THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF ECOSYSTEM SCIENCE AND MANAGEMENT

EFFICACY OF A SECONDARY ELECTRIC FENCE AT PREVENTING DIRECT CONTACT AT RISK FOR DISEASE TRANSMISSION BETWEEN WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS)*

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SPRING 2020

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Veterinary and Biomedical Sciences
with honors in Wildlife and Fisheries Science

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ABSTRACT

Although direct contact at fences separating free-ranging and captive cervid herds are at risk for chronic wasting disease transmission, no study has explored the use of a secondary electric fence to prevent these contacts in white-tailed deer (*Odocoileus virginianus*). Using a captive herd of white-tailed deer in Pennsylvania, USA, we tested the efficacy of two electric fence designs constructed along two primary fence lines (each composed of 20 m of chain link and 20 m of woven wire fencing) dividing paddocks of captive deer. From June to November 2019, we conducted three trials of variable lengths to assess how season, age, and sex impacted behavior and motivation to breach the test fence. When no electric fence was in place, we observed direct contact through both woven wire and chain link fences. With the electric fences in place, we observed fence breaches (some of which led to direct contact between deer) only by weaned fawns (37 breaches) and males in the late rut (1 breach). Our results suggest that no type of primary fence alone is sufficient to prevent direct contacts and that the addition of a secondary, properly designed electric fence constructed along the primary fence of captive white-tailed deer facilities could prevent direct contact between captive and free-ranging deer.

KEY WORDS chronic wasting disease, direct disease transmission, electric fence, fence-line contact, *Odocoileus virginianus*, Pennsylvania, white-tailed deer.

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ACKNOWLEDGEMENTS

Funding for this research was provided by the Pennsylvania Department of Agriculture.

I would like to thank Penn State's Department of Animal Science for allowing us to conduct this study at the Penn State Deer Research Center, a facility which provides the rare opportunity to conduct research on the behavior of white-tailed deer. I would also like to thank my coworkers at the Penn State Deer Research Center, Joseph Dell, Robert McGarry, Adrianna Mowrer, Anthony Musselman, Owen Neff, Dan Redcay, Rachel Reitz, Madeline Schneider, and Olivia Thornton, for their assistance with various aspects of the study including constructing the test paddocks and moving deer between trials. I would especially like to thank those who also assisted with reviewing video files: Nicole Glick, Noah Hawthorne, Kayla Schlichting, and Jarrett Wilson. Without you all, this project would not have been possible. I am enormously grateful to Don Wagner, manager of the Penn State Deer Research Center, for his support from the instant I joined this project. In the past year, I have learned everything from how to build an electric fence, to how to find newborn fawns scattered across 23 acres of woods, to how to treat common illnesses in white-tailed deer. Your dedication to the Deer Research Center and this project has kept things running smoothly from day one. I am extremely grateful to David Walter, who has mentored me through this entire process. Your guidance on this project has strengthened my research and writing skills, which I am endlessly grateful for. Thank you also to you, Don Wagner, and Paola Ferreri for applying your expertise to editing this paper. Finally, thank you to all that has energized me throughout this entire process: family, friends, mentors, and a daily dose of sunshine.

INTRODUCTION

Chronic wasting disease (CWD), a transmissible spongiform encephalopathy (TSE) of the family Cervidae, was first discovered in the late 1960's in Colorado (Williams and Young 1980). To date, CWD has been reported in 26 US states; 24 of these states report cases in free-ranging populations (CDC 2020). In an endemic region of Wyoming, white-tailed deer populations are declining by 10% annually (Edmunds et al. 2016). Though understanding of CWD transmission is incomplete, infectious prions are present in the saliva, urine, blood, cerebrospinal fluid, and feces of infected animals and both direct and indirect transmission are important to the spread of the disease (Mathiason et al. 2006, Safar et al. 2008, Nichols et al. 2012, Henderson et al. 2015). A recent study found that CWD prions are also present in the semen and reproductive tissues of male white-tailed deer, though it is unclear if CWD can be transmitted through copulation or artificial insemination (Kramm et al. 2019). Efficiently transmitted and always fatal, CWD is a pressing concern for numerous stakeholders, including wildlife agencies, environmentalists, hunters, producers, and state commerce groups (Angers et al. 2009).

Though most cervids are vulnerable to infection, the social nature of white-tailed deer (*Odocoileus virginianus*) makes the species highly vulnerable to infection. Furthermore, areas of high free-ranging deer density are artificially created through baiting and feeding, perpetuated in areas within refugia, or in response to hunter demands (Hansen et al. 1997, Miller et al. 2003, Wallingford et al. 2017). Bans on cervid baiting (complete bans in 24 states, some restrictions in 15 states) and feeding (complete bans in 9 states, some restrictions in 19 states) have reduced these risks of transmission (MI DNR 2018). However, a number of avenues of CWD transmission remain viable threats, including human movement of live deer and carcasses (many states now ban the movement of “high risk parts”), movement of infectious prions by predators and scavenging birds, and the uptake of CWD prions from infected soil by plants (Fischer et al. 2013, Nichols et al. 2015, Pritzkow et al. 2015). CWD prions can remain infectious in the environment for several years and are resistant to denaturing by heat, radiation, and formaldehyde, so preventing introduction of CWD to uninfected areas is paramount to controlling the disease (Miller et al. 2004, Osterholm et al. 2019).

Herd Certification Programs (HCPs), regulated on a federal level by the Animal and Plant Health Inspection Service (APHIS) and administered/enforced by state agencies, were designed to address the risk of highly concentrated populations of deer and movement of live deer across national and international boundaries—Canada and South Korea were two cases where transmission of CWD was traced back to imported cervids (Sohn et al. 2002, Bollinger et al. 2004). States are not required to enforce a HCP (as of 2018, only 28 states do), though interstate transport of live deer can only occur between certified herds (APHIS 2018). In Pennsylvania, farmed and captive cervid herds are mandated to participate in a Herd Monitored Program and can voluntarily participate in an HCP (PDA 2014). All certified herds nationally must maintain a structurally sound fence at least 2.4 m in height, though states can implement additional requirements (APHIS 2019). However, the level of fence-line contacts between captive and free-ranging deer has not been addressed by these programs. Some states require a secondary, exclusionary fence (either a double fence or an electric fence), but often only in “high-risk” situations such as positive farms under quarantine or farms in endemic areas that wish to import or export live animals (MN OLA 2018).

