined with an expanding human population and increased

vehicular traffic has increased the risk of deer-vehicle collisions. There are an estimated 1.5

million deer-vehicle collisions reported each year causing approximately 29,000 injuries, 150-200 human deaths (Conover et al. 1995), and $1.1 billion in property damage (State Farm Insurance Company 2009). Although the number of vehicle crashes from all causes remained relatively constant from 1990-2004, the number of wildlife-vehicle collisions has increased approximately by 6,769 /year with deer-vehicle collisions constituting 77% (5,212/year) of these additional collisions (Huijser et al. 2007).

Various mitigation devices and strategies have been employed in efforts to reduce the frequency of deer-vehicle collisions, including animal detection systems, deer whistles, roadside reflectors, roadway signage, population reduction, underpasses, overpasses, and exclusion fences. Construction of exclusion fences likely is the most effective strategy for prohibiting deer access to roadways and reducing the risk of deer-vehicle collisions (Falk et al. 1978, Feldhamer et al. 1986, Clevenger et al. 2001). Fencing $\geq$2.4-m in height is typically regarded as effective for excluding deer, but to maximize effectiveness, a fence needs to be located on both sides of the road and of sufficient length to extend beyond the home ranges of deer in the high risk area. Deer that circumvent the ends of a fence might become trapped within the roadway, thereby increasing the risk of a deer vehicle collision (Conover 2002). Thus, fencing that is effective at excluding deer while simultaneously enabling deer to escape from a roadway would be advantageous.

Few studies have utilized deer perception to develop effective barriers. Gallagher et al. (2003) reported that a 1.7-m vertical fence composed of hanging burlap (i.e., 100% visual barrier) prevented deer from entering an enclosure, suggesting that shorter (<2.4-m), opaque barriers may be as effective at preventing deer crossings as a taller woven-wire fence. When excited, wild ungulates are more likely to respect solid barriers than woven-wire fences, and are

17

unlikely to run into them (Grandin 2007). Jones and Longhurst (1958) reported deer were more likely to attempt to go under a fence or outrigger angled towards them than over them. They were successful at keeping deer out of an exclosure using outrigger fencing (i.e., 0.6-m vertical fence with a 1.8-m 25° outrigger and 1.2-m vertical fence with a 1.2-m 45° outrigger) and slanted fencing (i.e., 1.8-m fence at 49°). Therefore, opaque and outrigger fencing may be more effective than woven-wire fences, although experimental trials are lacking.

Our objective was to evaluate the potential for deer to cross various heights and designs of fence to find an effective, and cost-effective, roadside barrier to reduce the incidence of deer-vehicle collisions.

STUDY AREA

We conducted our study at the Daniel B. Warnell School of Forestry and Natural Resources' Whitehall Deer Research Facility at the University of Georgia, Athens, Georgia, USA. The Facility spans 2.4-ha bordered by a 3-m high woven-wire fence, and is composed of 5 outdoor paddocks (0.4-0.8-ha), 3 sorting pens (15 x 20-m), a barn containing 19 roofed stalls (3 x 6-m), and a rotunda with movable walls to direct deer movement. Outdoor paddocks used in this study had a dominant cover of pine (*Pinus* spp.) and oak (*Quercus* spp.) of various ages. Experiments were conducted in smaller pens (0.1-0.2-ha), called treatment areas, built within the outdoor paddocks.

METHODS

We selected 18 adult (≥1.5-≤8.5 years old), healthy, female deer based on their reactions when a person approached them. We censored deer that remained calm when approached in favor of those with evoked flight responses. In addition, only does that successfully jumped a 1.2-m woven-wire fence (positive control fence) were included in the experiment. This fence is

typical of the Georgia Department of Transportation fencing along roadways and is generally regarded as not effective in preventing deer crossings. We divided the deer into six, two-deer groups and fitted one deer in each group with a highly visible collar to differentiate between the two.

We constructed three (0.1 to 0.2-ha) treatment areas within two outdoor paddocks. The perimeter of each area was constructed of 2.4-m woven-wire fencing covered with 100% opaque shade cloth to limit external disturbances to the deer. We bisected each treatment area with the experimental fence designs. We provided deer with water ad libitum and on both sides of the test fence, while food was only available on one side. In each treatment area, we installed a 2.4-m solid gate to allow deer to pass unimpeded during the habituation portion of each experiment. To eliminate any pen effect, we tested each exclusion fence design in each treatment area with all two-deer groups.

Our experimental fence designs included: 1) woven-wire fencing (Solidlock® Fixed-Knot) of various heights (1.2-m, 1.5-m, 1.8-m, 2.1-m, and 2.4-m) with a 5.1-cm strip of white polytape (LACME Electric Fencing Systems) attached along the top; 2) woven-wire fencing (1.2-m, 1.5-m, and 1.8-m) covered with a 100% opaque woven landscape fabric (DeWitt Ultra Web 3000 Groundcover); and 3) 1.2-m woven-wire fence with a 0.6-m 50% opaque plastic outrigger attached to the fence top and angled at 45°. When testing fencing heights we began our trials at a height of 1.2-m and increased fence height in subsequent trials by intervals of 0.3-m. We tested the outrigger fence with the outrigger facing either towards or away from the deer. Because we anticipated that experimental deer would learn to jump the fences, we included an additional three two-deer groups of naïve deer in a separate trial of the outrigger fence. For all trials, each two-deer group was rotated through each of the three treatment areas without any

19

group encountering the same fence design twice. At the start of each new trial, groups were assigned randomly to each treatment area and then rotated through the remaining treatment areas

To stimulate desire to cross the barriers, we limited feed (Meadow's Edge Deer Feed, Meadow's Edge, Millen, GA and Omolene 300 Growth Horse Feed, Land O'Lakes Purina Mills, Gray Summit, MO) intake to 1.4-kg/deer/day. Before each trial, each two-deer group had 48 hours of unrestricted access throughout the treatment area via the gate. After the habituation period, deer were separated from their food by the experimental exclusion fence for 25 hours (i.e., treatment period), or until they jumped the fence. If a deer had not jumped the experimental fence within 24 hours, we applied light pressure to evoke a flight response, further encouraging it to attempt a crossing. Initial pressure was the presence of a human at the back of the test pen. Increasing levels of pressure included adding clapping and shouting and walking while clapping and shouting. We discontinued pressure once both deer had attempted to jump the experimental fence (successfully or unsuccessfully), it was apparent that the deer would not attempt, or 15 minutes had passed since the researcher entered the pen. Following the trials, deer were moved into barn stalls and had access to water ad libitum and an increased supply of food (1.6-kg/deer/day).

