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Comparison of fencing designs for excluding deer from roadways

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Abstract: We evaluated the efficacy of several fencing designs for restricting movements of 18 captive, female white-tailed deer (*Odocoelus virginianus*), including standard woven-wire fencing (1.2-m, 1.5-m, 1.8-m, 2.1-m, and 2.4-m tall), opaque fencing (1.2-m, 1.5-m, and 1.8-m tall), and an outrigger fence (i.e., 0.6-m outriggers attached to a 1.2-m-tall wire fence angled at 45º). We recorded the number of successful fence crossings for each deer and characterized behaviors associated with each failed crossing attempt. No deer crossed the 2.4-m fence, whereas all deer crossed the 1.2-m fence. We observed no differences in crossing success between woven-wire and opaque fencing at heights <1.8 m. The outrigger fence was as effective as the 2.1-m fence when the outrigger was angled toward the deer. Efficacy decreased when the outrigger was angled away from the deer. Therefore, this fencing design may act as a 1-way barrier, discouraging deer from entering the roadway, but, unlike standard 2.4-m fencing, allowing them to exit it should they become trapped.

Key words: deer–vehicle collision, fencing, human–wildlife conflicts, *Odocoileus virginianus*, white-tailed deer

Increasing populations of white-tailed deer (*Odocoileus virginanus*), particularly in urban and suburban areas, combined with expanding human populations and increased vehicular traffic, have increased the risk of deer–vehicle collisions (DVCs). For example, from 1990 to 2004, the number of wildlife-related collisions in the United States increased by 6,769 per year, with DVCs accounting for 77% (5,212 per year) of the increase (Huijser et al. 2007). Each year, an estimated 1.5 million DVCs cause 29,000 human injuries, 150 to 200 human deaths (Conover et al. 1995), and $1.1 billion in personal property damage (State Farm Insurance Company 2009).

Various mitigation devices and strategies have been employed to reduce the frequency of DVCs, including animal-detection systems, deer whistles, roadside reflectors, roadway signage, deer population reduction, underpasses, overpasses, and exclusion fences. Construction of exclusion fences is the most effective non-lethal strategy for prohibiting deer access to roadways and reducing the risk of DVCs (Falk et al. 1978, Feldhamer et al. 1986, Clevenger et al. 2001). Fencing ≥2.4 m in height typically excludes deer from the roadway when it is erected on both sides of a roadway (Knapp et al. 2004, Huijser et al. 2007). However, if roadside fences do not extend beyond the home ranges of deer, problem deer will likely circumvent the fence ends and become trapped within the roadway thereby increasing the risk of DVCs (Conover 2002, Gulsby 2010). To be most effective, exclusion fences must allow deer to escape when they become trapped between opposing fences.

Sauer (1984) reported that white-tailed deer could jump a 2.1-m-high fence from a standing start and a 2.4-m-high fence from a running start. In contrast, other researchers have reported that a 2.4-m-fence was sufficient to prevent deer crossings (Fitzwater 1972, VerCauteren et al. 2010). Ludwig and Bremicker (1981) concluded that 2.4-m fencing was effective at keeping deer out of roadways, provided that the fence was extended well beyond high-risk areas. Alternately, Gallagher et al. (2003) reported that a 1.7-m-tall visual barrier consisting of 100% opaque hanging burlap effectively excluded deer from a feeding station, suggesting that short, opaque barriers may be as effective at excluding deer as tall, woven-wire barriers. Additionally, it has been shown that solid barriers were more effective than woven-wire fencing when directing movements of excited, wild ungulates, with less risk of animal injury (Grandin 2007).

The lack of consensus among studies examining which fences excluded deer can be attributed to the variation in disposition of individual deer. Wilson et al. (1994) explained that it is difficult to predict how any individual within a population of animals will react in a given situation because risk-taking behavior is distributed along a shy-bold continuum. Therefore, bold deer might be sufficiently motivated to attempt a crossing when confronted with a low-level threat or food restriction. However, shy deer might not attempt to cross unless a flight response was evoked by a high-level threat, with the deer jumping only when panicked.

Our objective was to test various fence designs for their potential to exclude deer from roadways based on a deer's jumping ability and visual perception of barriers. We quantified deer behaviors in relation to exclusion fences and compared the efficacy of each fence design to that of standard 2.4-m woven-wire fencing. In addition, we conducted an a posteriori trial of 1 promising fence design to evaluate the effect of operant conditioning on the fence-crossing behavior of deer.