The risk of direct contact between free-ranging and captive deer remains, even in herd managed under a HCP. Studies on fence-line contact among white-tailed deer are inconclusive as to the rate of contact between free-ranging and captive populations, however, some have found that direct contacts do occur (VerCauteren et al. 2007*a*, *b*). Previous studies have explored the use of electric fences to modify deer behavior but focused on the use of fencing as an exclusionary measure, not as a means of preventing contact between deer (Brenneman 1982, Palmer et al. 1985, Phillips et al. 2012). The efficacy of adding a secondary electric fence to an existing primary (woven wire) fence was assessed in a captive elk (*Cervus elaphus*) herd (Fischer et al. 2011). A two-stranded electric fence was highly effective deterring adult elk from contacting elk in the adjacent pen and some adult elk were deterred without ever touching the electric fence (Fischer et al. 2011). The electric fence design was less effective at deterring elk calves, which accounted for 52 of 69 total electric fence contacts and all fence-line breaches (all breaches were by the same calf) (Fischer et al. 2011).

Adding a secondary electric fence to existing perimeter fences may provide a cost-effective mechanism to prevent fence-line contacts between free-ranging and captive white-tailed deer. Our objective was to assess the efficacy of four fence designs in preventing direct contacts between captive herds of white-tailed deer within the same facility. Our secondary objective was to test these fence design during 3 periods with different herd compositions to assess the influence of sex, age, and seasonality (in relation to doe-fawn interactions and breeding behavior) on motivation to breach the electric fence. We expected the highest rates of contacts and fence breaches from fawns. Due to the nonconductive nature of hard antlers, we expected the next highest fence breach and contact rates from antlered adult males. We expected rates for adult males to increase further into the breeding season due to mounting levels of testosterone.

We expected the lowest breach and contact rates from adult females due to their relatively low motivation.

STUDY AREA

This research was located at The Pennsylvania State University Deer Research Center, located in Centre County, Pennsylvania. The 8.9 ha facility had an elevation of ~350 meters and was divided into nine outdoor wooded paddocks with a total white-tailed deer population of 60–90, depending on the year and time of year. Three paddocks (Paddocks D, E, and F at 0.48, 1.17, and 1.54 ha, respectively; Fig. 1) in the facility were used for the study. The paddocks contained an eastern deciduous forest habitat (white oak, *Quercus alba*; black cherry, *Prunus serotine*; white pine, *Pinus strobus*; red maple, *Acer rubrum*), with little understory growth. Orchard grass (*Dactylis glomerate*), perennial ryegrass (*Lolium perenne*), clover (*Trifolium repens*), and stinging nettle (*Urtica dioica*) provided most of the groundcover. The exterior perimeter of the facility uses a 2.4 m chain link fence topped with three strands of barbed wire (total height of 2.7 m) and a secondary, 1.2 m in height, three-strand electric fence outside of the chain link fence to separate captive and free-ranging deer. The vegetation surrounding the facility consisted of mixed forested and agricultural land, which supports populations of wild white-tailed deer, American black bear (*Ursus americanus*), groundhog (*Marmota monax*), turkey (*Meleagris gallopavo silvestris*), skunk (*Mephitis mephitis*), racoon (*Procyon lotor*), gray fox (*Urocyon cinereoargenteus*), red fox (*Vulpes vulpes*), and coyote (*Canis latrans*).

METHODS

Paddock Design

We constructed a six-strand electric fence 1.5 m in height (evenly spaced) placed 0.6 m from either a primary (woven wire and chain link) fence in Paddock D (hereafter, six-strand electric fence; Fig. 1). We constructed a three-strand electric fence 1.2 m in height (evenly spaced) placed 0.3 m from the primary fence (woven wire and chain link) fence in Paddock F (hereafter, three-strand electric fence). A 20.0-m-long section of chain link and a separate 20.0-m-long section of woven wire in both Paddocks remained where direct contact could occur between each Paddock and the main population of deer in Paddock E (Fig. 1).

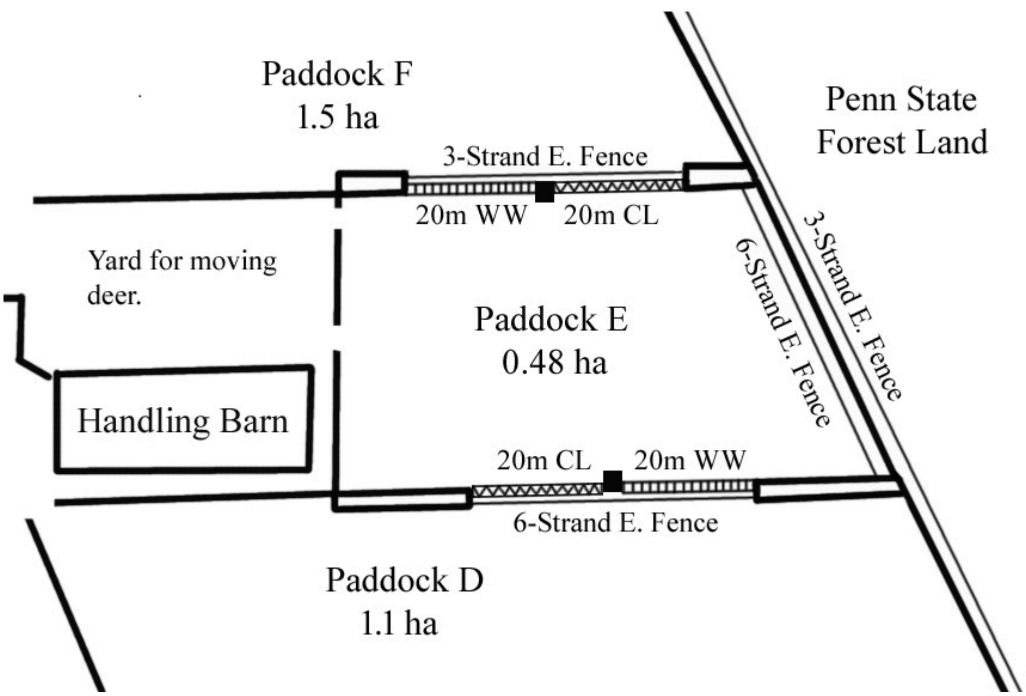

Figure 1. Diagram of study paddocks E, F, and G. "E. Fence" refers to "Electric Fence," "WW" refers to "woven wire" fencing, and "CL" refers to "chain link" fencing.