During the 25-hr trials we monitored the deer continuously with an infrared day/night camera (Model No. PC1771R-6; Supercircuits Inc., Austin, TX) recording to an ARCHOS 504 Digital Media Player (160 GB) with a digital video recorder station (Archos Inc., Greenwood Village, CO) housed in a waterproof container. Digital video files were stored on hard drives and transferred to computers for review. Videos were reviewed using Videolan-VLC media player 0.8.6 (videolan.org). We characterized and quantified deer behavior in relation to the experimental exclusion fence, defining crossing behaviors as Rearing 1, Rearing 2, Failed

Attempts, and Crosses. Rearing 1 was recorded when a deer faced towards the fence and lifted one foreleg towards the fence. Rearing 2 was recorded when a deer faced towards the fence and reared up on both hind legs. A failed attempt was recorded when all four feet left the ground but the fence was not breached successfully. We recorded time and duration for each crossing attempt. Once a deer successfully crossed the fence its actions were no longer recorded. The first half hour and last half hour were separated from the remainder of the food restriction period as this was the time that was more likely to have been influenced by human interaction, either by shutting the gate or through the light pressure applied at the end of the trials. We compared the mean number of attempts per hour by the motivational period in which they occurred (i.e., gate shutting, food restriction, and light pressure). Deer that had successfully crossed during one motivational period were excluded from analysis in the subsequent motivational periods. The percentage of deer that crossed during each motivational period for each fence type was found by combining all treatment periods into a single 75-hr period. Deer with multiple crossings had only their first crossing, and the motivational period it occurred in, used in the analysis.

We used statistical package R v. 2.9.2 (The R Foundation for Statistical Computing 2009) to analyze our data. We used orthogonal contrasts, though our groups were not independent of each other, to compare the relative efficacy of each fence design and height to a 1.2-m woven-wire fence, and to rank efficacies of the various experimental exclusion fences. A binomial logistic regression model was used to determine the probability of fence effectiveness in an odds ratio using the efficacy of 1.2-m woven-wire fence as a baseline as it was the least effective fence design. An odds ratio reports the probability of the likelihood of an occurrence compared to the likelihood of another occurrence. Naïve deer were not included in the orthogonal contrasts or binomial logistic regression. All animal use and handling procedures were approved by the

Institutional Animal Care and Use Committee of the University of Georgia (AUP# A2007-10127-0).

RESULTS

From 21 January 2008 through 14 November 2008 we recorded 1,210 actions directed at attempting or successfully crossing experimental exclusion fencing during 233 observation periods of 25 hours each. The rates of Rearing 1 and Rearing 2 attempts decreased as height of the woven-wire fence increased (Figure 2.1). The rates of Failed Attempts increased as fence height increased and the percentage of crossings decreased (Table 2.1). Successful crossings occurred most often during the gate shutting and light pressure periods. The number of deer that crossed decreased at each height from 1.8 to 2.4-m. As the height of the woven-wire fence increased the percentage of crossings during food restriction decreased and most crossings occurred during the period of light pressure. The 1.5-m and 1.8-m woven-wire fences had similar efficacy ($P = 0.226$; Table 2.2). The 2.4-m woven-wire fence had significantly higher efficacy compared to other heights of woven-wire fences (1.2-m: $P = <0.001$; 1.5-m: $P = <0.001$; 1.8-m: $P = <0.001$; 2.1-m: $P = 0.006$). We removed two deer after the 2.4-m experiment, one from injury and one from becoming habituated to the researchers. The remaining two deer from the dismantled groups were then paired together. As expected, the odds ratio from the binomial logistic regression reported the 2.4-m woven-wire fence had the lowest probability to be crossed (Figure 2.4).

Opaque fencing had more uniform distribution of crossings through the motivational periods than the woven-wire fencing (Figure 2.2). Attempts during the food restriction period decreased as fence heights increased while attempts occurring during the gate shutting and light pressure periods increased. Efficacy between opaque fences and woven wire fences of the same

22

height were not different (1.2-m: $P = 0.23$; 1.5-m: $P = 0.498$; 1.8-m: $P = 0.766$). The 1.5-m opaque fencing had similar efficacy as 1.2-m woven-wire fence as well ($P = 0.072$). Percentages of deer that successfully crossed the opaque fences were equal (90%).

During the experiments with the outrigger angled toward the deer Rearing 1 and Rearing 2 attempts were similar in all motivational periods however the rate of Failed Attempts was significantly higher (Figure 2.3). The outrigger angled away from the deer had fewer interactions than when the outrigger was angled toward the deer. Outrigger fencing angled towards the deer had higher efficacy than the outrigger fencing angled away from the deer ($P = 0.012$). Efficacy of a 2.1-m woven-wire fence and an outrigger fence angled towards the deer were not different ($P = 0.46$). The odds ratio reported the 2.1-m woven-wire fence and the outrigger fence angled towards the deer had similar probabilities of not being crossed.

Naïve deer had lower rates of activity than trained deer in all motivational periods during the outrigger experiments. When including the naïve deer groups ($n = 3$ for a total $n = 8$) in the contrast between the directions the outrigger angled, the outrigger angled towards the deer was still more effective than the outrigger angled away from the deer ($P = 0.014$). When contrasting successful crossings of naïve and trained deer, trained deer were more likely to cross the outrigger fences in both directions ($P = 0.02$). Combined percentage of trained and naïve deer that crossed the outrigger fence angled towards the deer (36%) were similar to the percentage of trained deer that crossed the 2.1-m woven-wire fence (41%). Each motivational period during the experiments with the outrigger angled away from the deer had similar percentages of deer crossings when trained and naïve deer were combined. Most of the crossings that occurred during the experiments with the outrigger angled towards the deer occurred with light pressure.