Study area

We conducted our study at the Warnell School of Forestry and Natural Resources' Whitehall Deer Research Facility at the University of Georgia, Athens, Georgia. The 2.6-ha facility was composed of 5 outdoor paddocks, each 0.4 to 0.8 ha in size, 3 sorting pens (15m × 20 m), and an enclosed 19-stall (3-m × 6-m) barn. The entire facility was surrounded by 2.4- to 3.0-m tall woven-wire fencing. We used 2 outdoor paddocks with a dominant cover of pine (*Pinus* spp.) and oak (*Quercus* spp.) of various ages. We constructed 3 (0.1 to 0.2 ha) treatment areas within these outdoor paddocks. Each treatment area was surrounded by 2.4-m woven-wire fence covered with 100% opaque shade cloth to limit external disturbances to the test deer. For each trial, we bisected the treatment areas with the test fence.

Methods

We selected 12 adult (≥1.5 years old), nonpregnant, female white-tailed deer for the trials based on their general appearance of good physical health, display of evoked flight responses when approached by a person, and their willingness to jump a 1.2-m woven-wire fence (positive control fence). We believed that the ability and motivation of each test deer to jump obstacles to obtain food or flee from a perceived threat was comparable to those of free-ranging deer. Our positive control fence was typical of that used by state transportation departments, including the Georgia Department of Transportation, to delineate the right-of-way along roadways.

We randomly assigned the deer into 6, groups, each with 2 deer, and fitted 1 deer in each group with a brightly-colored collar that enabled us to differentiate each deer in digitally recorded videos. We removed 2 deer (1 from each of 2 groups) following the 2.4-m woven-wire fence trials because one was injured and the other became habituated to researchers. The remaining 2 deer from these groups were then paired, resulting in 5 groups with 2-deer each. Although deer assigned to this experiment had no previous fence-jumping experience, we believed some learned to jump fences through operant conditioning during our trials. Therefore, we included 6 naïve deer (i.e., deer without fence-crossing experience) in 3 groups with 2 deer each in an *a posteriori* trial to test this possibility.

Our test fence designs included woven-wire fencing (Solidlock®, Bekaert, Marietta, Ga.) of various heights (1.5-m, 1.8-m, 2.1-m,

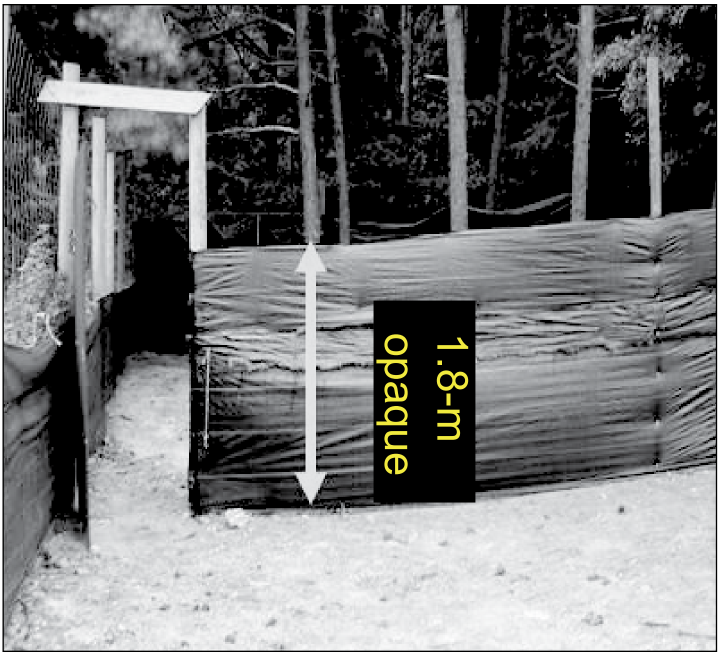

Figure 1. We tested the efficacy of each fence design and height to restrict deer movements in each of 3 treatment areas. This photograph shows an example of a treatment area with test fence and pass-through gate installed.

and 2.4-m high), woven-wire fencing (1.2-m, 1.5-m, and 1.8-m high) covered with a 100% opaque landscape fabric (DeWitt Ultra Web 3000 Groundcover, DeWitt, Sikeston, Mo.), and 1.2-m high woven-wire fencing with a 0.6-m, 50% opaque plastic outrigger attached to the top and angled at 45° (Figure 1). We tested the outrigger fence with the outrigger angled both toward and away from the deer. We attached a 5.1-cm strip of white polytape (LACME Electric Fencing Systems, La Flèche, France) linearly along the top, as a visual reference for the deer.

