

USING CAPTIVE WHITE-TAILED DEER TO INVESTIGATE VISUAL PERCEPTION AND
AGE-RELATED MORPHOMETRICS

by

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

ABSTRACT

Captive deer herds are useful for collecting data that are otherwise unobtainable. I used captive white-tailed deer (*Odocoileus virginianus*) to investigate deer visual perception by modifying an automated deer-training-apparatus (DTA) to elicit a behavioral response from deer as a basis for future sensory perception research. I trained 2 does to participate in data collection trials when pseudoisochromatic plate tests were presented as stimuli after mounting LG LCD monitors on the DTAs. I provide recommendations to troubleshoot potential issues with these devices. I also collected data from 11 fawns at the captive facility during summer 2012 to create a technique to accurately determine age of neonates. After collecting 17 different measurements, I identified strong individual predictors; however, only five measurements were significant predictors in a linear mixed effects model. These models make age estimation of fawns possible whether a great deal or very little information about the fawn can be obtained.

INDEX WORDS: age estimation, deer training, deer vision, deer-training-apparatus, DTA, linear mixed effects models, neonatal, operant conditioning, *Odocoileus virginianus*, white-tailed deer

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DEDICATION

I dedicate this work to my loving family; John, Laura, and Matthew.

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CHAPTER 1

INTRODUCTION

Captive animals are useful for collecting data not obtainable in a field setting, or that use techniques not ready for field application. Similarly to laboratory settings, extraneous variables are easily controlled in captive settings. Types of studies commonly conducted on captive deer include investigations of nutrition, disease, physiology, sensory perception, behavior, and morphology. These studies often provide results applicable in both captive settings and for free-ranging deer populations. My thesis research was designed to investigate aspects of deer behavior and morphology through the use of a captive herd of white-tailed deer (*Odocoileus virginianus*) housed at the University of Georgia's Whitehall Deer Research Facility that would not have been possible with field-based research efforts.

Nutrition, disease, and physiology studies are a few of the many topics of focus in captive deer research, and knowledge gained by this research can be useful in managing wild populations. Nutritional studies explain deer digestive physiology and habitat requirements. For example, fecal sample analysis collected from captive deer reveals that much about the digestibility of various plant species and deer digestive efficiency (Forbes et al. 1941, Mautz et al. 1974). Understanding the nutritive value of species within a region or within a season, and deer's ability to digest them, allows for the calculation of food supplies needed at different times of the year (Robbins et al. 1975, Short 1975). These results, along with a study investigating the fat cycle in deer, suggest that because the winter forage available to deer is the least digestible, and by extension the least nutritional, managers of wild deer should focus on creating and

supporting nutritional habitat in the other seasons to improve overwinter survival (Mautz 1978). Models like the one developed by Wallmo et al. (1977) for mule deer (*O. hemionus*) and Potvin and Huot (1983) for white-tailed deer demonstrate this process of quantifying nutrition of seasonally available plants in a habitat to develop a carrying capacity, citing these captive studies as benchmarks for accepted levels of nutritional requirements.

Controlling extraneous variables is paramount in isolating vectors, causative agents, and clinical signs of diseases. The list of diseases studied in captive herds is lengthy, and ranges from isolating bovine viral diarrhea virus in multiple cervid species (Frolich 1995) to experimental infection of black-tailed deer (*O. hemionus columbianus*) with bluetongue virus and epizootic hemorrhagic disease virus (Work et al. 1992). A current example of work being conducted on a captive herd of white-tailed deer is the baseline investigations of chronic wasting disease (CWD). CWD was first reported in free-ranging white-tailed deer in 1990 (Williams and Miller 2002). Little has been determined about the disease, and more importantly, all the methods of transmission. Studies using captive white-tailed deer suggest that transmission can occur through inhalation (Denkers et al. 2013), saliva and blood (Mathiason et al. 2006), environmental fomites (Mathiason et al. 2009), and bodily fluids excreted from oropharyngeal, urogenital, and gastrointestinal mucosa (Haley et al. 2011). By determining the mechanisms by which this disease spreads, preventative measures for the spread of the disease can be developed and possible treatments investigated.

Immunocontraception is the act of vaccinating an animal to prevent embryonic implantation. Two common methods of immunocontraception are porcine zona pellucida (PZP) immunization and gonadotropin releasing hormone (GnRH) vaccine. Experimenting with these vaccines in terms of dosages and routes of administration in a captive setting have allowed

further investigations of the possible use of these tools for managing suburban or overabundant deer populations where sport hunting is illegal or impractical. Trials on captive deer have allowed researchers to determine the most effective formulation for both the PZP (Turner et al. 1992, 1996; McShae et al. 1997) and GnRH immunocontraceptive vaccines (Miller et al. 2003). Researchers benefited by using captive deer to determine the dosages and administrations making these drug combinations potentially effective for direct application in a management scenario.

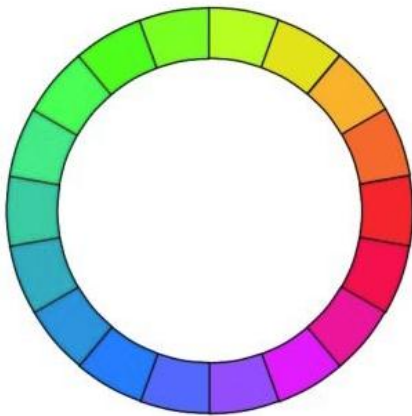
These cases of nutritional, disease, and immunocontraceptive studies in captive white-tailed deer herds exemplify the importance of captive herds in management-based fields of study. Captive herds allow researchers to gather information that would be impossible to collect on free-ranging deer. It also allows for the perfection of novel methods, like immunocontraception, prior to use in the field. While these three examples provide a representation of an expansive pool of literature investigating topics with captive deer, my interests and available resources led me to study sensory perceptions and age-related morphometrics.

Numerous studies have used operant conditioning to investigate visual acuity, discrimination, and detection in captive domestic animals like the horse (*Equus caballus*) (Blackmore et al. 2008, Timney and Keil 1992), goat (*Capra hircus*) (Blakeman and Friend 1986, Franz et al. 2002), cattle (*Bos taurus*) (Entsu et al. 1992, Gilbert and Arave 1985), cat (*Felis catus*) (Hall and Mitchell 1991), camel (*Camelus dromedaries*) (Harman et al. 2001), and dog (*Canis lupus familiaris*) (Pretterer et al. 2004). For example, group-housed goats have been trained to discern simple geometric shapes from one another (Franz et al. 2002) and horses have been trained to discriminate chromatic hues amongst achromatic stimuli (Blackmore et al. 2008). Kelber et al. (2003) list 21 species that have undergone various behavioral tests to determine

color vision aptitudes, and discusses procedures which reward test subjects with food when a discrimination of a chromatic stimulus from gray is made (Kelber et al. 2003).

Although abundant research has been conducted investigating some aspects of the sensory perceptions of white-tailed deer and the visual capabilities of domestic species, little is known about the visual aptitudes of white-tailed deer. A thorough understanding of the visual capabilities of white-tailed deer, specifically regarding color vision, may help formulate management actions that benefit both humans and deer populations. Deer can discriminate among wavelengths (i.e., perceive color), as demonstrated by operant conditioning methods in pen studies (Zacks and Budde 1983), as well as physiological studies of the retinal photoreceptors (Jacobs et al. 1994). Deer are dichromatic, meaning their vision is characterized by two cone types with different spectral sensitivities (Jacobs et al. 1994). In contrast, humans have trichromatic color vision. The range of colors dichromats perceive is much more limited since they rely on two spectral sensitivities instead of three like a trichromat (Carroll et al. 2001: Figure 1.1).