All electric fences on the facility were charged by a 110-V energizer (Stafix® model x6i Unigizer™; Datamars, Lamone, Switzerland). The energizer had 6.0 J output and maintained the voltage of the fences between 6.5 and 7.0 kV. Vegetation was cleared from all interior fence lines and maintained through the duration of the study.

Experimental Design

This study was divided into three trials of various lengths using herds of various compositions to allow us to compare the impact of sex, age (fawn vs. adult), and behavioral season on the behavior of the deer (Table 1). We tested the motivation of a white-tailed deer from captive research herd to breach a 12.5-gauge electric fence and assessed the change in behavior at a fence line by building an electric fence. All deer used in the study were born and raised in captivity at The Pennsylvania State University Deer Research Center. Throughout the study, deer were provided alfalfa hay, pellets, and water ad libitum. The Deer Research Center, managed by the Department of Animal Science, is accredited by the Association for the Assessment and Accreditation of Laboratory Animal Care (AAALAC) and this study was approved through The Pennsylvania State University's Institutional Animal Care and Use Committee (PROTO201800241).

Table 1. Experimental Design, including trial period designations and dates and the composition of deer groups in Paddock D, E, and F during each trial period. For more detailed information on study populations, see Appendix A, Supplemental Tables 3-12. Supplemental tables are color coded to match Table 1 for ease of locating relevant information. "Days Analyzed" refers to the number of days of video footage that were reviewed for this paper. Further data will be reviewed for a later publication.

Trial Number	Trial Period	Start Date	End Date	Days Analyzed	Paddock D	Paddock E	Paddock F
1	Control	6/10/2019	6/17/2019 (Paddock F) 6/18/2019 (Paddock D)	3	11 females (Female Group I)	1 male, 4 females, 6 fawns (Mixed Group I)	11 females (Female Group II)
	-	6/17/2019 (Paddock F) 6/18/2019 (Paddock D)	6/24/2019	5	11 females (Female Group I)	1 male, 4 females, 6 fawns (Mixed Group I)	11 (10) females (Female Group II)
	-	6/25/2019	6/29/2019	5	10 females (Female Group II)	1 male, 4 females, 8 fawns (Mixed Group I)	11 females (Female Group I)
2	2	8/27/2019	9/3/2019	5	10 females, 3 fawns (Fawn Group I)	1 male, 4 females, 2 fawns (Mixed Group I)	10 females, 3 (2) fawns (Fawn Group II)
3	Control	9/10/2019	9/15/2019	5	7 males (Male Group I)	1 male, 4 females, 2 fawns (Mixed Group I)	7 males (Male Group II)
	Pre-Rut	9/24/2019	9/30/2019	5	5 males (Male Group I)	1 male, 4 females, 2 fawns (Mixed Group I)	7 males (Male Group II)
	Pre-Rut	10/1/2019	10/8/2019	5	7 males (Male Group II)	1 male, 4 females, 1 fawn (Mixed Group I)	5 males (Male Group I)
	Mid-Rut	10/15/2019	10/22/2019	0	6 males (Male Group II)	1 male, 3 females (Mixed Group II)	5 males (Male Group I)
	Mid-Rut	10/22/2019	10/29/2019	0	5 males (Male Group I)	1 male, 3 females (Mixed Group II)	6 males (Male Group II)
	Late-Rut	11/5/2019	11/12/2019	2	5 males (Male Group I)	1 male, 3 females (Mixed Group III)	6 males (Male Group II)
	Late-Rut	11/12/2019	11/19/2019	2	6 males (Male Group II)	1 male, 3 females (Mixed Group III)	5 males (Male Group I)

Trial 1 tested the interactions between female-only groups of deer and a mixed group composed of one male and four females with their fawns in June 2019. After a 7-day control period with no secondary fence, the electric fences were constructed, marking the start of a two-week treatment period. The fence in Paddock F was constructed the day before the fence in Paddock D, so the treatment period for Trial 1 started on two different days for Paddocks D and F. After one week, the herds in paddocks D and E were switched, exposing the female deer to the other electric fence design for an additional week.

Trial 2 tested the motivation and ability of fawns to breach the electric fence when separated from their mothers by the fence from August to September 2019. The females from

Trial 1 remained in Paddocks D and F (ten and eleven females, respectively) for Trial 2 (Appendix A, Supplemental Tables 5 and 6). We did not record any interactions with these deer and the electric fence or other deer. Six fawns that had lived in Paddock E during Trial 1 were weaned (all fawns were 3 months of age), vaccinated, and released into either Paddock D or F, while their mothers remained in Paddock E. These fawns were selected because they had previous exposure to an electric fence in Paddock E (Fig. 1). There was no control period and after a 7-day trial, the fawns were removed from Paddocks D and F. We intended to add more fawns to the trial, but after one fawn was injured early in the trial, we decided to shorten the trial and avoid adding fawns who had no prior exposure to an electric fence.

Trial 3 tested the motivation of males to breach the electric fence when separated from a breeding herd (one male, four females) before the breeding season when females were in estrus (hereafter referred to as the rut), at the start of the rut, and at the peak of the rut from September to November 2019. We wanted to observe the effect of naturally increasing testosterone and aggression levels on motivation by males and their ability to breach the fence to spar with a male, or to initiate contact with females in the adjacent paddock. After the control period (10–15 September) we separated the trial into 3 periods: 1) pre-rut treatment period (24 September–8 October), mid-rut (15–29 October), and peak-rut (5–19 November) with the dates between periods reserved for antler removal and routine vaccinations (Table 1). Each period was two weeks long and had both herds of males exposed to each fence design for an equal amount of time. Between trial periods, the electric fence remained on and cameras were left running in case of deer injury or destruction of the fence. During the control period, all males in Paddock D and Paddock F had intact antlers that were out of velvet (hereafter, hard antlers). Two groups of males in Paddocks D and F were established—in both groups, antlers were removed from some males and left on others (Appendix A, Supplemental Tables 7 and 8). All males were antlered for the control period, but during the trials, some males had their antlers removed to minimize the risk of injury from fighting (Appendix A, Supplemental Tables 10, 11, and 12). We left antlers on a "small," "medium," and "large" male in each study group, which was determined by body weight and antler size. The male in the breeding herd in Paddock E always had intact antlers.