DISCUSSION

In our study, no deer crossed a 2.4-m woven-wire fence. Presumably, trained deer would be the most apt to cross woven-wire fences, although from the height of 1.8-m and higher there were significantly fewer crosses at each increasing height. Sauer (1984) reported white-tailed deer could jump a 2.1-m fence from a standing start and could jump a 2.4-m fence from a running start. In contradiction, Fitzwater (1972) indicates that a 2.4-m fence is sufficient to prevent deer from jumping. Ludwig and Bremicker (1981) concluded that 2.4-m fencing was effective at keeping deer out of roadways as long as the length of the fence is extended well beyond the high-risk area for deer-vehicle collisions.

Opaque fencing had similar efficacy as woven-wire of the same height. Similarly, the number of attempts and/or crossings decreased as fence height increased for opaque fencing. However, the percentage of deer that crossed the opaque fences remained the same at each height. Crossing attempts by deer for the opaque fencing may have been influenced by the deer having prior knowledge of the other side of the fence; however, Gallagher et al. (2003) reported that free-ranging deer did not cross a 1.7-m high burlap fence to access a corn feeder, even though the deer had gained access to the feeder at lower heights by jumping the fence. Deer in our opaque fencing study successfully crossed more often under human motivation during the gate shutting and light pressure periods. Increased motivation levels in our captive deer compared to free-ranging deer may responsible for the differing crossing rates between our study and Gallagher et al. (2003).

In our study, deer had prior experience on the other side of the opaque fence. Solid barriers are used in deer handling facilities to prevent deer from colliding with fencing by visually emphasizing the fences (Matthews 2007). How deer will react to a solid barrier fence

without prior experience to the other side of the fence is unknown. In a roadway situation, solid fencing may prove more effective at restricting access to roadways by naïve deer, although experimental evaluation is necessary.

Because deer often attempt to go through fencing rather than over it (Jones and Longhurst 1958), we evaluated leaving the lower section of fencing uncovered and using a 50% opaque material as an outrigger. We hypothesized that when deer confronted the fence, they would see the outrigger above them and therefore not attempt to jump. Similarly, we assumed a deer encountering the outrigger facing in the opposite direction would perceive it as little more than a 1.5-m fence. Our observations indicated that the outrigger fencing had similar effectiveness as a 2.1-m woven-wire fence, even though the vertical portion of the outrigger fence was only 1.2-m. Three deer that did not cross the fence when angled towards them did cross when the outrigger angled away from them. In our trials using naïve deer, none crossed the outrigger fence when angled toward the deer, and only one crossed in the opposite direction. As such, outrigger fencing may have potential application along roadways. Because deer were more likely to cross when outriggers were angled away from the animal, if a deer became caught on the roadway between fences, it may be more likely to escape over an outrigger fence as opposed to a 2.4-m fence. In areas where lower heights of fencing are already in place, outriggers could be retrofitted to existing fence.

Jumping ability could be considered a learned skill through both the acts of doing (i.e., learning) and watching the actions of others (i.e., observational modeling). Our deer were tested in pairs to allow for any group dynamic when crossing a barrier. The responses of the herd are often influenced of the behavior of the lead animal (Matthews 2007); however, in our study,

there were no differences in the efficacy of barriers when considering whether one deer or both deer crossed the barrier.

Experiments evaluating the effectiveness of fences in prohibiting white-tailed deer access often do not consider the behaviors and motivation of the deer. Studies have been conducted which examined the effectiveness of a fence by evaluating reduction in crop damage (Jones and Longhurst 1958) or the decrease in the number of carcasses along a roadway (Ludwig and Bremicker 1981) rather than the actual deterring ability of the fence. If the motivational factor to cross a barrier is not sufficiently strong, then a deer may select an alternate resource. Although this might indicate a fence was effective, it does not mean that a deer could not successfully cross it given the proper motivation. We attempted to pressure our deer to cross while also avoiding injury to themselves or us in the process. Most successful crossings occurred when the deer were influenced by human activity and not during the 24-hr food restriction period.

Deer often panic when confronted by stressful circumstances that which may hinder their ability to assess a situation. Deer in our study appeared to remain calm throughout the food restriction period; however, during any interaction with humans (i.e., gate shutting or light pressure) they became alert. When excited, deer may not react to a fence the same way as if they approached it without being stressed. Wilson et al. (1994) describes a shy-bold continuum as it relates to optimal risk-taking strategies. Therefore, deer on the boldness side of the continuum may be able to breach a fence without being pressured, whereas deer on the shyness side may need to be pressured to elicit a flight response in order for them to cross.

MANAGEMENT IMPLICATIONS

We concluded that the 2.4-m woven-wire fence may be the best choice for prohibiting deer access to roadways, but could trap deer that circumvent the ends of the fence and is likely

the most expensive to build. Depending on how frequent deer-vehicle collisions occur on a particular roadway, it may be as cost-effective to construct a 2.1-m woven-wire fence or outrigger fence. Outriggers allow movement in one direction reducing risk of trapped deer and could be retrofitted to existing fencing 1.2-m and higher to enhance efficacy. Further experiments should be conducted to assess the application of these fence designs under field conditions with free-ranging deer.

ACKNOWLEDGEMENTS

LITERATURE CITED

Blumstein, D.T., and A. Bouskila. 1996. Assessment and decision making in animals: a mechanistic model underlying behavioral flexibility can prevent ambiguity. Oikos 77:569-576.

Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin 29:646-653.

Conover, M.R. 2002. Threats to human safety. Pages 39-65 *in* M.R. Conover, ed. Resolving human-wildlife conflicts: The science of wildlife damage management. Lewis, Boca Raton, Florida, USA.

Conover, M.R., W.C. Pitt, K.K. Kessler, T.J. DuBow, and W.A. Sanborn. 1995. Review of
human, injuries, illnesses, and economic losses caused by wildlife in the United States.
Wildlife Society Bulletin 23:407-414.

Dostálková I., and M. Špinka. 2007. Synchronization of behaviour in pairs: the role of
communication and consequences in timing. Animal Behaviour 74:1735-1742.

Falk, N.W., H.B. Graves, and E.D. Bellis. 1978. Highway right-of-way fences as deer
deterrents. Journal of Wildlife Management 42:646-650.

Feldhamer, G.A., J.E. Gates, D.M. Harman, A.J. Loranger, and K.R. Dixon. 1986. Effects of
interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management
50:497-503.