We provided water *ad libitum* on both sides of the test fence, in each treatment area. Food (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 available only on 1 side of each test fence. During a 48-hour habituation period, which immediately preceded each trial, a 2.4-m solid wooden gate (pass-through gate) located at the end of each test fence remained open, allowing deer to move freely throughout the treatment area (i.e., both sides of the test fence; Figure 1). During this period, we limited food consumption to <1.4-kg per deer per day. Immediately after the habituation period, deer were restricted to the side of the treatment area with no food by closing the pass-through gate. Once the gate was closed, with the exception of the 100% opaque fences, deer could look through the fences and see the opposite side, but not gain access without jumping the fence. To control for possible treatment area effects, we exposed each 2-deer group to each test fence design in each treatment area ($n = 3$).

We provided deer with 3 levels of motivation to encourage them to attempt a fence crossing, and we recorded behaviors specific to each level. We believed that the presence of a researcher in the treatment area during gate closing provided a low-level threat to the deer. Therefore, we defined the first 0.5 hour of each trial as the early-forced-choice period. During the subsequent 24 hours of the trial, we separated deer from their food by placing them on the opposite side of the test fence (i.e., food-restriction period). If a deer had not crossed the test fence during the food-restriction period, we attempted to evoke a flight response. During this late-forced-choice motivation period, an individual researcher quietly entered the treatment area and stood motionless. If each deer did not attempt a crossing, the researcher increased the threat level by clapping, shouting and walking toward it. The trial ended when each deer had attempted to cross the fence, or it was determined that it would not do so.

Following each 25-hour trial (early-forced-choice, food-restriction, and late-forced-choice periods, combined), deer were moved into barn stalls and supplied with water *ad libitum* and an increased supply of feed (1.6-kg/deer/day). All animal care and handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A2007-10127-0).

Throughout each 25-hour trial, deer behaviors were continuously recorded by an infrared day-night camera (Model No. PC1771R-6, Supercircuits Inc., Austin, Tex.), attached to a digital video recorder (DVR; ARCHOS 504 Digital Media Player, Archos Inc., Greenwood Village, Colo.) housed in a waterproof container. Digital video files were stored on hard drives and transferred to computers for subsequent data retrieval. Videos were viewed using the Videolan-VLC media player 0.8.6 (<www.videolan.org>). We characterized and quantified deer behavior in relation to each test fence, defining behaviors as a fence interaction, failed attempt, or a successful crossing. We recorded a behavior as a fence interaction when a deer raised 1 or both forelegs toward the test fence, exhibited a failed attempt, or exhibited a successful crossing. We recorded a behavior as a failed attempt when all 4 of a deer's hooves left the ground, but it did not gain access to the other side. We recorded a behavior as a crossing when a deer jumped completely over the test fence. We recorded the time (i.e., elapsed time since gate closing) and duration of each observed behavior. For deer that crossed a test fence multiple times, we used only their first crossing in our data analysis. Deer that crossed during 1 motivation period were excluded from analysis in subsequent periods. For example, if a deer jumped the fence when the gate was closed, the trial ended for that deer-test fence-treatment area combination. We summed each deer's observed behaviors during each 25-hour trial across the 3 treatment areas (i.e., 75-hour of combined observation). Because each deer had 3 opportunities (i.e., 3 treatment areas) to jump a particular test fence design, the cumulative number of crossings could exceed the number of deer tested.

We modeled the probability of a deer jumping the fence types (fixed effects) during any motivation period using logistic regression with the lme4 package (<www.cran.r-project.org/web/packages/lme4>) in the R statistical system (version 2.9.2; R Foundation for Statistical Computing, Vienna, Austria). We believed *a priori* that deer within common groups would not be independent samples; thus, we treated each deer group as a random effect in a multilevel model (Gelman and Hill 2006). This allowed us to report the least-biased parameter estimates and estimates of variance. Posterior parameter estimates, variances, and *P* values for the fixed-effects (i.e., fence type) were generated using Markov chain Monte Carlo (MCMC) sampling in the languageR package (<http://cran.r-project.org/web/packages/languageR>). The fixed effect parameter estimates were transformed into odds ratios to aid in interpretation and are to be interpreted as a measure of effect size. We used cross validation to assess model prediction accuracy. We refit the logistic regression model to a training dataset and then compared it to the test dataset not used to fit the model. We used this error rate to determine how well the model fit the data and its predictive accuracy. Given the economic importance and human-life risk associated with DVCs, we believed *a priori* that a misclassification rate ≥25% was unacceptable.