Data Collection

In each paddock, two video cameras (LOREX® model LBV8721AB; LOREX Technology, Markham, Canada) were mounted 2.7 m high on the same post, facing opposite direction along the fence line. We boarded up a 3.0-m-long "blind spot" on the fence between the fields of view of the cameras to ensure that no fence-line contact between deer could occur off-camera. All videos were recorded to a DVR (LOREX® model DV9082; LOREX Technology, Markham, Canada) and moved to external hard drives for analysis. The camera system recorded the entire duration of each control or treatment period. For the purposes of this thesis, we did not analyze the entire duration of each trial (Table 1). Additional data were collected and will be reviewed to be included in a future publication. During Trial 1, video cameras recorded continuously from 06:00 to 20:00 and recorded only motion events outside of this window. During all subsequent trials, the cameras ran continuously for 24 hours/day.

Data Analysis

Videos were sorted into folders based on the type of occurrences (ex. no deer in view, deer bed by fence, deer contact fence, etc.) by multiple primary viewers. A single secondary viewer reviewed all videos in folders that encompassed occurrences of interest and assessed any videos that the original observer was unsure of how to classify (Table 2). The secondary viewer recorded each event of note and classified it based on a set of predetermined categories (Table 2).

Table 2. Classifications of Fence-Line Occurrences for Control Periods. The qualitative criteria were used to categorize interactions between deer in different paddocks and between deer and the electric fence.

Classification	Criteria
Contact with live electric fence	Deer touches one or more strands of the electric fence while it is charged
Sparring without electric fence contact	Males lock antlers and do not contact each other with any other body part; no part of either buck touches the electric fence
Sparring with electric fence contact	Males lock antlers and do not contact each other with any other body part; some part of either buck touches the electric fence
Antler contact w/ live electric fence; entanglement	The deer contacts the electric fence with ONLY their antlers and gets antlers caught on fence; may lead to contact with live electric fence
Breach of primary fence line	Deer reaches head through primary (woven wire or chain link) fence, but do NOT contact another deer, could come into contact with deer in bordering paddock if they were present
Breach of electric (secondary) fence line with head	Deer crosses live electric fence with their head/neck
Breach of electric (secondary) fence line with entire body	Deer had entire body between primary and secondary fences with all feet planted on the ground
Direct contact between deer	Deer in different pens touch noses through the primary fence

We coded each entry with camera number to compare the effect of primary fence type (i.e., chain link or woven wire) and paddock (to compare the effect of the electric fence design). We also recorded the date, trial number, time of contact, length of contact between deer through the fence, and deer ID (if the tag color was visible). For Trial 2, we only recorded data from fawns in Paddocks D and F, not the adult females that were in those paddocks. Each entry was assigned an "hour since first exposure" value based on the time the deer were released into Paddocks D and F for that trial period to assess changes in behavior as deer became acclimated to the fence design. There is a difference between "hours since first exposure" and "trial length" because, in Trials 1 and 3, the herds in Paddocks D and F were swapped halfway through each treatment period to expose each group to both electric fence designs. As a result, the hour since first exposure "reset" when the herds were moved to a new paddock. For example, although 218 hours of the treatment period were analyzed for the Pre-Rut period of Trial 3, the "Hours of exposure" only spans from 0 to 109. Because the herds in Paddocks D and F were not switched during control periods, the total length of the trial period is equal to the hours of exposure for the control periods of Trials 1 and 3.

We calculated the frequency and change in frequency of contacts between deer in Paddocks D and F and the electric fence (hereafter, "electric fence contacts") over time. We calculated the rate of direct contacts between deer in different paddocks (hereafter, "direct contacts") in the control and trial periods. In trial periods where direct contacts occurred, we assessed the impact of the primary fence type. For Trial 3 only, we also compared the electric fence contact and breach rates of antlered and antlerless males to assess if antlered males were more successful due to the nonconductive property of hard antlers. We also compared the electric fence contact and breach rates across treatment periods to see if mounting testosterone levels in males through the rut would cause an increase.

RESULTS

Control Period – No Electric Fence in Place

In 60 hours of the control period of Trial 1, we observed 53 direct contacts (0.040 contacts/hour per individual) between deer in Paddock E and adult female deer in Paddocks D and F during the control period of Trial 1. The majority of direct contacts (77%) were between two adult females, 8 (15%) were between an adult male and an adult female, the remaining 4 contacts (8%) were between an adult male and an unrelated fawn. Twenty-eight (53%) direct contacts occurred through the chain link fence and 25 (47%) occurred through the woven wire (Fig. 2A). The average contact time was 2.8 s through chain link and 3.7 s through woven wire (Fig. 2B). There was no control period in Trial 2.

In 108 hours of the control period of Trial 3, we observed 70 direct contacts (0.046 contacts/hour per individual) between deer in Paddock E (mixed group) and adult male deer in Paddocks D and F. Sixteen contacts (23%) were between an adult male and an adult female, 52 (74%) contacts were between two adult males, and 2 contacts (3%) were between an adult male and an unrelated fawn. Twenty-seven (39%) direct contacts occurred through the chain link fence and 43 (61%) occurred through the woven wire (Fig. 2A). The average contact time was 2.3s through chain link and 6.0s through woven wire (Fig. 2B). We observed 12 sparring bouts (6 across chain link and 6 across woven wire) between adult males. While sparring, males did not come into direct contact with any body part other than their antlers.