Human Trichromatic Color Vision



Horse Dichromatic Color Vision

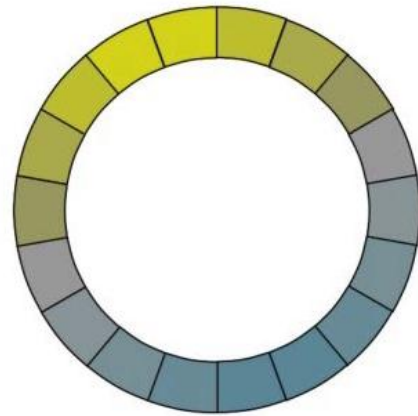


Figure 1.1. Color wheels for trichromats (left) and dichromats (right); developed from photopigment basis for color vision in the horse (Carroll et al. 2001). This image illustrates the greater variety of colors that trichromats are able to be perceived from just one more photopigment receptor.

Operant conditioning trials often have been influenced by human presence at the time of testing, particularly those using semi-tame or untamed animals. Eliminating human presence during data collection eliminates this problem. The development of an automated deer-training-apparatus (DTA) allowed for the efficient training of a large sample of deer to various stimuli in controlled experiments while simultaneously eliminating investigator influences (Cohen 2011, Cohen et al. 2012). The DTAs present two stimuli over separate food troughs to a single deer (Figure 2). Deer select a stimulus by attempting to feed in the corresponding trough below. An infrared sensor in front of the trough detects an animal's choice of a stimulus, and the decision is automatically recorded. The DTAs automatically dispense the food reward and also limit access to feed when incorrect decisions are made. The DTAs were initially used in experiments to delineate the visual threshold of deer. The positive stimuli were lights of varying wavelength and intensity. The wavelengths selected for study were based upon the findings of Jacobs et al.

(1997). Stimuli were presented for eight seconds after a bell rang. If the deer responded to the positive stimulus, the doors to the feed troughs stayed open for one minute, allowing the deer to feed. When the deer selected the trough that was not associated with the positive stimuli, the doors shut immediately. This research demonstrated that the DTA is an effective and efficient method by which to train white-tailed deer. Furthermore, it was used to determine that the relative spectral sensitivity of deer is comparable to the photoreceptive sensitivity of deer with only one variation from the previous literature at 590 nm (Cohen 2011). As a logical next step, I evaluated an adaptation of Cohen et al. (2012) for its efficacy in future experiments. Potential future experiments include determining the ability of deer to discriminate chromatic stimuli from both achromatic and other chromatic stimuli.

Some techniques to estimate animal age, like tooth replacement and wear in white-tailed deer (Severinghaus 1949) or dry eye lens weight in many lagomorph species (Lord 1959, Connolly et al. 1968, Wheeler and King 1980), have been widely adopted as accurate means for determining age of wild individuals. Age determination methods have been established for white-tailed deer (Severinghaus 1949), elk (*Cervus elaphus*; Quimby and Gaab 1957), and mule deer (Robinette et al. 1957). The technique of determining age via examination of incisor cementum annuli originated in the mammalian pinniped families Otariidae and Phocidae (Scheffer 1950, Laws 1952). This method has been established as a viable means for determining age of many cervid species, including moose (*Alces alces*; Sargeant and Pimlott 1959, Wolfe 1969), caribou (*Rangifer tarandus*; McEwan 1963), roe deer (*Capreolus capreolus*; Aitken 1975), mule deer (Low and Cowan 1963, Thomas and Bandy 1973), red deer (*Cervus elaphus*; Mitchell 1963, 1967), elk (Keiss 1969), and white-tailed deer (Gilbert 1966, Ransom 1966).

Although tooth replacement and wear or cementum annuli can place individual deer into an age class by year, there is not a precise technique to determine the exact age of neonatal white-tailed deer. Being able to accurately determine the age of a white-tailed deer fawn would allow determination of when fawns are susceptible to depredation, disease, and other age-specific mortality factors. In addition, conception and parturition dates could be determined without the lethal collection of the mother while parturient. Published aging techniques for white-tailed deer fawns include hoof length, hind leg length, and hoof growth (Haugen and Speake 1958, Sams et al. 1996). While these methods proved accurate for the sample from which they were developed, a fawn must be alive or mostly intact to obtain most of these measurements. The hoof growth can be a difficult measurement to obtain because of the development of the growth ridge used to identify this new growth. It is bumpy and can vary in distance to the hairline across the hoof. For these reasons, I found it necessary to investigate other methods to determine age in fawns.

The fields of white-tailed deer vision and neonatal age determination are ripe for investigation in a controlled, captive situation. I used the captive deer herd at the University of Georgia's White-tailed Deer Research Facility to develop and determine the viability of a modification of the Facility's DTA to expand on our understanding of deer vision. In addition, I capitalized on the ability to determine the birth dates of fawns in the facility to collect sequential data as the fawns matured in an effort to develop a more accurate technique to determine age of white-tailed deer fawns.

OBJECTIVES

The goals of my project were to further elucidate visual perception and neonatal morphometrics in captive deer for potential management application to wild, free-ranging deer. My specific objectives were to: (1) determine the efficacy of computer screen modifications to the DTA for future vision and sensory perception research; (2) provide recommendations for future studies with the DTA; and (3) create an accurate model to estimate age of neonatal fawns in multiple research and management contexts.

THESIS FORMAT

Chapter 1 is an introduction and a literature review of similar research topics also utilizing captive deer populations. Chapter 2 presents the recommendations for modifying the DTA for future studies investigating sensory perception capabilities of deer, primarily vision. Chapter 3 reports modeling techniques for aging fawns from birth to 1-month-old using combinations of morphometric measurements. Chapter 4 is a conclusion which discusses the implications of the findings of these two studies.

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CHAPTER 2

TROUBLESHOOTING AND POTENTIAL USES OF A DEER-TRAINING APPARATUS: A BEHAVIORAL ASSAY

INTRODUCTION

Although abundant research has investigated the visual capabilities of domestic species, little is known about the visual aptitudes of white-tailed deer (*Odocoileus virginianus*). An understanding of the visual capabilities of deer will help develop management plans that benefit both humans and deer populations. For example, deer-vehicle collisions (DVCs) claim \$1.1 billion worth of damages and 200 human lives per year in the United States (Sullivan and Messmer 2003). Deterrent devices used to mitigate DVCs by controlling deer movement, such as deer whistles and roadside reflectors, target the sensory processes of deer. However, these methods have been designed without an adequate understanding of deer sensory perceptions, and have been found to be ineffective (D'Angelo et al. 2006, Valitski et al. 2009). Therefore, additional research into the visual capabilities of white-tailed deer, specifically regarding color vision, may help to develop methods to mitigate DVCs.

Additionally, vision research would have implications on the hunting camouflage industry. For example, an ideal combination of camouflage and blaze orange may be highly visible to humans while remaining inconspicuous to game species. Most states have safety regulations regarding blaze orange. Blaze orange is any hue within the range of 595-605 nanometers. Blaze orange clothing for hunting must not exhibit luminance values less than 85%

and luminosity factors of at least 40% (Neitz et al. 1995). Previous research supports that dichromats, such as the white-tailed deer, do not detect orange hues against foliage as effectively as trichromats such as humans (Caine and Mundy 2000). However, other research suggests that some color-camouflage patterns may be more discernible to dichromats than to trichromats (Morgan et al. 1992) because they are less likely to incorrectly segregate differences due to color interference. Further knowledge of the ability of deer to discriminate color, coupled with future studies about their visual acuity may result in safer and more effective camouflage patterns for hunters.