Results

During January 21 to November 4, 2008, we recorded 1,210 observations of deer behaviors associated with the various test-fence designs during 233, 25-hour trials. When compared to 12 (100%) deer that crossed the 1.2-m woven-wire control fence, fewer deer crossed each subsequently taller woven-wire fence (1.5 m = 92%), 1.8 m = 75%, 2.1 m = 42%, and 2.4 m = 0%. When pooled across treatment areas, the number of fence interactions and successful crossings trended downward as the height of woven-wire fences increased (Table 1). The number of failed attempts trended upward as woven-wire fence height increased from 1.5 m to 2.1 m, then dropped when fence height was raised to 2.4 m. Most deer crossed the 1.5-m woven-wire fences during the early-forced-choice and food-restriction periods (Table 2). When the height of woven-wire fence was raised to 1.8-m and 2.1-m, most deer crossed during the late-forced-choice period. The 2.4-m woven-wire fence prevented all deer from crossing.

Of deer in the opaque fence trails, 9 (90%) crossed the 1.2- and 1.5-m fences, and 5 (50%) crossed the 1.8-m fence. When considering opaque fences, the number of fence interactions and crossings trended downward as fence height increased. The number of failed attempts was relatively low during all opaque fence trials, but relatively more deer failed when the fence height reached 1.8 m (Table 1). Most deer crossed opaque fences during the early-forced-choice and food-restriction periods (Table 2).

Table 1. Number of behaviors recorded for captive white-tailed deer motivated to jump fences during 75-hour observation period (25 hours per treatment area) when pooled across 3 (0.1 tp 0.2 ha) treatment areas, Athens, Georgia, January 21 to November 4, 2008.

Fence design	Number of deer tested	Number of behaviors		
		Fence interaction[1]	Failed attempt[2]	Crossing[3]
1.5-m woven	12	302	4	27
1.8-m woven	12	117	14	23
2.1-m woven	12	109	31	7
2.4-m woven	12	16	6	0
1.2-m opaque	10	153	1	27
1.5-m opaque	10	119	1	25
1.8-m opaque	10	94	6	18
1.2-m outrigger toward	10	177	20	8
1.2-m outrigger away	10	79	2	15
1.2-m outrigger toward, naive[4]	6	21	2	0
1.2-m outrigger away, naive[4]	6	17	0	2

[1] Fence interaction = 1 or 2 forelegs raised toward fence, failed attempt, or successful crossing.

[2] Failed attempt = all 4 legs off the ground, but deer remained on same side of fence.

[3] Crossing = deer jumped the fence.

[4] Deer without previous fence-crossing experience.

Deer with previous experience crossing fences (in our trials) crossed the outrigger fence; more deer (90%) crossed when it was angled away from them than toward them (60%). However, deer interacted with fences less and failed to cross them less when the outriggers were angled away (Table 1). When outriggers were angled away from the deer, most crossings occurred during the early-forced-choice and food-restriction periods (Table 2). When outriggers were angled toward the deer, a majority of crossings occurred during the late-forced-choice period. In comparison, deer without previous experience crossing fences (i.e., naïve deer) rarely interacted with either outrigger fence design or successfully crossed (Table 1). The only fence crossing by naïve deer (2 of 6 deer) occurred when the outrigger was angled away from them during the late-forced-choice period.

The logistic regression model predicted 83% (17% misclassification rate) of the fence crossings for the subsample of the dataset used to test model predictive accuracy (Table 3). This error rate fell within our *a priori* rate of acceptability. The fixed effects within the model indicated that the probability of an individual crossing a fence is affected by fence height and design (Figure 2). Generally, as fence height increased, the odds ratios decreased. The 2.4-m fence had the lowest odds ratio (0.32), suggesting that deer were 3.08 (1/0.324 = 3.08) times less likely to cross this fence than the 1.2-m fence. The 2.1-m fence was the second most effective, and deer were 2.07 times less likely to cross it than the 1.2-m fence. Deer were 2.07 and 1.64 times less likely to cross the outrigger fence than the 1.2-m fence when it was angled toward versus away from them, respectively. Among the opaque fences, only the 1.8-m-tall fence reduced the likelihood of a successful jump.