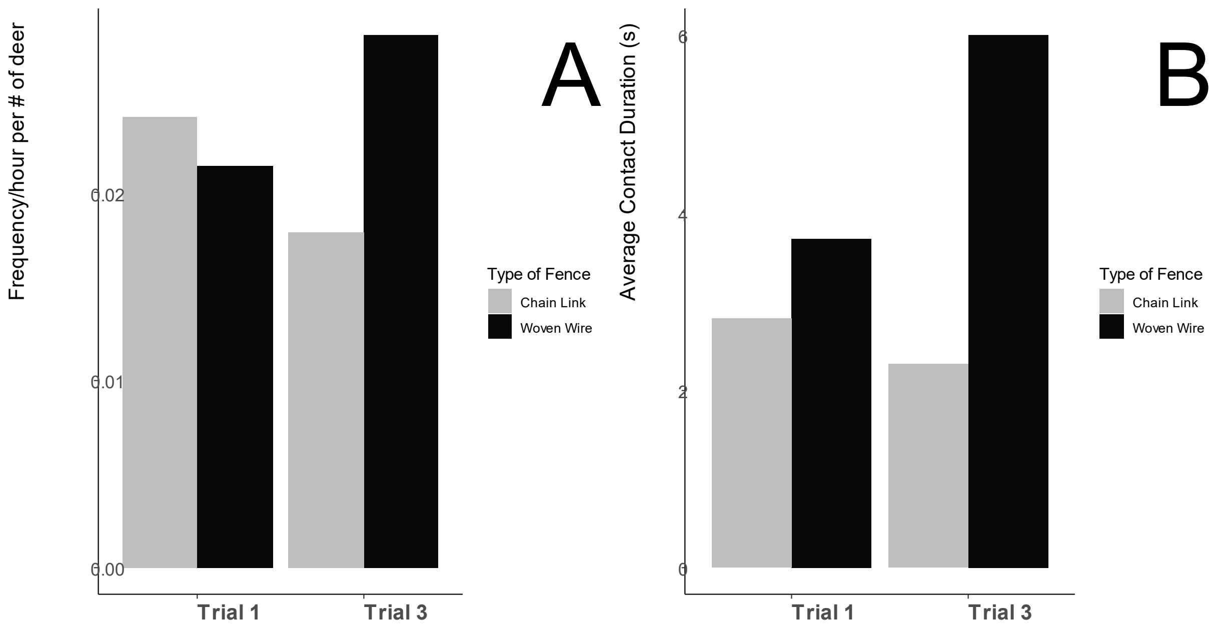

Figure 2. Comparison of the impact of the type of primary fencing (woven wire or chain link) on direct contacts in the control periods of Trials 1 and 3. A) Frequency of direct contacts per hour per individual. B) Average length of direct contacts.

Treatment Period – Electric Fence in Place

During Trial 1, we did not observe any direct contacts once the electric fence was in place. However, one deer in Paddock E reached her head through a section of woven wire fencing and in between the strands of the three-strand electric fence on two separate occasions. There was a doe approximately 1.2 m away from the fence in the adjoining paddock that may have motivated this behavior. If a deer in Paddock F had approached the fence, direct contact could have occurred. There were 93 electric fence contacts over 215 hours of footage reviewed (0.021 contracts/hour per deer). Electric fence contacts were highly concentrated upon first exposure of deer to the electric fence with 49% of electric fence contacts occurring in the first 5 hours that deer were exposed to a novel fence design (Fig. 3A).

During Trial 2, fawns breached the electric fence 37 times over 108 hours. Fawns breached the electric fence with only their head and neck 24 times and with their entire body 13 times. Four breaches with the head/neck resulted in direct contact (0.007 contacts/hour per deer) between fawns in Paddocks D and F and female deer in Paddock E (three of these direct contacts involved the same fawn), averaging 1.75 seconds of direct contact. There were no direct contacts with the fawns or adult males in Paddock E. All four direct contacts occurred along the three-strand electric fence line and three occurred across woven wire. Fawns contacted the electric fence 64 times without breaching (0.101 contacts/hour per deer) and 45% of these occurred when a female deer was standing close to the fence in Paddock E. Only 17 (17%) of the electric fence breaches and contacts occurred in the first 6 hours. Fawns contacted or breached the electric fence as many times in the second 24 hours as they did in the first 24 hours (38% and 37% of total, respectively) (Fig. 3B).

During pre-rut in Trial 3, we did not observe any direct contacts or sparring. We recorded 65 electric fence contacts over 218 hours of footage (0.025 contacts/hour per deer). Electric fence contacts were highly concentrated in the first 6 hours of exposure (49%) and the majority of electric fence contacts occurred in the first 12 hours (58%) (Fig. 3C). During late-rut in Trial 3, we recorded 50 electric fence contacts over 78 hours of footage (0.058 contacts/hour per deer). (Fig. 3D). There was one direct contact between an antlerless male and a female in Paddock E when the male reached his head between two strands of the three-strand electric fence without contacting it. There were 9 attempts at sparring, with seven occurring at the three-strand electric fence and two occurring at the six-strand electric fence. All occurrences of sparring involved the same male.