White-tailed deer vision

Deer possess large eyes relative to their body size (Walls 1942) which allow increased ability to absorb light due to a greater number of photoreceptors. A unique spatial arrangement of the deer's eye, along with its thick lens, are thought to project onto the retina an image of moderate size and brightness (Walls 1942, Howland et al. 2004).

The deer retina contains a tapetum fibrosum, a variant of the tapetum lucidum, consisting of dense fibrous tissue that acts as a mirror to increase perceived differences in brightness of objects (Duke-Elder 1958). The tapetum aids in visual discrimination in dim light settings and is an adaptation to crepuscular habits. The pupil openings of white-tailed deer are roughly rectangular in shape, rather than circular as in humans, and aid eye function in a range of lighting conditions (D'Angelo et al. 2008). The size of the retina and the amount of light let into the eye exhibit an exponential relationship. Because of this feature, deer are able to collect more ambient light in low-light situations, and thus see better relative to humans when ambient light is low. Deer can discriminate among wavelengths (i.e., perceive color), as demonstrated by operant conditioning methods in pen studies (Zacks and Budde 1983), as well as physiological

studies of the retinal photoreceptors (Jacobs et al. 1994). Deer are dichromatic; vision is characterized by two cone types with different spectral sensitivities (Jacobs et al. 1994). In contrast, humans have trichromatic color vision. Electroretinogram (ERG) flicker photometry has similarly indicated that horses (*Equus caballus*), (cattle (*Bos taurus*), goats (*Capra hircus*), and sheep (*Ovis aries*) are also dichromatic (Carroll et al. 2001, Jacobs et al. 1997). The range of colors dichromats perceive is much more limited because they rely on two peak spectral sensitivities instead of three like a trichromat (Carroll et al. 2001: Figure 2.1).

The human retina possesses a fovea centralis (Ahnelt et al. 2006), a small circular area that allows human visual acuity to be much more precise than that of some species. The fovea centralis has a medium wavelength cone density $> 150,000/\text{mm}^2$. A deer, which lacks a fovea centralis, has a maximum retinal density of medium wavelength cones averaging $30,000/\text{mm}^2$ (D'Angelo et al. 2006). While this limitation in the density of medium wavelength cones negatively affects visual acuity in deer, deer have a visual streak that, much like the human fovea centralis, contains a higher density of photoreceptors. Along this entire area of the retina, the image is equally focused. This feature, in combination with widely set eyes, seemingly allows deer to monitor the horizon for detection of motion. Without moving their heads, a deer's widely set eyes allow it to have a 310° field of vision (Muller-Schwarze 1994).

Mammalian vision testing

Numerous studies have used operant conditioning to investigate visual acuity, discrimination, and detection in horses (Blackmore et al. 2008, Timney and Keil 1992), goats (Blakeman and Friend 1986, Franz et al. 2002), cattle (Entsu et al. 1992, Gilbert and Arave 1985), cats (*Felis catus*; Hall and Mitchell 1991), camels (*Camelus dromedaries*; Harman et al. 2001), and dogs (*Canis lupus familiaris*; Pretterer et al. 2004). For example, group-housed goats

have been trained to discern simple geometric shapes from one another (Franz et al. 2002) and horses have been trained to discriminate chromatic hues amongst achromatic stimuli (Blackmore et al. 2008). Kelber et al. (2003) list 21 species that have undergone various behavioral tests to determine color vision aptitudes, and discusses procedures which reward test subjects with food when a chromatic stimulus is discriminated from gray.

One difficulty in evaluating color discrimination capabilities is standardizing brightness. Brightness is the psychological perception of luminance, and differences in brightness must be controlled to eliminate those differences as discernible cues. This has been accomplished by creating stimuli for which brightness varies across the entire image, such as the use of an adapted Cambridge Color Test (CCT; Mancuso et al. 2006). Tests such as these eliminate the ability of individuals to discern embedded differences due to differences in luminance or perceived brightness.

Operant conditioning trials may be influenced by human presence at the time of testing, particularly those using semi-tame or untamed animals. Eliminating human presence during data collection eliminates this problem. The development of an automated deer-training-apparatus (DTA) allows for the efficient training of a large sample of deer to various stimuli in controlled experiments while simultaneously eliminating investigator influences (Cohen et al. 2012). These DTAs present two stimuli over separate food troughs to a single deer (Figure 2.2). Deer select a stimulus by attempting to feed in the corresponding trough. An infrared sensor in front of the trough detects an animal's choice of a stimulus, and the decision is automatically recorded. The DTAs dispense a food reward when a correct choice is made and limit access to feed upon an incorrect decision. The DTAs were initially used in experiments to delineate the visual threshold of deer. The positive stimuli were lights of varying wavelength and intensity; the negative

stimuli were lights that did not turn on. The wavelengths chosen were based on Jacobs et al. (1997). Stimuli were presented for 8 seconds after a bell rang. If the deer responded to the positive stimulus, the doors to the feed troughs stayed open for 1 minute, allowing the deer to feed. When the deer responded to the negative stimulus, the doors shut immediately. After determining the visual threshold of deer in Cohen's study, we wanted to proceed to investigate deer vision within these thresholds. We evaluated an adaptation of Cohen et al. (2012) for its efficacy in future experiments determining the ability of deer to discriminate chromatic stimuli from both achromatic and other chromatic stimuli.

MATERIALS AND METHODS

Our research was conducted at the University of Georgia's Whitehall Deer Research Facility in Athens, Georgia. This facility includes a deer barn consisting of 19 barn stalls and 2.42 hectares of fence-enclosed pens. Each stall is 3.05 meters wide by 4.88 meters. Seven stalls in the deer barn are equipped with a DTA. Prior to our modifications, the DTAs consisted of two food troughs covered by pneumatic lids, a stimulus light situated above each trough, two food dispensers, and a programmable relay that serves as the timer and instruction for the entire sequence of events. The DTAs are constructed such that a deer simultaneously views two stimuli, each over a different feed trough. An infrared beam of light crosses 30.5 centimeters in front of the feed bin. As the deer approaches the feed bin and breaches the beam, the relay records which stimulus the deer was approaching. Thus, the computer records the deer's response as a correct choice or an incorrect choice. If the deer approaches the correct choice, then the feed bin remains open for the deer to eat. If the deer approaches the incorrect choice, then the feed bin closes as soon as the beam is broken.

Using the DTAs and a classic operant conditioning theme, we evaluated the effectiveness of modifying the device to proceed with various aspects of color vision. These modified DTAs allowed simultaneous presentation of two images on paired 14" LG FLATRON W1934S LCD computer monitors, which were mounted above the food troughs (Figure 2.3), and rewarded the deer with a ration of food for correct responses. Stimuli on the left side of the DTA are controlled by one computer and those on the right by another. These computers are kept in a separate, sound-proof room and connected to the DTAs via wiring running above the barn stalls. We administered an experiment to gauge the response of the deer to the retrofitted DTAs. If deer responded to our retrofitted DTAs, then we could proceed with several color vision trials that allowed the training of, and collection of data from, an adequate sample size.