Discussion

Because of their effectiveness, fences have been used throughout history to alter wildlife movements and reduce wildlife-related damage

Table 2. Cumulative number of fence crossings and percentage of crossings by period of motivation (pooled across 3 treatment areas) for captive white-tailed deer during a 75-hour observation period, Athens, Georgia, January 21 to November 4, 2008.

Fence design	*n*	Cumulative crossings	Percentage of crossings by period		
			Early-forced-choice	Food restriction	Late-forced-choice
1.2-m woven-wire	12	–			
1.5-m woven-wire	12	27.0	33.3	25.9	40.8
1.8-m woven-wire	12	23.0	21.7	4.3	74.0
2.1-m woven-wire	12	7.0	14.3	0.0	85.7
2.4-m woven-wire	12	0.0	0.0	0.0	0.0
1.2-m opaque	10	27.0	29.6	40.8	29.6
1.5-m opaque	10	25.0	16.0	40.0	44.0
1.8-m opaque	10	18.0	22.2	38.9	38.9
1.2-m outrigger toward	10	8.0	0.0	12.5	87.5
1.2-m outrigger away	10	15.0	20.0	40.0	40.0
1.2-m outrigger toward, naïve deer[1]	6	–	0.0	0.0	0.0
1.2-m outrigger away, naïve deer[1]	6	–	0.0	0.0	17.0

[1] Deer without previous experience of crossing fences.

Table 3. Parameter estimates, odds ratios, *P*-values, and confidence limits for each fence type (fixed effects) estimated by a logistic regression model[1] using fence-crossing data for captive white-tailed deer during a 75-hour observation period, Athens, Georgia, January 21 to November 4, 2008.

Parameter	Model coefficient			*P*-value[2]	Odds ratio		
	Estimate	LCL	UCL		Estimate	LCL	UCL
(Intercept) 1.2 m contained in intercept	1.001	0.812	1.191	0.0001			
1.2 m opaque	-0.099	-0.265	0.066	0.2452	0.906	0.768	0.905
1.5 m	-0.219	-0.378	-0.065	0.0074	0.803	0.685	0.803
1.5 m opaque	-0.165	-0.333	-0.002	0.0510	0.848	0.719	0.845
1.8 m	-0.303	-0.456	-0.142	0.0001	0.739	0.631	0.743
1.8 m opaque	-0.332	-0.497	-0.167	0.0002	0.717	0.608	0.718
2.1	-0.803	-0.960	-0.642	0.0001	0.448	0.382	0.449
2.4	-1.127	-1.325	-0.924	0.0001	0.324	0.266	0.324
1.2 outrigger toward	-0.732	-0.898	-0.564	0.0001	0.481	0.408	0.481
1.2 outrigger away	-0.499	-0.664	-0.331	0.0001	0.607	0.515	0.607

[1] AIC = 276.9; unexplained within deer-group variation, $\alpha = 0.33$; MR=17%.
[2] *P*-value based on *t*-distribution; $\alpha = 0.05$.

(VerCauteren et al. 2006). However, efficacy, cost, and longevity of service vary considerably among fence designs. The efficacy of a particular fence is determined by a deer's physical abilities to cross, motivation, and the ability of that fence to modify deer behavior in response to operant conditioning (i.e., the process of learning based on positive and negative reinforcement of behavior over time; VerCauteren et al. 2006). To affect the road-crossing behavior of deer, the negative reinforcement associated with going over or under an exclusion fence must exceed the positive reinforcement associated with successfully crossing it. In addition, the level of negative reinforcement must be sustainable, or fence efficacy will decline as deer change the balance between negative and positive reinforcement through learning and subsequent behavior modification. It is generally accepted that deer behavior in relation to exclusion fences is influenced by the consequences of their own actions and by observations of the actions of other deer (VerCauteren et al. 2006).