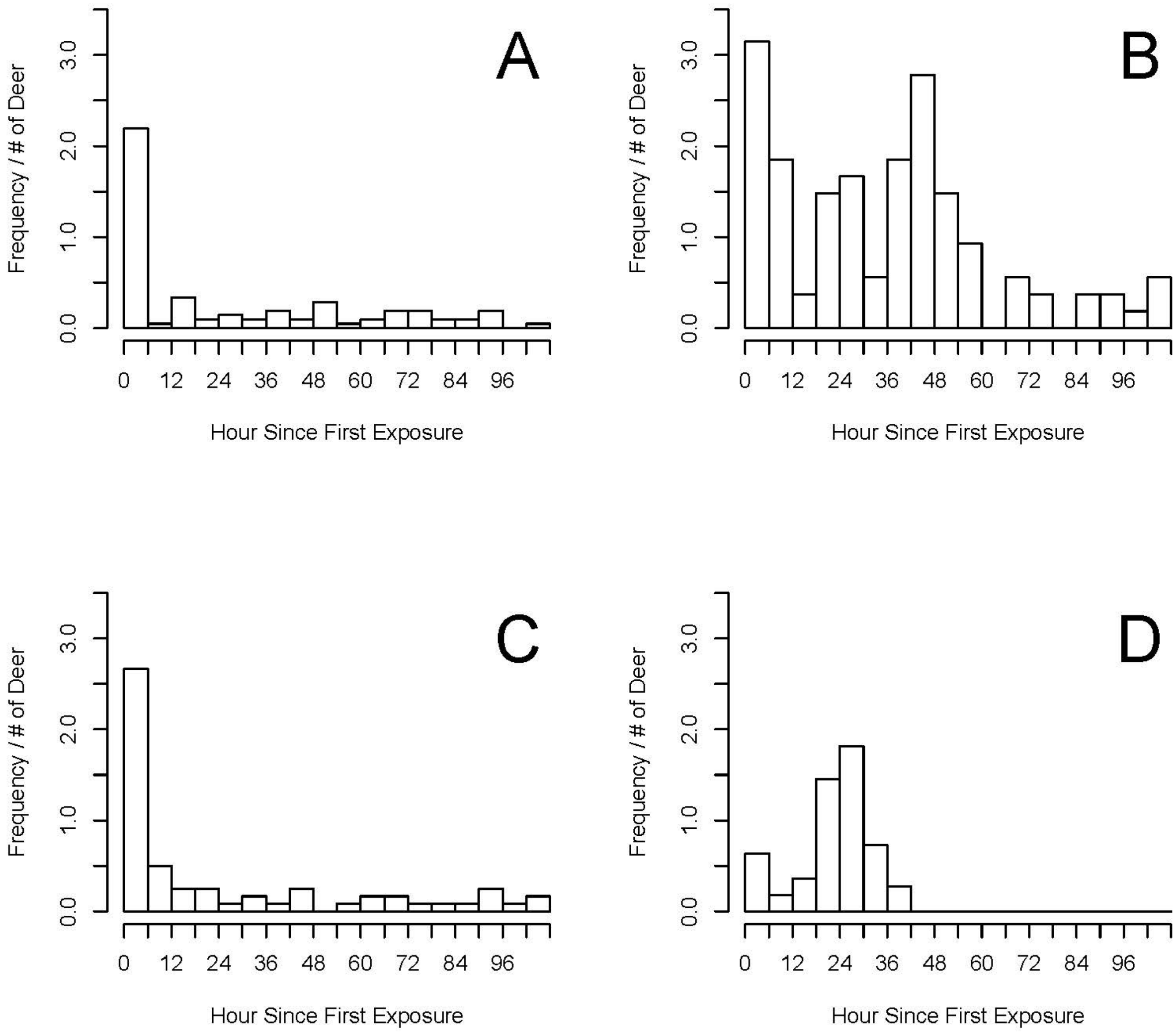

Figure 3. Electric fence contacts by hour since first exposure in A) Trial 1, B) Trial 2, C) Trial 3 Pre-Rut period, D) Trial 3 Late-Rut period. No data were analyzed after 39 hours since first exposure for the late-rut of Trial 3. All frequencies were adjusted by the number of deer in the trial populations in Paddock D and F.

DISCUSSION

In the United States and Canada, a 2.4-3.0 m woven wire fence is the most popular style used in captive cervid facilities (Demarais et al. 2002, Phillips et al. 2012). With no secondary fence in place, we observed more frequent direct contacts between deer through a woven wire fence than through a chain link fence during Trial 3, but not during Trial 1. However, direct contacts were longer on average through woven wire than chain link in both Trials 1 and 3. Deer from the same social group may come into contact 22 times more frequently than deer in different social groups (Schauber et al. 2007), so we can assume that the contact rates that we recorded are higher than those between captive and free-ranging deer. However, we observed that direct contacts are possible across both types of fencing, indicating that a single fence of any type is inadequate for eliminating contact between deer. A secondary electric fence holds many benefits over a secondary additional chain link or woven wire fence. For facilities with large perimeters, a broken electric fence is easily discovered by checking the voltage indicated by the fence energizers (which can be centrally located) or a handheld voltmeter. Some fence energizers have Wi-fi capability so that producers can monitor fence voltage from a mobile device. On the contrary, damage to a secondary chain link or woven wire fence can go unnoticed for extended periods of time.

Adult female and male deer (in the pre-rut trial period) contacted the electric fence at similar rates, indicating that sex may not impact behavior in this situation outside of the rut. During Trial 1, direct contacts between deer and contacts with the electric fence would not have been recorded if they occurred outside of continuous recording hours (8:00-20:00) and the camera did not register them as motion. Thus, we assume that the recorded contacts for Trial 1 may slightly underestimate contact rates between deer and with the electric fence. Electric fence contacts by males were more frequent in the late-rut than the pre-rut. Additionally, fence contacts increased after the first 6 hours of exposure in the late rut, which is contrary to the pre-rut period, during which contacts decreased significantly after the first 6 hours. Further analysis of late-rut period data will confirm if this trend continues through the entire late-rut period. Sparring did not occur in the pre-rut but occurred nine times in the late-rut. Only one male (five years of age) was recorded sparring with the male in Paddock E (three years of age). Because the other males in Trial 3 were all yearlings, they may not have attempted to spar with the male in Paddock E during the late-rut due to lower positions on a dominance hierarchy (Townsend and Bailey 1981). On several occasions, yearling bucks ran away instead of attempting to spar when the 3-year-old buck approached the fence. The only direct contact in Trial 3 occurred in the late-rut, between an antlerless male and a female. This indicates that though males may be highly motivated to breach an electric fence during the rut, their antlers may prevent them from reaching between the strands of an electric fence. Males express behaviors during the rut that may explain this increased motivation to contact both males and females during the rut, such as sparring with other males and seeking females in estrus (Townsend and Bailey 1981, Foley et al. 2015).

Fawns contacted the electric fence at a much higher rate than adults. Additionally, the electric fence contacts did not decline after the first 6–12 hours, as seen in adults in Trial 1 and the pre-rut period of Trial 3. When elk calves were separated from their mothers by a secondary electric fence, they showed similarly high motivation to breach the electric fence, however this motivation diminished more rapidly than we observed in white-tailed deer fawns. In one trial where elk calves were exposed to the electric fence, 44 of 46 (96%) electric fence contacts occurred in the first 30 hours of the trial (Fischer et al. 2011). The exact age of calves in this study was not reported, so it is possible that they learned to avoid the electric fence faster than we observed in fawns due to age. We observed several instances of fawns breaching the electric fence deliberately after they learned that they could stand between the primary and electric fences. After jumping forward in surprise after touching the electric fence, one fawn injured a forelimb that got stuck in the three-stranded electric fence and the woven wire fence. Fawns should not be separated from their mothers by an electric fence to prevent fawns from trying to breach the electric fence. Additionally, an uncharged lowest strand of the electric fence would protect fawns from entanglement due to poor coordination and small size until they are at least 3 months of age. This could potentially be accomplished with a fence constructed with a cut-off switch that allows the bottom strand to be charged independently.

The six-strand electric fence was more successful at preventing direct contacts and may be safer for deer. With the three-strand fence design, fawns could reach their heads and necks in between the electric fence strands and reach the primary fence relatively easily, because the strands were too spaced out and the fence was constructed too close to the primary fence. All four direct contacts in Trial 2 and the one direct contact in Trial 3 occurred through the three-strand electric fence. Although fawns breached both electric fence designs, the majority of breaches (78%) occurred at the three-strand fence. The one recorded instance of a deer in Paddock E reaching their head and neck through the woven wire fence and between the electric fence strands on the other side occurred with the three-strand design. Because the six-strand design was constructed further from the primary fence (0.6 m as opposed to 0.3 m), it was safer for fawns that got stuck between the fences because they had more room to stand and turn around without being shocked.