The stimuli used in this study were digitally constructed pseudoisochromatic plate tests, which were built using CorelDRAW X5 software. A previous study investigated the vision of horses by using a version of pseudoisochromatic plate testing called the Color Vision Testing Made Easy Test (CVTMET; Waggoner 1994, Hanggi et al. 2007). This version of pseudoisochromatic plate tests uses shapes instead of numbers and therefore has a lower degree of cognitive difficulty (Dain 2004). Images constructed for this study emulated CVTMET and adapted CCT plates in that they were simple representations of two different hues composed of circles. Originally, our positive stimulus, or image, was an achromatic background with a block of circles of the selected hue occupying approximately 25% of the center of the monitor space. The negative stimulus was a uniformly achromatic, or gray, plate (Figure 2.4). The color selected for constructing the positive stimuli was 225°, a blue hue, based upon what is visible to other dichromats (Carroll et al. 2001) and according to what should be visible to deer (Jacobs et al. 1994).

We measured the luminance of each hue and saturation combination with a Tektronix J17 photometer/radiometer/colorimeter with a J1820 Chromaticity Head (Tektronix, Beaverton, OR). We also measured the luminance of the entire range of grayscale options. The pseudoisochromatic plate tests were constructed such that the luminance of the hue portion of the stimuli was equal to the luminance of the gray portion. This prevented luminance borders from becoming a distinguishing factor. Because brightness is the psychological aspect of luminance, we controlled for differences in brightness by controlling luminance. In addition, we standardized brightness of the screens across all trials to eliminate brightness as a factor across hue and saturation discrimination. This design ensured that hue alone was the distinguishing feature of the pseudoisochromatic plate.

In 1931, the CIE established a novel color model to pose as an international standard (Smith and Guild 1931). The model has since been updated, resulting in a 1976 model attempting to achieve perceptual uniformity (Ohno 2000). This model was derived by a standard transformation of coordinate values from the original model. The values can be measured in degrees from 0 to 360. We identified hues in this experiment from this color model.

The experiment was designed to determine if white-tailed deer could participate in future studies investigating their ability to discriminate color stimuli from achromatic stimuli. To do so, we designed our experiment as if it were a training period prior to a color discrimination experiment. During the first 2 days, no images were displayed on the monitors but both troughs of the DTA were open. Food was available *ad libitum* to acclimate the deer to feeding out of the troughs. For the third and fourth day, the positive stimulus was displayed above both troughs while they both stayed open for 2-hour increments of time four times a day. On Day 5, we began the trials of the experiment.

We conducted 28 trials in each 24-hour period. A 24-hour period started at 1530 hours on the first day and ran until 1000 hours the subsequent morning. We scheduled trials to occur every 30 minutes from 1530 to 2200 hours and 330 to 1000 hours. This was intended to mirror the crepuscular activity of deer.

Our program was written in the SG2 Client software, which was compatible with the TECO SG2 Programmable Logic Smart Relay delivering the commands to the DTAs. The program controlled the occurrence of events (Figure 2.5). Our program coded for a bell to ring for 1 second to initialize the trial. After 1 second, the screens turned on, displaying the stimuli. We introduced the experiment to the deer in a two-phase process. In the first, we used a plain black screen as our negative stimulus. We proposed that this would further enforce the deer's association of the positive stimulus with the food reward. We designed our positive stimulus to emulate the pseudoisochromatic techniques we would actually use in future trials. Once the deer were trained to the positive stimulus, we would begin the second phase in which the negative stimulus was actually displayed alongside the positive stimulus instead of the black screen. Positive and negative stimuli were assigned to the left and right by randomization. Eight seconds after the screens turned on, the trough lids opened. The 8 second delay existed so that the deer had ample time to view the stimuli before approaching the feed troughs. Deer had 120 seconds to make a decision once the screens were activated. If the deer chose incorrectly, then the screens turned off and the trough lids closed immediately and the trial ended. If the deer chose correctly, both trough lids remained open for an additional 70 seconds allowing the deer to eat as a reward for the correct decision. Trough lids closed after the 70 second reward, and 28 grams of pelleted feed were deposited into both troughs.

When deer respond to the correct stimulus $\geq 75\%$ of the time for five consecutive days, the individual was considered trained. We chose 75% because it is well above the percentage that the correct decision was chosen due to chance alone, and it was the established threshold in the only previous DTA trials (Cohen et al. 2012).

Decisions recorded were documented by performance values. Performance was measured as the percent of correct choices made when a decision was made. Hues were considered discriminable when performance values were greater than 75%.

Changes in protocol

This experiment involved a novel device. We had one paper to reference in published literature when deciding on protocol. As such, we knew our efforts would require troubleshooting as the experiment progressed. The protocol described thus far in the materials and methods reflects the protocol we chose for the majority of the experiment and that we suggest be used for future studies. Major changes in protocol included timing changes, mechanical changes, and changes to the stimuli.

We changed the program in regards to timing on two occasions. Both changes were an attempt to counteract behavior of the deer that was interfering with their decision making. The first change in the program's timing occurred when we observed deer hovering over feed troughs as soon as the bell rang. These deer were already breaking the sensor beam, so as soon as the screens came on and the doors opened, decisions were incorrectly recorded for deer. To circumvent this issue, we introduced the 8-second delay described above. This provided the deer enough time to view the stimuli, then move between the troughs if they desired, before registering their decision. We noticed variability in the deer's interest to participate in the trials, most commonly associated with high temperatures. We extended the time period during which

they could make a decision to 120 seconds to encourage participation by deer that did not respond soon enough.

The experimental deer developed some habits within their stalls that hindered the collection of data. They chewed exposed wires and some even learned to lift the pneumatic lids of their troughs, negating food as a motivating factor driving participation. We made alterations to the devices so that this behavior, whether it continued or not, would not impact the experiment or the recording of data collected in the experiment. We applied Chew Stop, a cinnamon-flavored cribbing formula, to exposed wires that could not be concealed by plastic conduit or other means. We sanded trough lids so that they were flush with the trough, therefore providing no lip by which the deer were able to raise them. Additionally, constant maintenance was required on these devices to keep them working despite conditions presented by the barn setting of this experiment.

In the final 2 weeks of the experiment, we began Phase II. Phase II differed from Phase I in that the negative stimulus was introduced alongside the positive stimulus. We no longer used a black screen as the negative stimulus. For Phase II, we altered the positive and negative stimulus to create an even lower level of cognition required to distinguish the differences. We eliminated the circles that composed the first set of stimuli and created a plate which had an uninterrupted solid color block on an uninterrupted solid gray background (Figure 2.6). The color was the same blue used for the entire experiment thus far, 225°. The University of Georgia Institutional Animal Care and Use Committee approved the project protocol for animal use and handling (AUP# A2010 1-010) at the Whitehall Deer Research Facility.

RESULTS AND DISCUSSION

After numerous revisions and repeated testing, we developed a program that provided us with the exact sequence of events and timing regimes we deemed most effective for future research endeavors with the DTA. With our successfully retrofitted device and a corresponding program, we encourage future studies using the DTA to discover more about the visual capabilities of white-tailed deer. Understanding the maintenance requirements of this type of device should not be underestimated by those seeking to continue similar research. Maintenance was the most time-consuming aspect of this experiment. Not only is it necessary for the routine functioning of the equipment, but failure to constantly monitor all the possible malfunctions may result in inaccuracies or results that cannot be considered in data analysis. For example, if a wire is chewed and one monitor no longer receives power, all the data collected while that screen was nonfunctional will have been rendered useless. The complex interconnectivity of all the technologies involved across the barn's seven devices required constant monitoring of all equipment. Tracing sources of error, even identifying them preemptively, was pivotal for continued success throughout the duration of an experiment.