Matthews (2007) reported that the actions of herding animals are often influenced by the behavior of a lead animal. Although we viewed the group dynamic as positive (i.e., 1 deer crossing might encourage the other deer to cross) in regards to our trials, we did not analyze our data for group effect. However, we believe that group dynamics, use of multiple treatment areas (*n* = 3), and use of multiple levels of motivation best simulated real-world interactions between deer and roadside fences. Our measures of deer behavior in relation to each fence design and at each level of motivation provided insight into how deer might have perceived fences and why some designs were more effective than others. Because our experimental treatments (i.e., fence heights and designs) were not independent of each other, we did not statistically test for treatment-related differences in deer behavior. However, we considered general patterns in deer behavior among treatments, and subjectively evaluated those patterns as related to fence efficacy. Although our treatment areas were not large, deer frequently attempted to jump fences from a running start and from various angles. Therefore, we believed our experimental design was appropriate for the scope of our research, and the results were applicable to typical roadway conditions.

When considering woven-wire fences, it is our opinion that deer perceived taller fences as more difficult to jump. This hypothesis is substantiated by the inverse relationship between deer interactions and fence height. Furthermore, it appeared that either a low-level threat (i.e., early-forced choice) or food restriction provided adequate motivation for deer to jump fences that they perceived as less challenging. A high-level threat designed to elicit a flight response (i.e., late-forced-choice) was necessary to motivate deer to jump fences that they perceived as more challenging. It was unclear if deer learned that 2.4-m woven-wire fences were difficult to jump because of failed attempts at lower heights, or if they simply perceived them as impenetrable barriers. We believed that the increasing trend in the number of failed attempts as fence height increased from 1.5 m to 2.1 m, followed by a sharp decline when the fence was raised to 2.4 m, suggested that deer learned that their efforts to cross would likely result in failure. Although running deer, stressed deer, and deer on uneven terrain might sometimes jump 2.4-m woven-wire fences (VerCauteren et al. 2006), none did so in a 2.4 ha experimental pen in Wisconsin (VerCauteren et al. 2010), and few (<6) are known to have done so at the Whitehall Deer Research Facility during the past 17 years of routine operation (D. A. Osborn, University of Georgia, unpublished data).

The percentage of deer that crossed opaque fences in our study remained high (50 to 90%), regardless of fence height. In addition, most deer crossed fences during the early-forced choice and food-restriction periods, suggesting that they perceived them as a relatively low-level challenge. Gallagher et al. (2003) reported that free-ranging deer crossed a burlap fence to access a corn feeder, until the fence reached 1.6 m in height. Our results might have differed from this earlier report because we used multiple levels of motivation. Our finding that only the tallest (1.8-m) opaque fence tested was more effective than the 1.2-m woven-wire fence suggests that opaque fences offer no increase in efficacy over woven-wire fences of similar heights. However, because deer in our trials had previous experience on both sides of the treatment area, we were unable to test efficacy of opaque fences when deer had no perception of the other side.

Although the percentage of deer that crossed the outrigger fence in each direction was high (60 to 90%), the relative odds (compared to 1.2-m woven-wire) of the deer crossing when the outrigger was angled toward them was similar to the odds that they would cross the 2.1-m and 2.4-m woven-wire fences (Figure 2). Also, the behavioral data suggested that deer perceived the outrigger fence as more challenging to jump when the outrigger was angled toward them. When the outrigger was angled away from them, most deer (60%) crossed during the early-forced-choice and food-restriction periods. When the outrigger was angled toward the deer, most (88%) of the deer crossed during the late-forced-choice period when the outrigger was angled toward them, suggesting that they attempted to jump it only after they panicked. Further, the relative number of failed attempts was highest. Although the total number of interactions between the deer and the outrigger fence was high, it appeared that deer were less likely to fail at a crossing attempt when the outrigger was angled away from them. Finally, the 3 deer that did not cross when the outrigger was angled toward them, crossed when it was angled away from them.

In our trials using 6 naïve deer, none crossed the outrigger fence when it was angled toward them, and only one crossed when the outrigger was angled away. Therefore, we believed that deer with previous fence-crossing experience learned to jump fences through operant conditioning and habituation. The naïve deer that crossed the fence with the outrigger angled away did so only after becoming panicked during the late-forced-choice period of motivation. In our opinion, naïve deer perceived the outrigger fence, in both directions, as difficult to jump. Falk et al. (1978) tested a slightly different outrigger fence design and found that, when the outrigger was angled toward the deer, it reduced deer crossings on a major roadway. Also, Jones and Longhurst (1958) tested a 0.6-m tall fence with a 1.8-m 25_o outrigger and a 1.2-m-tall fence with a 45_o outrigger and found that deer preferred to cross under, rather than jumping over, the fence when the outrigger was angled toward them.