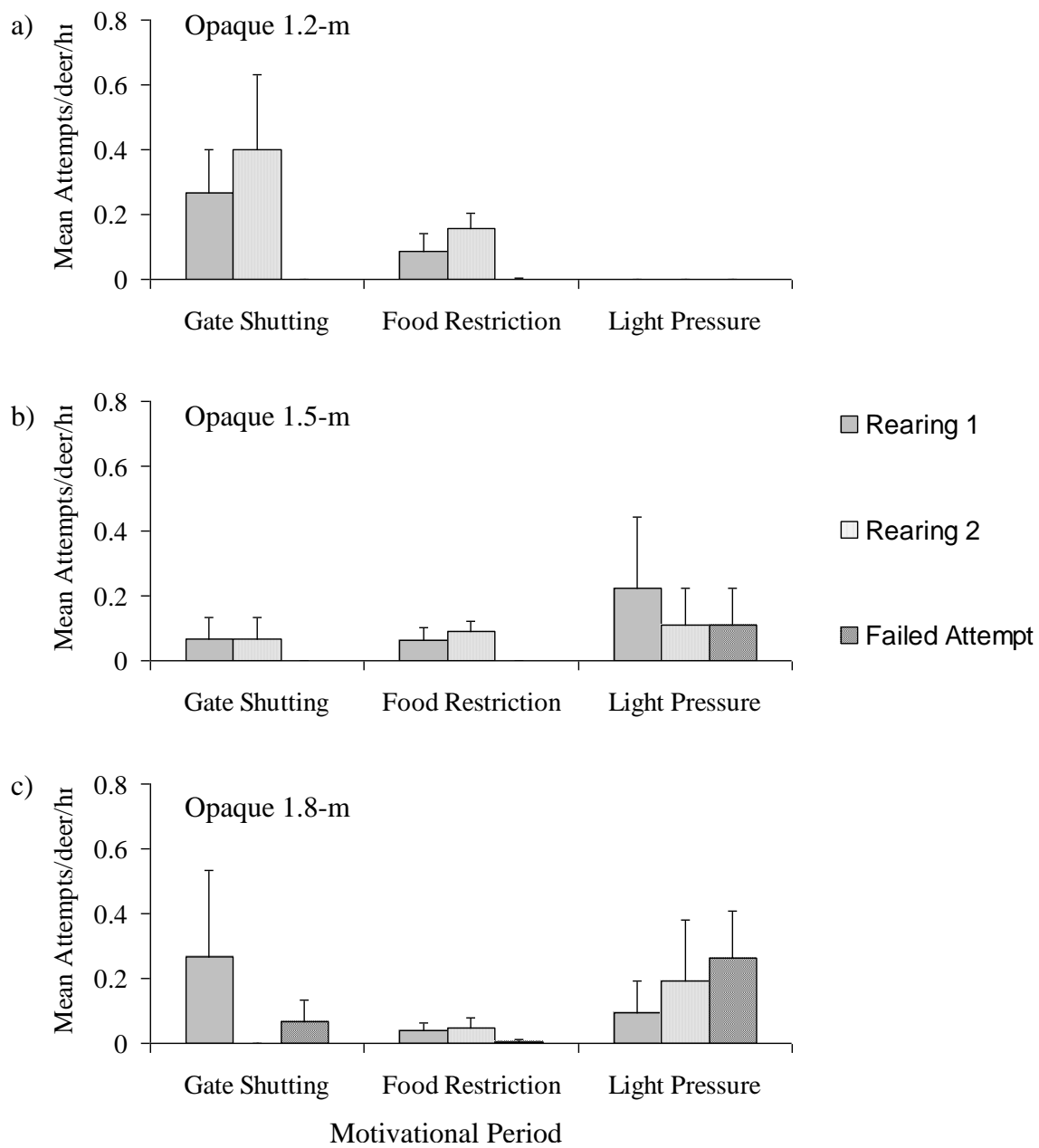Fitzwater, W.D. 1972. Barrier fencing in wildlife management. Proceedings of the Vertebrate
Pest Control Conference 5:49-55.

Gallagher, G.R., H.A. Keen, and R.H. Prince. 2003. Effectiveness of a perceived solid barrier
as an exclusion fence to prevent white-tailed deer damage. Proceedings of the Wildlife
Damage Management Conference 10:23-29.

Grandin, T. 2007. Behavioral principles of cattle handling under extensive conditions. Pages
44-64 *in* T. Grandin ed. Livestock handling and transport 3rd edition. CAB International,
Wallingford, UK.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R.
Ament. 2007. Wildlife-vehicle collision reduction study. Report to congress. U.S.
Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Jones, M.B., and W.M. Longhurst. 1958. Overhanging deer fences. Journal of Wildlife
Management 22:325-326.

Ludwig, J., and T. Bremicker. 1981. Evaluation of 2.4-meter fences and one-way gates for

    reducing deer-vehicle collisions. Minnesota Wildlife Resources Quarterly 41:77-88.

Matthews, L.R. 2007. Deer handling and transport. Pages 271-294 *in* T. Grandin ed. Livestock

    handling and transport 3rd edition. CAB International, Wallingford, UK.

Sauer, P.R. 1984. Physical characteristics. Pages 73-90 *in* L.K. Halls, editor. White-tailed

    deer: ecology and management. Stackpole Books, Harrisburg, Pennsylvania, USA.

State Farm Insurance Company. 2009. <http://www.statefarm.com/>. Accessed October 7,

    2009.

Wilson, D.S., A.B. Clark, K. Coleman, and T. Dearstyne. 1994. Shyness and boldness in

    humans and other animals. Trends in Ecology and Evolution 9:442-446.