We used this program to gauge the reaction of seven does to the retrofitted device. These seven does were exposed to various versions of the program as it was being developed, as we needed to observe their behavior at times to accept or reject certain changes to the program. We measured the performance of these does during Phase I (20 September to 20 October 2012) in accordance to the program we had developed up to this point. We successfully trained two deer during this time, Does B69 and B70 (Figure 2.7). The absence of data on 28 September 2012 occurred from the loss of power to the barn following a thunderstorm. The absence of data from

Doe B69 on 4 October and 5 October 2012 was from a failure of the deer to participate in the trials.

During Phase II (25 October to 5 November 2012), we used the same program that we used during Phase I; only the stimuli used changed from Phase I to Phase II. However, because of malfunctions in the monitors in several barn stalls during Phase II, there was a void in the data. We repaired the problem and continued trials with the five deer that we deemed had shown the most progress to that point during Phase II. We defined this progress by examining the performance of individuals, selecting those which performed most consistently at elevated levels. We were unsuccessful in training any deer during Phase II (Figure 2.8).

We concluded that it was feasible to train multiple deer with the final program that we developed. We successfully trained two, as indicated by does B70 and B69 (Figure 2.7). With more time, we believe more does would have achieved the criteria we considered to be trained (>75% correct). However, we experienced a much lower success rate than Cohen et al. (2012) reported. Factors that contributed to failure of does to train in Phase I likely include the greater distance from the stimulus to the food source (Figure 2.3). Additionally, the stimuli required a greater cognitive effort (i.e., discerning colors and shapes) in this study, as compared to the stimuli used previously (i.e., a single wavelength). Perhaps more time must be allotted for the training period for these new stimuli before we can expect does to demonstrate that they have been successfully trained.

No deer were trained in Phase II. We suggest that these does had been exposed to so many changes in the development of the training regime that they may have been too confused to continue successfully in the study. Even does that reached the level of successful training criteria during Phase I subsequently regressed to below the training threshold of 75%. In future

studies, we suggest introducing naive deer to the devices and program at the beginning of the training period, rather than adapting to revisions in the program and devices.

We conclude that future sensory perception research, particularly studies focusing on vision, can be conducted with these devices and program. The addition of computer monitors to the DTAs creates numerous possibilities. The variety of images and videos that can be displayed on the DTA may allow future studies to determine the limitations of deer's color vision capabilities, precision of their visual acuity, ability to detect motion, ability to distinguish patterns and textures, and other aspects yet to be defined. These results will facilitate continued studies of some very basic baseline observations of one of the world's most-studied large mammal species.

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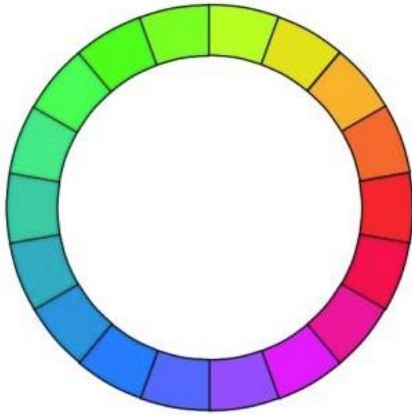
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Human Trichromatic Color Vision



Horse Dichromatic Color Vision

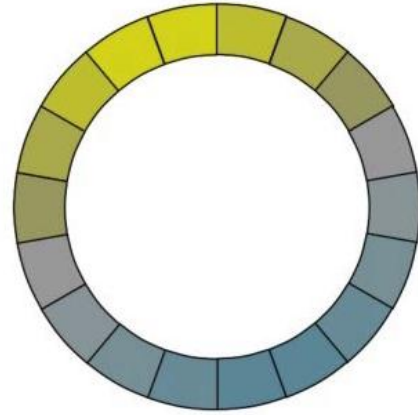


Figure 2.1. Color wheels for trichromats (left) and dichromats (right); developed from photopigment basis for color vision in the horse (Carroll et al. 2001). This image illustrates the greater variety of colors that trichromats are able to be perceived from just one more photopigment receptor.



Figure 2.2. A photo of an installed Deer-Training-Apparatus in a barn stall in the Whitehall Deer Research Facility, as seen by test subjects.



Figure 2.3. A photo of a retrofitted Deer-Training-Apparatus in a barn stall in the Whitehall Deer Research Facility, as seen by test subjects. The modifications include mounting LCD computer monitors in place of flashlights.

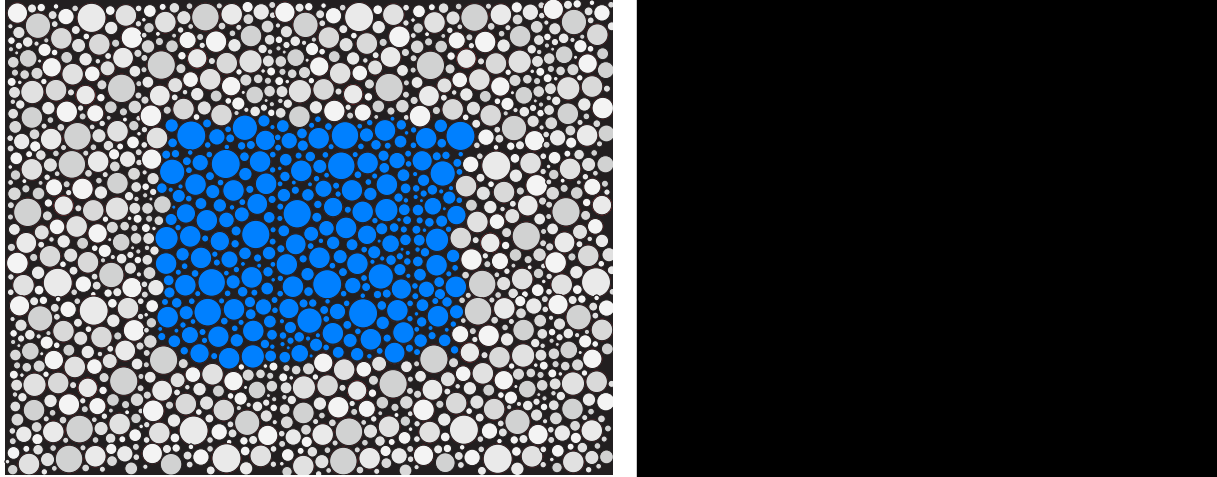


Figure 2.4. An example of paired images displayed on a DTA during Phase I. The left image is the positive stimulus, while the right is the negative.