Although operant conditioning likely affects deer behavior toward fences over time in field situations, we believe that the relative rate of learning in our trials was accelerated by each deer's frequent exposure to a high level of motivation when a researcher approached close enough to them to evoke a flight response. The rate at which free-ranging deer learn will depend on the relative number of negative and positive reinforcements that each deer receives. This number is determined by the spatial and temporal distribution of deer, level of

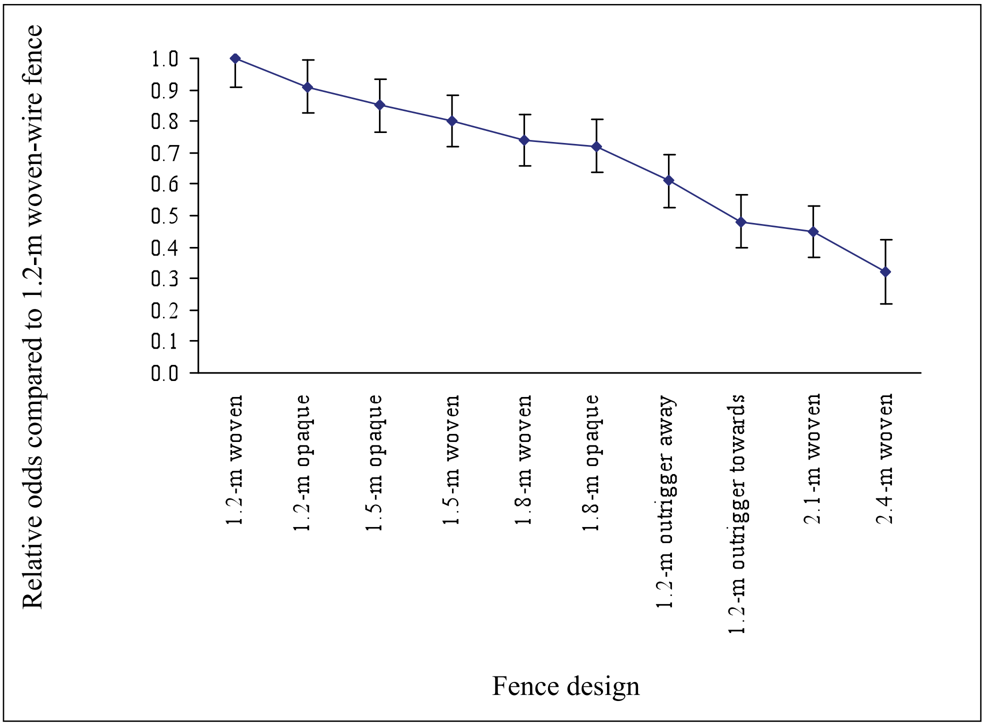

Figure 2. Relative odds (95% CI) that captive, adult, female white-tailed deer would cross each of various exclusion fence designs during a 75-hour observation period (25 hours per treatment area) compared to a 1.2-m woven-wire fence, Athens, Georgia, January 21 to November 4, 2008.

motivation to cross, and the frequency of their interactions with the fence. However, our research suggested that 2.1 and 2.4-m woven-wire fences and 1.2-m outrigger fences with the outrigger angled toward approaching deer had the highest probability of preventing deer crossings. VerCauteren et al. (2010) reported a similar decrease in the number of successful fence crossings once height of woven-wire fence reached 2.1 m. Because deer in our study were more likely to jump an outrigger fence when the outrigger angled away from them, a 1.2-m fence erected on both sides of a roadway with the outrigger angled away from the road might allow trapped deer to exit the roadway when they become panicked.

Management implications

Our findings suggest that woven-wire fences <2.1 m in height are mostly ineffective for preventing deer crossings, and any cost of retrofitting existing fences with an opaque covering is unjustified. Efficacy of 1.8-m to 2.4-m woven-wire fences might be acceptable depending on the level of exclusion required along a particular roadway. However, the potential gains in efficacy and increased cost associated with each increase in fence height should be taken into consideration when constructing DVC-mitigation fencing. Where exclusion fences of ineffective heights already exist along roadways, their efficacy might be improved by adding height with more woven-wire, or outriggers, to their tops. However, 1.8-m to 2.4-m woven-wire fences could trap deer in the roadway, if they circumvented the fence ends. Shorter woven-wire fences with an outrigger angled away from the road might allow 1-way travel of deer from the roadway, minimizing the potential of DVCs.

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