Figure 2.1. Mean (+/- SE) attempts per hour prior to a successful crossing by captive white-tailed deer in experiments comparing various heights of woven-wire fencing: (a) 1.5-m fence, (b) 1.8-m fence, (c) 2.1-m fence, and (d) 2.4-m fence. Note: The y-axis has a maximum of 2.2-attempts/deer/hr.
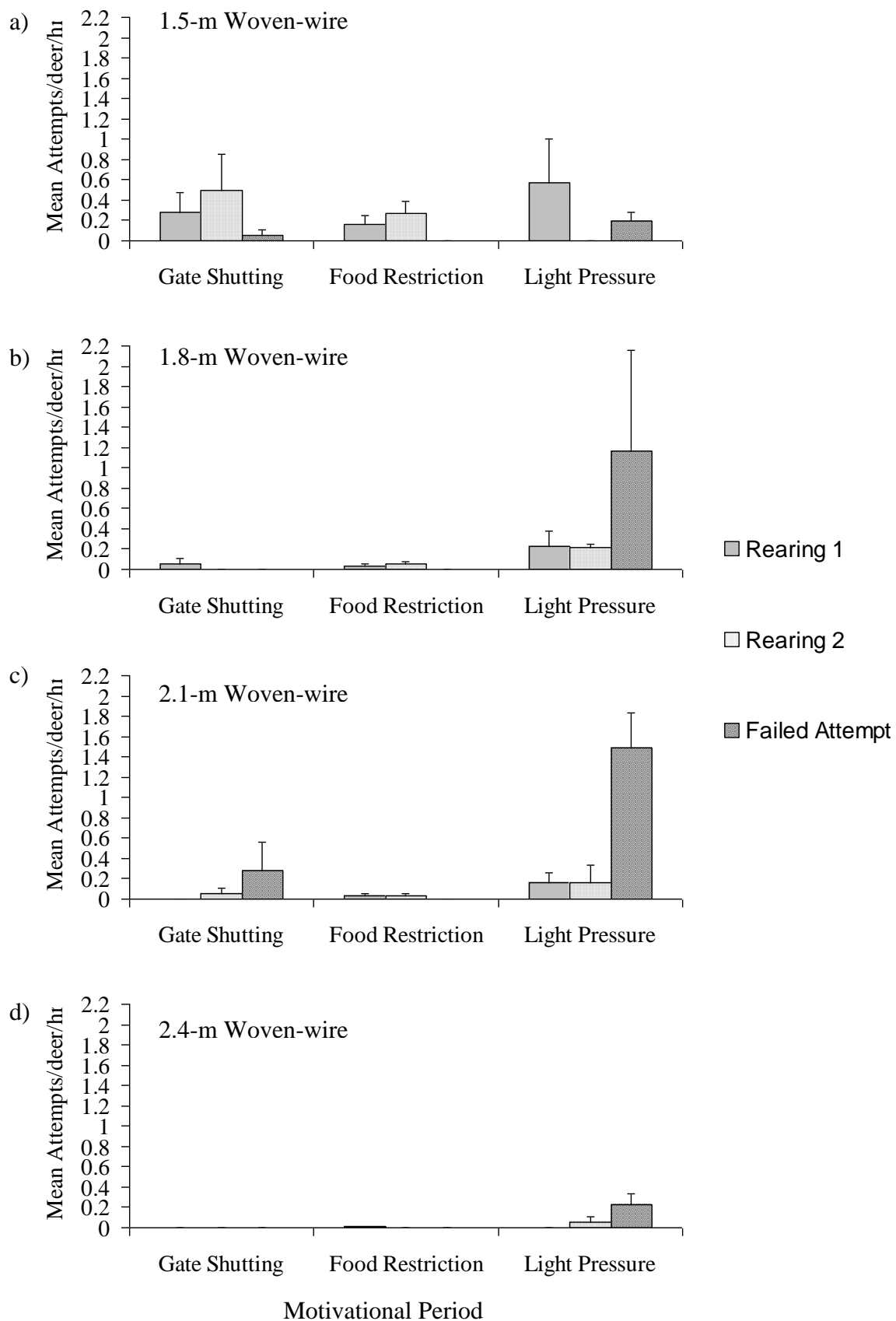
Figure 2.2. Mean (+/- SE) attempts per hour prior to a successful crossing by captive white-tailed deer in experiments comparing various heights of opaque fencing experiments: (a) opaque 1.2-m, (b) opaque 1.5-m, and (c) opaque 1.8-m. Note: The y-axis has a maximum of 0.8-attempts/deer/hr.

a)

Opaque 1.2-m

b)

Opaque 1.5-m

c)

Opaque 1.8-m

Mean Attempts/deer/hr

Motivational Period

Gate Shutting   Food Restriction   Light Pressure

Rearing 1

Rearing 2

Failed Attempt

Figure 2.3. Mean (+/- SE) attempts per hour prior to a successful crossing by captive white-tailed deer in outrigger fencing experiments: (a) outrigger angled towards trained deer, (b) outrigger angled towards naïve deer, (c) outrigger angled away from trained deer, and (d) outrigger angled away from naïve deer. Note: The y-axis has a maximum of 0.8-attempts/deer/hr.

a) **Trained Outrigger Towards**

Mean Attempts/deer/hr

Gate Shutting   Food Restriction   Light Pressure

b) **Naïve Outrigger Towards**

Mean Attempts/deer/hr

Gate Shutting   Food Restriction   Light Pressure

▢ Rearing 1

▢ Rearing 2

▣ Failed Attempt

c) **Trained Outrigger Away**

Mean Attempts/deer/hr

Gate Shutting   Food Restriction   Light Pressure

d) **Naïve Outrigger Away**

Mean Attempts/deer/hr

Gate Shutting   Food Restriction   Light Pressure

Motivational Period

Table 2.1. Percentage of captive white-tailed deer that successfully crossed, by motivational period, in all fencing experiments when treatment periods for each fence type were combined into single 75-hr periods.

Fence Type	n	Percentage Crossed			
		Gate Shutting	Food Restriction	Light Pressure	Total
1.2-m	12	33	50	17	100
1.5-m	12	25	25	42	92
1.8-m	12	25	8	42	75
2.1-m	12	8	0	33	41
2.4-m	12	0	0	0	0
Opaque 1.2-m	10	40	30	20	90
Opaque 1.5-m	10	20	50	20	90
Opaque 1.8-m	10	30	20	40	90
Trained Outrigger Towards	10	0	10	50	60
Trained Outrigger Away	10	30	30	20	80
Naïve Outrigger Towards	6	0	0	0	0
Naïve Outrigger Away	6	0	0	17	17
Combined Outrigger Towards	16	0	6	31	37
Combined Outrigger Away	16	19	19	19	57

Table 2.2. Contingency table of orthogonal contrast p-values for comparing the effectiveness of two types of fence at prohibiting captive white-tailed deer crossings. The 1.2-m fence was used as a control and compared across all fence types.