Baiting an electric fence with molasses and grain feed to encourage elk to contact the fence and learn to avoid it was suggested (Fisher et al. 2011). We did not find it necessary to bait the electric fences to encourage white-tailed deer to contact them. The deer were quick to explore the novel addition to the paddocks and were negatively reinforced for touching it. This suggests that the cost and time needed to bait an electric fence, which could be high in facilities with large perimeters, could be avoided.

Individual deer react differently to a shock from a live wire. Deeper analysis of the video data would be required to understand why some deer jump away from the fence (low to no risk of injury) and some deer jump forward (high risk of injury). The outcome of introducing males to the fence while in velvet could also be explored, to see if contact rates would be lower in the rut if males were already conditioned to the electric fence. It could also be beneficial to conduct follow-up studies to see if deer who are reintroduced to an electric fence months after their initial exposure will touch the electric fence or if they will remember to avoid contact. Elk calves exposed to an electric fence in three separate trials breached the electric fence sixteen times in the first trial, once in the second, and did not breach in the third trial (Fischer et al. 2011). However, the calves were yearlings by the third trial, so multiple factors, including increased body size and lower motivation to contact their mothers, may have had more impact on the decrease in breaches than being exposed to the fence multiple times (Fischer et al. 2011). Electric fences constructed along the inner fence-line of a facility potentially raises the chances of aversive conditioning because captive deer are constantly exposed to the fence, unlike free-ranging deer. However, we could expect to see similar trends based on seasonality if free-ranging deer were exposed to these fence designs. That is, the highest risks of breaches would be highest in young fawns and adult males in the late rut. Monitoring the perimeter of a facility for entangled deer or damage to the electric fence would be particularly important during these times of the year.

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APPENDIX

SUPPLEMENTAL TABLES

Supplemental Table 3. Tag color and number and age of deer in Female Group I, used in Trial 1. All deer were female.

Tag Color and ID #	Age
Purple 1216	2 yr.
Royal Blue 1218	2 yr.
Orange 6119 (Orange)	6 yr.
Orange 8119	4 yr.
Forest Green 9108	3 yr.
Black 2201	Yearling
Pink 2220	Yearling
Purple 2223	Yearling
Salmon 2228	Yearling
Forest Green 2208	Yearling
Turquoise 2234	Yearling

Supplemental Table 4. Tag color and number and age of deer in Female Group II, used in Trial 1. All deer were female. One deer (PS2213) was removed from the study on 6/20/2019 to be treated for diarrhea (unrelated to the study).

Tag Color and ID #	Age
Green 1208	2 yr.
Orange 9024	12 yr.
Purple 5122 (Blue)	7 yr.
Orange 8118	4 yr.
Royal Blue 9126	3 yr.
Orange 2219	Yearling
Brown 2204	Yearling
Tan 2232	Yearling
Forest Green 2213*	Yearling
Chartreuse 2207	Yearling
Forest Green 2209	Yearling

Supplemental Table 5. Tag color and number, age, and sex of deer in Fawn Group I, used in Trial 2.

Tag Color and ID #	Age	Sex
Green 1208	2 yr.	F
Orange 9024	12 yr.	F
Purple 5122 (Blue)	7 yr.	F
Orange 8118	4 yr.	F
Royal Blue 9126	3 yr.	F
Orange 2219	Yearling	F
Brown 2204	Yearling	F
Tan 2232	Yearling	F
Chartreuse 2207	Yearling	F
Forest Green 2209	Yearling	F
Purple 3223	Fawn	M
Purple 3222	Fawn	F
Grey 3215	Fawn	M

Supplemental Table 6. Tag color and number, age, and sex of deer in Fawn Group II, used in Trial 2. One fawn (PS3205) injured a leg in the fence and was removed from the study on 8/28/2019.

Tag Color and ID #	Age	Sex
Purple 1216	2 yr.	F
Royal Blue 1218	2 yr.	F
Orange 6119 (Orange)	6 yr.	F
Forest Green 9108	3 yr.	F
Black 2201	Yearling	F
Pink 2220	Yearling	F
Purple 2223	Yearling	F
Salmon 2228	Yearling	F
Forest Green 2208	Yearling	F
Turquoise 2234	Yearling	F
Brown 3204	Fawn	M
Brown 3205*	Fawn	M
Grey 3214	Fawn	F

Supplemental Table 7. Tag color and number, age, and when antlers were removed (if applicable) of deer in Male Group I, used in Trial 3. All deer were male. Two deer (PS1219 and 1224) were only included in the study for the control period.

Tag Color and ID #	Age	Antlers Removed For Study?
Maroon 7116	5 yr.	No, Antlers intact – "large"
Royal Blue 1219*	2 yr.	-
Turquoise 1224*	2 yr.	-
Orange 2218	Yearling	Yes, between control period and Pre-rut trial period
Maroon 2216	Yearling	No, Antlers intact – "medium"
Light Blue 2203	Yearling	Yes, between control period and Pre-rut trial period
Royal Blue 2227	Yearling	No, Antlers intact – "small"

Supplemental Table 8. Tag color and number, age, and antler status and size (if left intact for study) of deer in Male Group II, used in Trial 3. All deer were male. One deer (PS1206) was removed from the study after the Mid-rut trial period.

Tag Color and ID #	Age	Antlers Removed For Study?
Forest Green 1206*	2 yr.	-
Green 1209	2 yr.	No, Antlers intact – "large"
Yellow 2238	Yearling	No, Antlers intact – "small"
Black 2200	Yearling	Yes, between control period and Pre-rut trial period
Green 2212	Yearling	Yes, between Mid-rut and Late-rut trial periods
Purple 2222	Yearling	Yes, between Mid-rut and Late-rut trial periods
Salmon 2229	Yearling	No, Antlers intact – "medium"

Supplemental Table 9. Tag color and number, age, and sex of deer in Mixed Group I, used in Trial 1. Two fawns (PS3208 and 3209) were born on 6/25/19.

Tag Color	Age	Sex
Maroon 9117	3 yr.	M
Purple 6124	6 yr.	F (antlered)
Pink (Pink) 6121	6 yr.	F
Chartreuse 4157	8 yr.	F
Forest Green 8109	4 yr.	F
Brown 3204	Fawn	M
Brown 3205	Fawn	M
Grey 3214	Fawn	F
Grey 3215	Fawn	M
Purple 3223	Fawn	M
Purple 3222	Fawn	F
Forest Green 3208*	Fawn	F
Forest Green 3209*	Fawn	F

Supplemental Table 10. Tag color and number, age, and sex of deer in Mixed Group I, used in Trial 2 and 3 (Control and Pre-rut periods only). One fawn (PS3208) was removed from the study on 10/2/2019, during the Pre-Rut period of Trial 3.