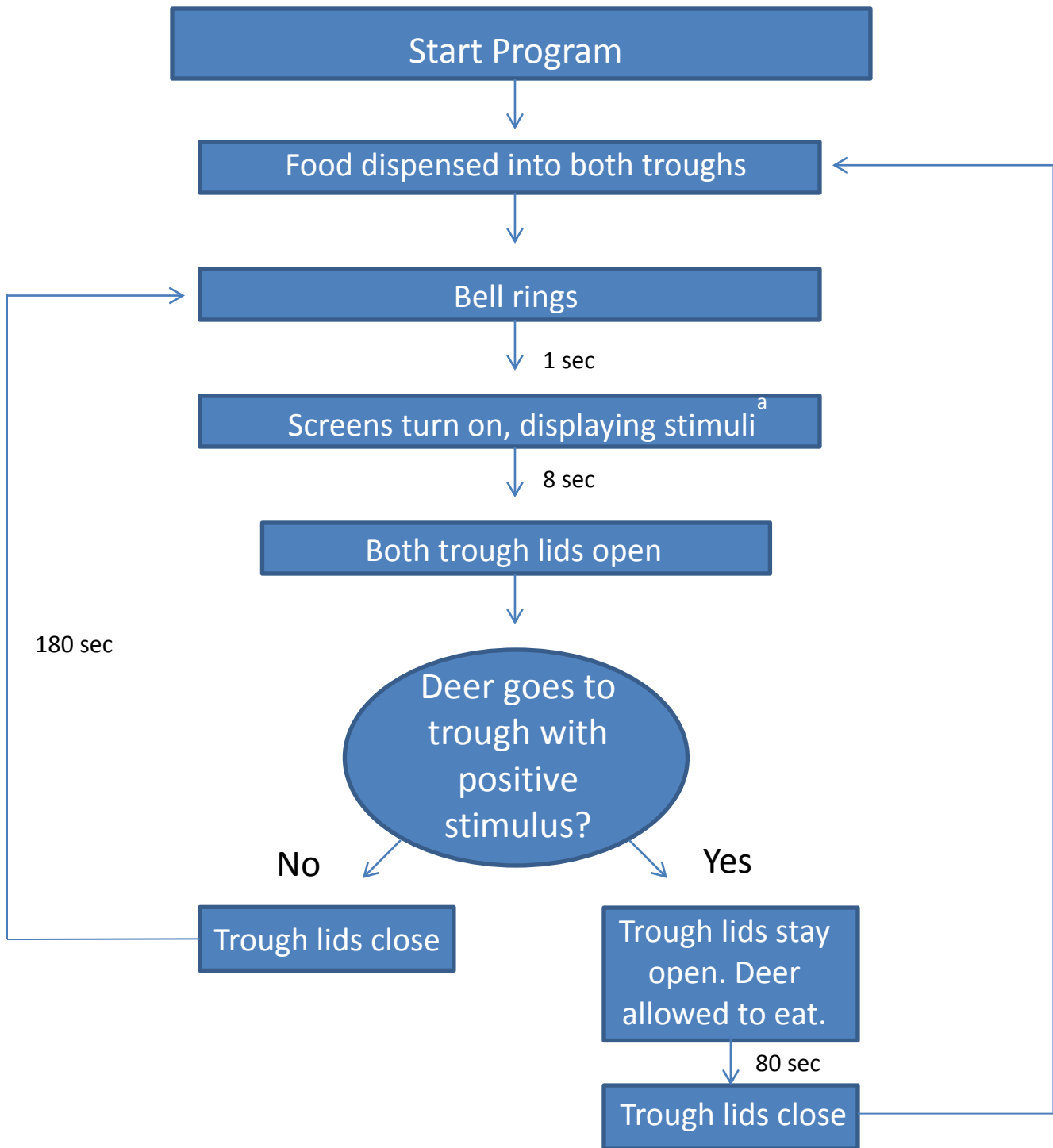


Figure 2.5. Functional block diagram of the program for “deer-training-apparatus” adapted from Cohen et al. (2012), explaining the course of events occurring as the relay instructs the DTA during trials.

^aDuring Phase I, the stimuli displayed were those presented in Figure 2.4. In Phase II, the stimuli displayed were those presented in Figure 2.6.

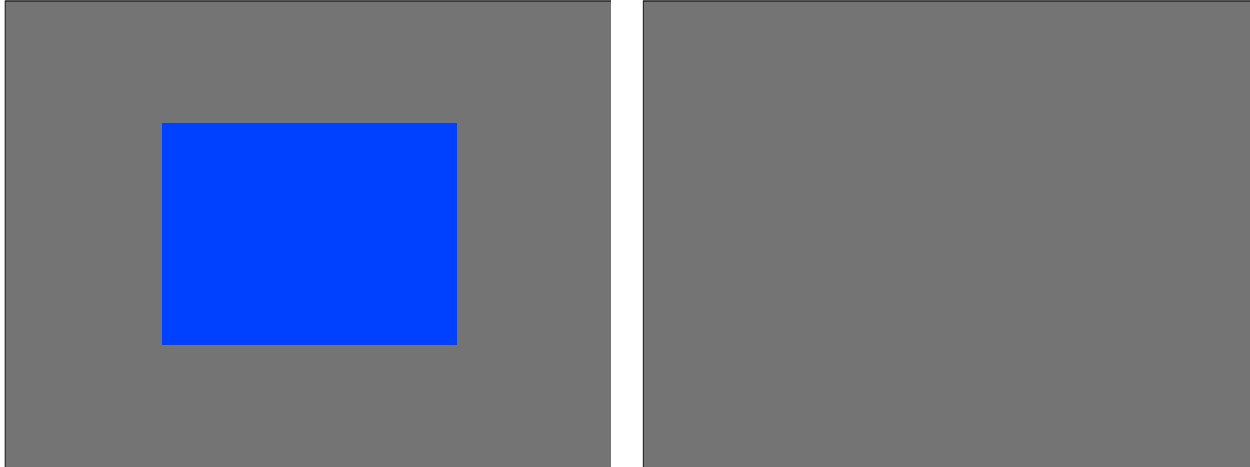


Figure 2.6. An example of the paired stimuli introduced in the last two weeks of the experiment, also called Phase II. This change was meant to determine if simpler stimuli would affect the deer's performance in distinguishing the positive and negative stimuli correctly. The left image is the positive stimulus, while the right is the negative.