	1.2-m	Opaque 1.2-m	1.5-m	Opaque 1.5-m	1.8-m	Opaque 1.8-m	2.1-m	2.4-m	Outrigger Towards	Outrigger Away
1.2-m		0.23	0.006	0.072	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Opaque 1.2-m	0.23			0.442		0.008				
1.5-m	0.006			0.498	0.266		<0.001	<0.001		
Opaque 1.5-m	0.072	0.442	0.498			0.046				
1.8-m	<0.001		0.266			0.766	<0.001	<0.001		
Opaque 1.8-m	<0.001	0.008		0.046	0.766					
2.1-m	<0.001		<0.001		<0.001			0.006	0.46	
2.4-m	<0.001		<0.001		<0.001		0.006			
Outrigger Towards	<0.001						0.46			0.012
Outrigger Away	<0.001								0.012	

Figure 2.4. Odds ratio for the likelihood of captive white-tailed deer not crossing a fence type when compared to the likelihood of not crossing a 1.2-m woven-wire fence.
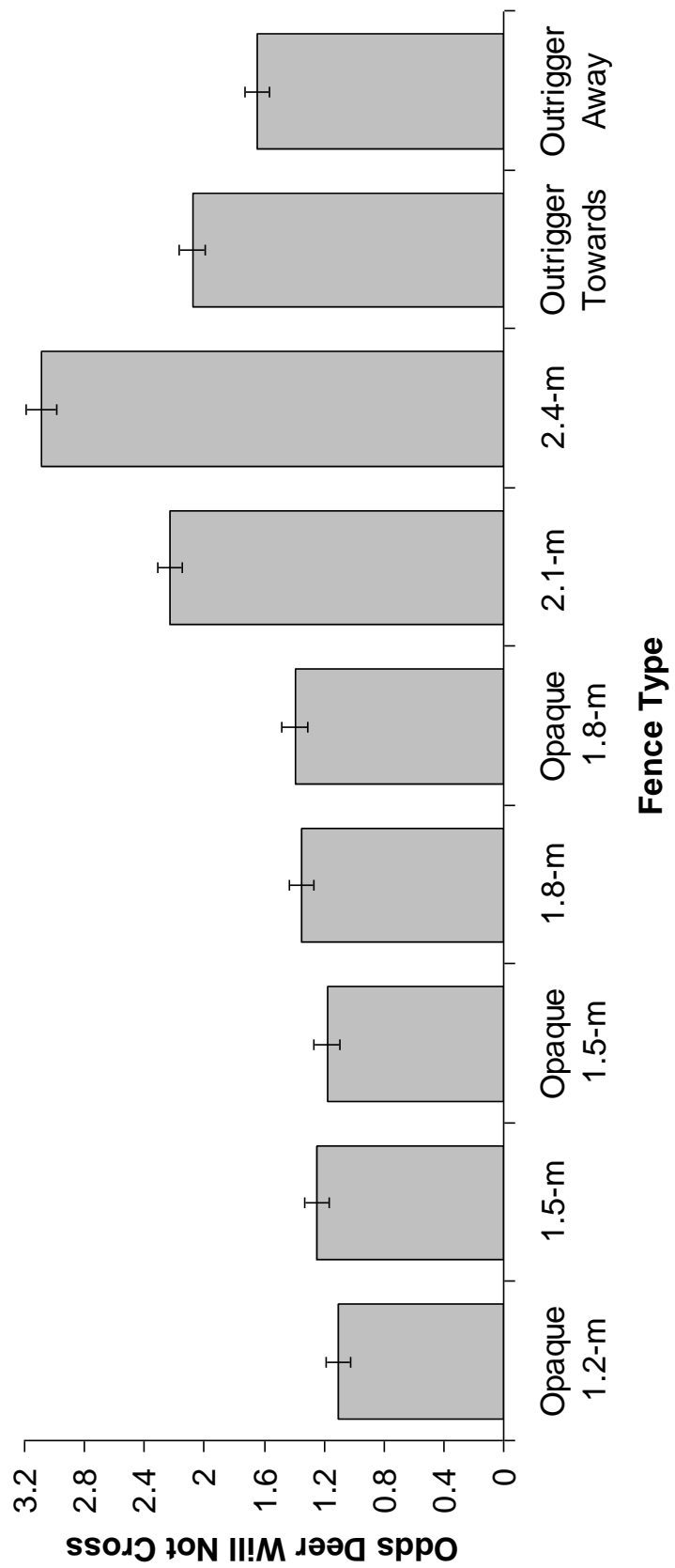
CHAPTER 3

SUMMARY AND CONCLUSIONS

As the number of deer-vehicle collisions continually increases across the country, state and federal transportation departments look for ways of effectively keeping deer out of roadways. Existing strategies, such as deer visual and auditory deterrents, have been shown to be ineffective as have attempts to alter motorist behavior through roadway signage. Many states have begun incorporating fencing along roadways as a barrier to exclude deer from roads. Height of these fences varies by location and year of construction. Therefore, we evaluated the ability of untamed, captive deer to cross fences of various heights and evaluated design modifications that could be retrofitted to preexisting fences.

From the University of Georgia captive deer herd, we selected adult females (i.e., does ≥1.5 years-old) that appeared to be the least habituated to humans and most likely to act like wild deer. These deer were placed into two-deer groups and then subjected to a series of fencing trials. We first tested their interactions with a 1.2-m woven-wire fence and increased fence heights by 0.3-m increments for each subsequent trial to a maximum of 2.4-m. A trial was completed, and fence height was raised, when each two-deer group had interacted with that particular fence height in each of three treatment areas. Frequency of woven-wire fence crossing by deer decreased as fence height increased. No deer successfully crossed a 2.4-m woven-wire fence.

After the woven-wire fence trials were concluded, we tested efficacy of woven-wire fences retrofitted with an opaque covering. We began these trials with 1.2-m fences and

40

increased the height of fences by 0.3-m increments to a maximum of 1.8-m. There was no decrease in successful crossings when we added the opaque covering to fences.

After the opaque fence trials were concluded, we tested the efficacy of 1.2-m woven-wire fences retrofitted with a 50% opaque, 0.6-m wide, 45° outrigger fence. This outrigger fence was attached to the top strand of each woven-wire fence and secured to each support post. We tested the ability of deer to cross these fences with the outrigger fence facing towards them and away from them. When outrigger fences faced away from the deer, frequency of successful crossings was greater ($P = 0.012$) We then included naïve deer in the experiment to determine if fence-crossing experiences during previous trials influenced a deer's ability to cross a 1.2-m fence with the outrigger modification. In these trials, none (0 of 6) of the naïve deer crossed the fence when the outrigger fence faced towards them. Only one naïve deer crossed the fence when the outrigger fence faced away from them.