Tag Color and ID #	Age	Sex
Maroon 9117	3 yr.	M
Purple 6124	6 yr.	F (antlered)
Pink (Pink) 6121	6 yr.	F
Chartreuse 4157	8 yr.	F
Forest Green 8109	4 yr.	F
Forest Green 3208*	Fawn	F
Forest Green 3209	Fawn	F

Supplemental Table 11. Tag color and number, age, and sex of deer in Mixed Group II, used in Trial 3 (only Mid-rut period only).

Tag Color and ID #	Age	Sex
Orange 9119	3 yr.	M
Royal Blue 6130	6 yr.	F
Black 7100	5 yr.	F
Turquoise 9040	12 yr.	F

Supplemental Table 12. Tag color and number, age, and sex of deer in Mixed Group III, used in Trial 3 (Late-rut period only).

Tag Color and ID #	Age	Sex
Maroon 9117	3 yr.	M
Purple 2223	Yearling	F
Chartreuse 4157	8 yr.	F
Salmon 7133	5 yr.	F

ACADEMIC VITA

Renée Khouri

EDUCATION

Bachelor of Science (B.S.) in Veterinary and Biomedical Sciences
Schreyer Honors College
The Pennsylvania State University Graduation Date: May 2020
University Park, USA

University College Dublin (study abroad) Jan. 2018 – May 2018
Dublin, Ireland

RESEARCH EXPERIENCE

Department of Ecosystem Science and Management May 2019 – April 2020
The Pennsylvania State University
Supervisor: Dr. W. David Walter
Type of Project: Undergraduate honors thesis

- Completed honors thesis on the efficacy of various fence designs in preventing direct contact between white-tailed deer populations to minimize the spread of chronic wasting disease between wild and farmed deer
- Wrote code in software *R* to translate manually recorded data from video footage to quantitative data

Ecology & Wildlife Behavior Lab Jan. 2018 – May 2018
University College Dublin
Supervisor: Dr. Simone Ciuti
Type of Project: Independent research project

- Applied satellite telemetry data to create activity models to elucidate the role of environmental factors on the movement of wild giraffes in Namibia
- Built generalized additive mixed models using *R*
- Presented an abstract, method summary, and poster to a panel of professors
- Presented the poster in the 2019 Undergraduate Research Exhibition at he Pennsylvania State University

Dairy Nutrition Lab Aug. 2017 – Dec. 2017
Pennsylvania State University
Supervisor: Dr. Alexander Hristov
Role: Undergraduate research assistant

- Aided in lab research goal to mitigate environmental impacts of dairy cows through nutritional modifications
- Weighed, grinded, processed, labeled, and created composites of samples
- Utilized micro-pipetting, centrifuging, and sterile sample transfer techniques

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LEADERSHIP

Ag Advocate, Penn State College of Agricultural Sciences Apr. 2018 – May 2020

- Engaged prospective students through campus tours and information sessions
- Educated current students, faculty, and community members through events highlighting the College of Ag Sciences and Pennsylvania agriculture

- Organized "Ag Day," the College's annual event to showcase the importance of agriculture and the opportunities offered by the college
- **Ag Day Chair, Outreach Committee** Nov. 2019 – April 2020
    - Lead the Outreach Committee, in charge of inviting and managing the clubs and organizations that participate in Ag Day, including university, alumni, and community groups

Peer Advisor, Penn State Education Abroad Office Aug. 2018 – May 2020
- Held weekly office hours devoted to advising students intending to study abroad
- Answered queries submitted in person, by email, and by phone
- Provided pertinent information on programs, funding, and application procedures through tabling, presentations, and classroom visits

PennVet Working Dog Center Ambassador, Penn State Aug. 2018 – Aug. 2019
- Promoted internship & volunteer opportunities to students at Penn State through presentations, flyers, and social media targeted to a college-age audience
- **Campus Ambassador Program Chair** Jan. 2019 – Aug. 2019
    - Coordinated ten ambassadors at universities across the country
    - Created recruitment materials for ambassador team

Learning Assistant, Penn State Chemistry Department Jan. 2019 – May 2019
- Served as an educational resource for students in Organic Chemistry II
- Facilitated active learning through in-class exercises
- Held office hours to guide students through difficult topics and assignments
- Completed a pedagogy class focused on teaching scientific topics

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HONORS AND AWARDS

Gamma Sigma Delta Honors Society Spring 2018 – Spring 2020
College of Agricultural Sciences Dean's List All semesters
National Merit Scholarship All semesters
Academic Excellence Scholarship All semesters
Veterinary Founders Scholarship Fall 2019 – Spring 2020
Oswald Scholarship Fall 2018 – Spring 2019, Fall 2019 – Spring 2020
Blosinski Scholarship in Ag Fall 2017 – Spring 2018
EB and GW Groff Scholarship Fall 2017 – Spring 2018
Shigley Memorial Pre-Veterinary Scholarship Fall 2017 – Spring 2018
Theavos Scholarship Fall 2016 – Spring 2017

SKILLS

Languages: French [Speaking: C1, Reading: B1, Writing: A2], German [Speaking: A2, Reading: A2, Writing: A1]
Lab Techniques: proficient with light microscopy, sterile transfer, agar inoculation, sample staining, micro-pipetting, centrifuging, simple distillation, liquid/liquid extraction, TLC, column chromatography, recrystallization

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WORK EXPERIENCE

Animal Care Attendant May 2019 – May 2020
Penn State Deer Research Center State College, PA, USA
- Performed daily care for herd of 100 white-tail deer

- Administered standard medical treatments including vaccinations, chemical immobilization, and removal of hard antlers
- Conducted mandatory identification procedures including placing ear tags in fawns and tattooing yearlings
- Maintained facility hygiene, safety, and adherence to biosecurity policies

Canine Training Intern May 2018 – Aug. 2018
PennVet Working Dog Center (PVWDC) Philadelphia, PA, USA

- Trained high-drive canines for careers in fields including policework, arson detection, and search-and-rescue
- Tailored training regimens to address individual behavioral issues
- Worked in a variety of physically demanding settings with high-drive dogs
- Led agility, husbandry, socialization, environmental exposure, live human search, scent imprinting and search, obedience, and fitness sessions
- Participated in ongoing research focused on canine olfactory capabilities and how the expression of drive in young dogs can predict their working success