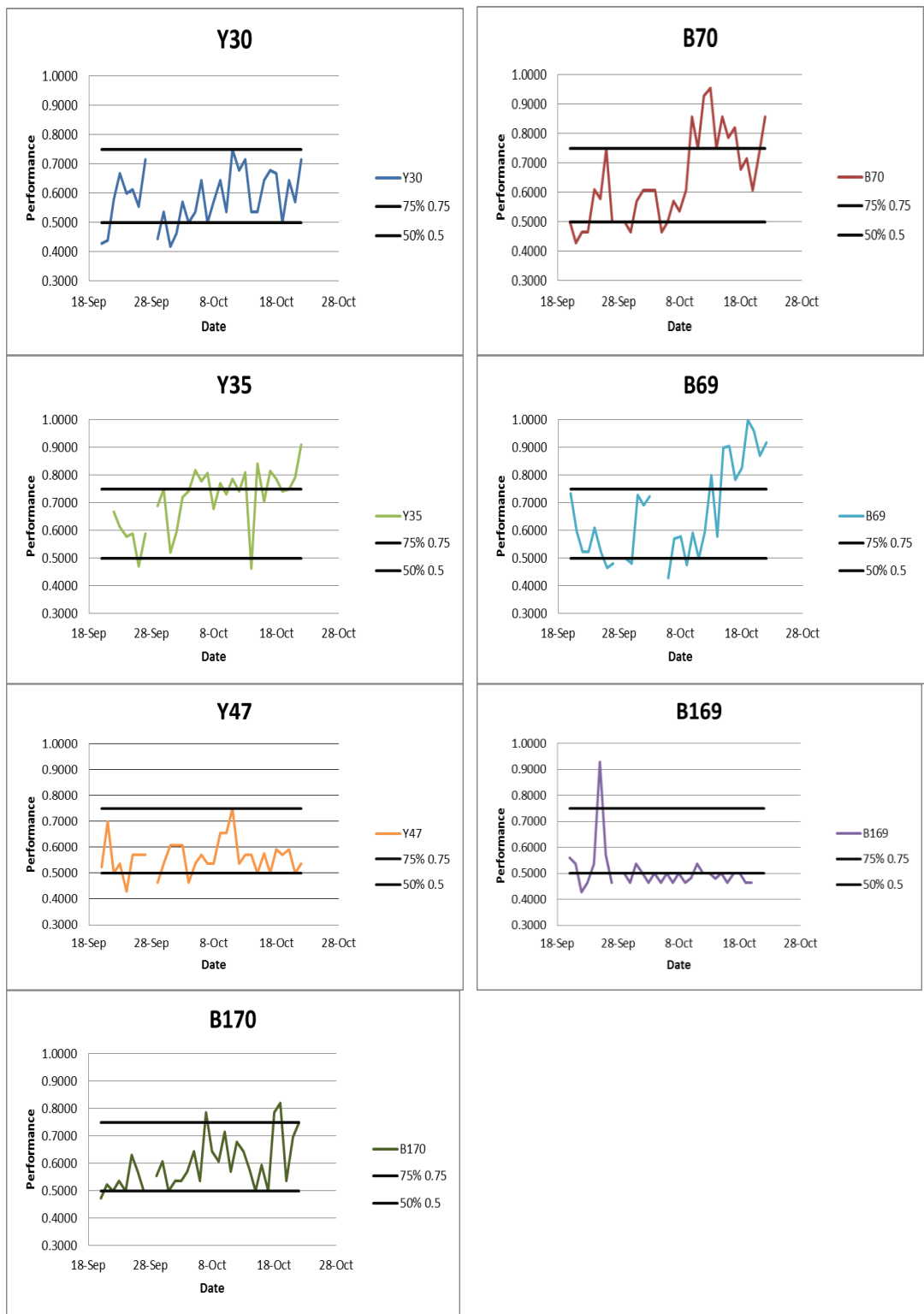


Figure 2.7. Performance results for 7 does from Phase I of the DTA experiment conducted at the Whitehall Deer Research Facility from 20 September to 20 October 2012, which displayed the stimuli from Figure 2.4.

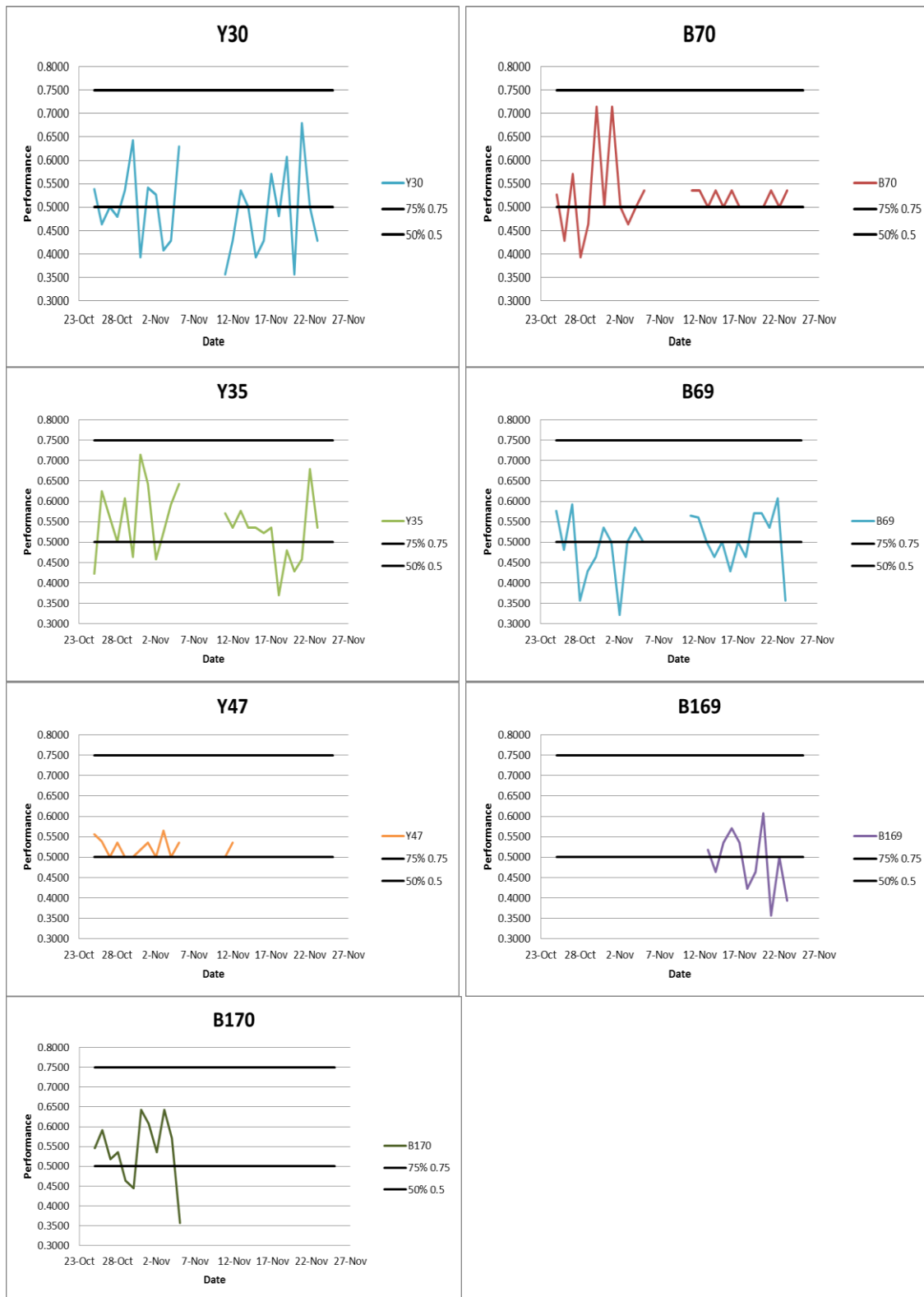


Figure 2.8. Performance results for 7 does from Phase II of the DTA experiment conducted at the Whitehall Deer Research Facility from 25 October to 5 November 2012, which displayed the stimuli from Figure 2.5.

CHAPTER 3

MODELING AGE OF NEONATAL WHITE-TAILED DEER FROM MORPHOMETRICS AND HAIR MEASUREMENTS

INTRODUCTION

The ability to accurately estimate the age of individual wildlife species is often important in wildlife management or research. Some techniques, such as tooth replacement and wear in white-tailed deer (*Odocoileus virginianus*; Severinghaus 1949) or dry eye lens weight in many lagomorph species (Lord 1959, Connolly et al. 1969, Wheeler and King 1980), have been widely adopted as accurate means for estimating ages of wild individuals. Tooth replacement and wear places individual deer into an age class by year, but there is currently not an accepted, precise age determination technique available for neonatal white-tailed deer. Being able to determine age of white-tailed deer fawns to the day of parturition would provide insight as to when fawns are susceptible to predation, disease, and other instances of age-specific mortality. In addition, conception and parturition dates could be determined without the lethal collection of the doe while parturient.

Cervids are often categorized into age classes by patterns in tooth replacement and wear. Techniques using this method have been established for white-tailed deer (Severinghaus 1949), elk (*Cervus elaphus canadensis*; Quimby and Gaab 1957), and mule deer (*O. hemionus*; Robinette et al. 1957). The technique of estimating age via examination of cementum annuli, or deposited layers of a specialized calcified substance, originated in the mammalian pinniped

families Otariidae and Phocidae (Scheffer 1950, Laws 1952). This method has been established as a viable means for estimating age for many cervid species, including moose (*Alces alces*; Sargeant and Pimlott 1959, Wolfe 1969), caribou (*Rangifer tarandus*; McEwan 1963), roe deer (*Capreolus capreolus*; Aitken 1975), mule deer (Low and Cowan 1963, Thomas and Bandy 1973), red deer (*Cervus elaphus elaphus*; Mitchell 1963, 1967), elk (Keiss 1969), and white-tailed deer (Gilbert 1966, Ransom 1966).