In our experiments, no deer crossed the 2.4-m woven-wire fence. The woven-wire fences with opaque coverings had similar efficacy as the same height woven-wire fence without the covering (1.2-m: $P = 0.2$, 1.5-m: $P = 0.5$, 1.8-m: $P = 0.8$). We believed the opaque covering provided deer with a better visual reference, and enhanced their ability to cross. The 2.1-m woven-wire fence and the 1.2-m woven-wire fence with an outrigger fence facing towards the deer had similar efficacy ($P = 0.46$). It may be beneficial to retrofit existing 1.2-m roadway exclusion fences with a top-mounted outrigger fence facing away from the road. This design would decrease successful crossings into the road, and allow deer trapped between two exclusion fences to escape, without the added cost of building earthen ramps or one-way gates. Field trials of the outrigger-style fence should be tested along segments of roadways to evaluate its effectiveness in a real world application before being considered further.

APPENDIX A

EFFICACY OF TACTILE BARRIER AT PROHIBITING DEER MOVEMENT

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*)-vehicle collisions present a significant hazard

to motorists in the United States. Dense deer populations, coupled with a growing human

population and concurrent expansion of the nation's roadway system have increased the risk of

deer-vehicle collisions. Recently published statistical accounts reported 1.5 million deer-vehicle

collisions each year, causing approximately 29,000 injuries, 150-200 human deaths, $1.1 billion

in property damage, and the deaths of 92% of involved deer (Allen and McCullough 1976,

Conover et al. 1995, State Farm Insurance Company 2009). Although the total number of all

vehicle crashes throughout the United States has remained relatively unchanged since 1990, the

proportion of wildlife vehicle collisions has increased steadily by 6,769 each year with deer-

vehicle collisions constituting 77% (5,212/yr) of the collisions with wildlife (Huijser et al. 2007).

Barriers that attempt to exploit "weaknesses" in the hoof function of the white-tailed

deer, hereafter called tactile barriers, have shown promise in preventing crossings. Cattle guards

and other grates of varying materials and patterns have been used in urban areas to successfully

prohibit deer access by creating a surface that is uncomfortable under the hoof (Belant et al.

1998, Peterson et al. 2003, Sebesta et al. 2003). However, cattle guards can be breached if they

are not spaced correctly or if the animal's hooves can reach the ground beneath the grate (Reed

et al., 1974, Sebesta et al. 2003). Other tactile designs, such as the "slippery fence" design,

which uses lubricated sheets of metal angled at 10°, also serve as effective tactile barriers by

reducing friction under the hoof of the animal, hindering crossing (Gallagher et al. 2005).

Although long expanses of cattle guards and the "slippery fence" are likely infeasible, alternative

tactile barriers such as rip-rap (i.e., large pieces of crushed rock) have not been evaluated for

effectiveness.

Rip-rap has not been tested specifically as a tactile barrier for deer crossings, although

Austin and Garland (2001) and Cramer and Bissonette (2006) discussed how rip-rap was

removed from wildlife underpasses and other passageways because it prohibited deer movement.

Additionally, in 2004 a swath of rip-rap was used along the Christopher Creek Section of

Arizona's State Route 260 as an alternative to ungulate fencing (Dodd et al. 2005). Our

objective was to evaluate the effectiveness of rip-rap as a tactile barrier to prohibit movement by

captive white-tailed deer.

STUDY AREA

We conducted our study at the Daniel B. Warnell School of Forestry and Natural

Resources, Whitehall Deer Research Facility at the University of Georgia, Athens, Georgia,

USA. This facility spans 2.4-ha and is bordered by 3-m high, woven-wire fence. The facility

has 5 outdoor paddocks (0.4-0.8 ha), 3 sorting pens (15 x20-m), a barn containing of 19 roofed

stalls (3 x 6 m), and a rotunda with movable walls to direct deer movement. The outdoor

paddock used in this study was dominated by grasses (*Festuca arundinacea* and *Cynodon*

dactylon). Experiments were conducted in a smaller pen (0.2 ha) built within the paddock.

METHODS

Animal use and handling procedures were approved by the Institutional Animal Care and

Use Committees of the University of Georgia (AUP# A2007-10127-0) at the Whitehall Deer

Research Facility. We selected 10 adult females (≥1.5 year-old does) based on their reaction to

human interaction, age, and physical condition. We selected does to eliminate extraneous variables, such as the effects of rut, and to ease the process of moving deer between indoor stalls and outdoor paddocks. All deer were ear-tagged for identification and divided into five, two-deer groups, additionally one deer in each group was fitted with a highly visible rubber collar to distinguish individuals among groups. White-tailed deer are social animals, therefore it is important to account for group dynamics when assessing deer behavior around a tactile barrier. Hence, we used two-deer groups as opposed to individuals as it is more natural.

We constructed a treatment area (i.e., C1) within one of the paddocks. The treatment area was bisected by a 6.1-m swath of a single layer of Type III rip-rap. The treatment area was surrounded by 2.4-m, woven-wire fence covered with 100% opaque shade cloth to limit external disturbances to the deer. Water was available at all times on both sides of the tactile barrier within each treatment area, while food was only available on one side. A gate was constructed to allow deer to pass unimpeded during the habituation period. An equal parts mix of Meadow's Edge Deer Feed (Meadow's Edge, Millen, GA) and Omolene #300 Growth Horse Feed (Land O'Lakes Purina Mills, Gray Summit, MO) was used as the food incentive. Food was rationed to 1.4 kg/deer in the treatment areas to increase motivation, via hunger, to access food during the treatment period.

During each behavioral trial, a two-deer group spent 48 hours in the treatment area with access to both sides of the tactile barrier, via a gate, to become habituated to the pen layout (i.e., habituation period). After 48 hours, the deer were excluded from the side of the treatment area containing food and were required to breach the tactile barrier to access their food (i.e., treatment period). This food restriction lasted for approximately 24 hours. At the end of each 24-hour treatment period, we applied "light pressure" to encourage the deer to breach the tactile barrier if

it appeared they had not already crossed. We standardized the characteristics of "light pressure" by progressing through three levels of human activity, applied by the same researchers, each time. If deer did not attempt to cross the tactile barrier during Level 1 pressure, we proceeded to Level 2 pressure, and so on. Level 1 pressure involved a researcher standing at the back of the treatment area with the deer that had not crossed. During Level 2, the researcher remained standing and began antagonizing the deer with noise (i.e., clapping and shouting). If Level 3 was necessary, the researcher moved about the pen while continually making antagonistic noise. We discontinued all "pressure" once both deer had attempted to breach the tactile barrier (i.e., attempt to cross and fail or successfully crossed), it was apparent that the deer would not attempt, or 15 minutes had passed since the researcher had entered the pen. If deer had not successfully crossed the tactile barrier after Level 3 pressure, we considered the tactile barrier effective during that individual trial. The deer groups were moved into barn stalls following the treatment period and had access to water ad libitum and an increased ration of food (1.6 kg/deer).

The two-deer groups were monitored continuously throughout the 72-hour experimental period with an infrared day/night camera (Model No. PC1771R-6; Supercircuits Inc., Austin, TX) recording to an ARCHOS 504 Digital Media Player (160 GB) with a digital video recorder station (Archos Inc., Greenwood Village, CO) housed in a waterproof container. We stored the digital video files on hard drives and transferred to computers for review. Videos were reviewed using Videolan-VLC media player 0.8.6 (videolan.org).

RESULTS AND DISCUSSION

During November-December 2008 we conducted tactile barrier experiments with five 2-deer groups. A single layer of Type III rip-rap substrate did not appear to inhibit white-tailed deer crossings. All deer successfully crossed the tactile barrier with little or no hesitation. Some

45

deer attempted to leap across the gap but were unsuccessful. Deer were able to continue moving across the substrate without faltering after landing.

Although, there have been studies that have referenced the use of rip-rap to direct the movement of deer to a certain location or removal of rip-rap to provide access to deer, none have actually evaluated the effectiveness of rip-rap as a tactile barrier (Austin and Garland 2001, Dodd et al. 2005, and Cramer and Bissonette 2006). The most common and prohibitive type of tactile barriers have gaps large enough for the legs of deer to slip through and are deep enough so they cannot make contact with the ground beneath. Mule deer (*O. hemionus*) reportedly crossed narrow, flat, metal cattle guards by catching their dew claws on the guard to keep from falling through (Reed et al. 1974). If mule deer can cross such obstacles, then white-tailed deer might also. Peterson et al. (2003) discovered that a rectangular grid pattern with the rectangle diagonally dissected by a cross member was the most successful grate for prohibiting Florida Key deer (*O. v. clavium*) access to a corn feeder when compared to two different rectangle grid patterns. If rip-rap mimicked the visual and tactile complexity of the above grate pattern, then we expected it to minimize deer crossings.

Over time, rip-rap settles, collects organic and inorganic debris, and plants become established between the rocks. Multiple layers of rip-rap may be needed to effectively minimize deer crossing attempts, but frequent maintenance of the rip-rap would be necessary. In our experiment, plants grew among the rip-rap rocks within weeks of construction, requiring herbicide control. Without frequent maintenance, this would have created a flat mat of rock and grass and further reduced the unevenness and presumably the efficacy of this tactile barrier.

LITERATURE CITED

Allen, R. E. and D.R. McCullough. 1976. Deer-car accidents in southern Michigan. Journal of
    Wildlife Management 40:317-325.

Austin, J.M. and L. Garland. 2001. Evaluation of a wildlife underpass on Vermont State
    Highway 289 in Essex, Vermont. Pages 616-624 *in* C.L. Irwin, P. Garrett, and K.P.
    McDermott, eds. Proceedings of the 2001 International Conference on Ecology and
    Transportation. Center for Transportation and the Environment, North Carolina State
    University, Raleigh, North Carolina, USA.

Belant, J.L., T.W. Seamans, and C.P. Dwyer. 1998. Cattle guards reduce white-tailed deer
    crossings through fence openings. Journal of Pest Management 44:247-249.

Conover, M.R., W.C. Pitt, K.K. Kessler, T.J. DuBow, and W.A. Sanborn. 1995. Review of
    human, injuries, illnesses, and economic losses caused by wildlife in the United States.
    Wildlife Society Bulletin 23:407-414.

Cramer, P.C. and J.A. Bissonette. 2006. Wildlife crossings in North America: the state of the
    science and practice. Pages 442-447 *in* C.L. Irwin, P. Garrett, and K.P. McDermott, eds.
    Proceedings of the 2006 International Conference on Ecology and Transportation. Center
    for Transportation and the Environment, North Carolina State University, Raleigh, North
    Carolina, USA.

Dodd, N.L., J.W. Gagnon, S. Boe, R.E. Schweinsburg. 2005. Characteristics of elk-vehicle
    collisions and comparison to GPS-determined highway crossing patterns. Pages 461-477
    in C.L. Irwin, P. Garrett, and K.P. McDermott, eds. Proceedings of the 2005
    International Conference on Ecology and Transportation. Center for Transportation and
    the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Gallagher, G.R., H.A. Keen, and R.H. Prince. 2005. Effectiveness of a white-tailed deer

 exclusion fence based on traction limitations of the hoof: the slippery fence.

 Proceedings of the Wildlife Damage Management Conference 11:233-241.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R.

 Ament. 2007. Wildlife-vehicle collision reduction study. Report to Congress. U.S.

 Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Peterson, M.N., R.R. Lopez, N.J. Silvy, C.B. Owen, P.A. Frank, A.W. Braden. 2003.

 Evaluation of deer-exclusion grates in urban areas. Wildlife Society Bulletin 31:1198-

 1204.

Reed, D.F., T.M. Pojar, and T.N. Woodward. 1974. Mule deer responses to deer guards.

 Journal of Range Management 27:111-113.

Sebesta J.D., S.W. Whisenant, R.R. Lopez, N.J. Silvy. 2003. Development of a deer guard

 prototype for Florida Key deer. Proceedings of the Annual Conference of the

 Southeastern Associations of Fish and Wildlife Agencies 57:337-347.

State Farm Insurance Company. 2009. <http://www.statefarm.com/>. Accessed October 7,

 2009.