Neonatal black bear (*Ursus americanus*) cub age estimates were developed by creating a mixed effects model that used hair and ear length measurements; several morphological measurements were reliable indicators of age, including skull width and total body length (Bridges et al. 2002). In neonatal elk, tooth length, umbilicus condition, tooth eruption, mass, and hoof measurements provide reliable estimates of age with tooth length, mass, and hoof measurements identified as the strongest predictors of age (Montgomery et al. 2005, Zager et al 2008). Hoof growth was also used as a tentative tool for determining age of endangered Patagonian huemul (*Hippocamelus bisulcus*) fawns (Flueck and Smith-Flueck 2005).

The most widely accepted published technique for estimating age of white-tailed deer fawns is hoof growth (Haugen and Speake 1958, Sams et al. 1996). This measurement, however, is subjective and allows for human error. In addition, a fawn must be alive or mostly intact to obtain this measurement. In addition to anecdotal accounts of the subjectivity of this measurement, Haskell et al. (2007) reported that the actual age of neonatal white-tailed deer differed by as much as 10 days when using the hoof growth method provided by Sams et al. (1996). Haskell et al. (2007) also reported a different rate of hoof growth than Haugen and Speake (1958), and discouraged the use of established age predictors that are not site- and time-specific (Haskell et al. 2007). They support their reasoning by citing differences in doe and fawn

nutrition and growth rates between captive and wild individuals documented in O'Regan and Kitchener's (2005) study. We conducted a study in which we monitored several morphometric growth rates and hair growth rates to examine relationships that may accurately estimate the age of fawns for deer populations in the Southeast.

MATERIALS AND METHODS

We obtained fawns born at the University of Georgia's Whitehall Deer Research Facility at Athens, Georgia. This facility included a 19-stall barn and 2.6 ha of interconnected fenced paddocks. Each barn stall measured 3.1 x 4.9 m. We moved pregnant does to barn stalls during late gestation and monitored them daily to ensure known parturition dates. Neonatal fawns were measured on 1, 2, and 3 days postpartum at this facility. On the third day, fawns were transported to an alternate captive deer facility in Hancock County, Georgia where they were housed singly or in pairs in 1.2 x 1.5-m barn stalls. During our study, they each received four daily feedings of species-specific milk formula (Fox Valley, Lake Zurich, IL). The fawns were hand-reared at this location to ensure tameness for future studies. At this site we recorded morphometrics and collected hair samples every other day from 3 – 30 days postpartum.

We selected 17 potential variables to measure including 11 morphometric measurements and 6 hair measurements. The morphometric measurements were: (1) length of the ear, (2) distance from the eye to the tip of the rostrum, (3) distance between the eyes, (4) distance from the base of the skull to the tip of the rostrum, (5) distance from the eye to the base of the jaw directly below the eye, (6) width of the skull at the widest point, (7) length of the front hoof posterior to the new hoof growth, (8) new hoof growth, (9) total length of the tail, (10) total length of the hind leg, and (11) length of the hind leg from the hock to the dewclaw. The hair

measurements were the length of hairs collected from six different locations: (1) middle of the forehead, (2) tip of the ear, (3) the back along the spine, (4) the back within a spot along the spine, (5) from the middle of the left tarsal tuft, and (6) from the tip of the tail. When measurements involved the distance from any feature to an eye, we defined the eye as the point at which the eyeball and tear duct met. To reduce sampling bias, all measurements were collected by the same one or two observers.

We stored hair samples individually and froze them until the day they were measured to prevent desiccation of the roots. We photographed hairs using a SPOT Idea microscope camera attached to a Leica mz6 Stereomicroscope (Sterling Heights, MI; Buffalo Grove, IL). Images were saved using SPOT Basic software and then were uploaded and analyzed with the measuring tool in ImageJ free downloadable software (rsb.info.nih.gov/ij/). We collected and measured 3 hairs per location per day per fawn to arrive at an average value.

Statistics were computed by the University of Georgia Statistical Consulting Center. Our final sample size consisted of 11 fawns. We plotted the 17 measurements against age for each fawn in the study. From these plots, we identified and removed outliers from the entire data set. These errors were likely due to misreadings from equipment or misrecordings due to human error. We then calculated Pearson correlation coefficients in SAS (SAS Institute, Inc., Cary, NC) for each measurement for each fawn to determine correlations between measurements and ages for each individual fawn. These data were not directly applicable for estimating age, but were used to calculate weighted correlations that represent the correlation between measurements and age across our sample of fawns. These values aid in determining which variables were likely to contribute to an estimating model, and were useful in identifying which variables were the strongest predictors of age. Weighted correlations help to correct for the

problem presented by small sample sizes which can result in less reliable measurements. For example, if one fawn only has two observations for a given measurement, then it will either be a perfectly positive correlation (1.00) or a perfectly negative correlation (-1.00) Such a strong correlation based on two data points would be misleading in terms of the model for predicting age from these measurements (i.e., would not represent a perfect correlation for this measurement and age across time and for multiple fawns). Calculating the weighted correlations allowed fawns with a greater number of observations over the duration of the study to influence the predictive equation more than those fawns with fewer measurements. For our modeling, we created a linear fixed effect model by a forward variable selection approach. Model creation and root-mean-square errors (RMSE) also were calculated in SAS. Because model parsimony was our top priority, we created two linear mixed effects model types. The first models were built on individual variables as predictors of age, whereas a subsequent model incorporated a combination of variables to best predict fawn age.

RESULTS AND DISCUSSION

Weighted averages of the Pearson correlations identified the eye to nose (EN), hind leg (HL), and hock to dewclaw (HDC) as particularly strong individual morphometric measurements that were correlated ($r \geq 0.90$) to age (Table 3.1). The least correlated measures based on the weighted correlation analyses were front hoof (FH), forehead hair (FHH), and ear tip hair (EH) ($r \leq 0.20$; Table 3.1).

Our full model for predicting fawn age included both fixed and random effects, where β represents the fixed effects coefficients and b represents the random effects coefficients:

$$\text{Fawn age} = \beta_0 + \beta_1 \times \text{predictor} + b_0 + b_1 \times \text{predictor} + \text{error}$$

The reduced model did not incorporate any random predictors, just a random intercept (b_0), which are specific to an individual fawn:

$$\text{Fawn age} = \beta_0 + \beta_1 \times \text{predictor} + b_0 + \text{error}$$

Generally, the full model is better fitting for the morphometric values, while the reduced model is a more appropriate application for the hair measurements. This is because the hair measurements were re-scaled prior to analysis by multiplying by 0.001 in order to accommodate for their very large scale. Therefore, the estimates for these covariates are not a 1 unit increase, but rather a 1000 unit increase. The reconfiguration of these data points did not allow for convergence with the full model, a common indication that we have attempted to over fit the data. For this reason, we used the full model for predictors without blank values in the “random” column in Table 3.2, and the reduced model for those predictors that are missing values. The input values for these models are found in Table 3.2.

A final, combined linear mixed effects model for predicting fawn age included five morphometrics that were found to be significant in the forward variable selection process. The final model was:

$$\text{Fawn age} = \beta_0 + \beta_1 \times \text{HDC} + \beta_2 \times \text{HL} + \beta_3 \times \text{E} + \beta_4 \times \text{NG} + \beta_5 \times \text{Head} + b_0 + b_4 \times \text{NG} + \text{error}$$

although the equation reads:

$$\text{Fawn age} = \beta_0 + \beta_1 \times \text{HDC} + \beta_2 \times \text{HL} + \beta_3 \times \text{E} + \beta_4 \times \text{NG} + \beta_5 \times \text{Head}$$

when using only fixed effects variables to estimate the age of a fawn outside of the population used to construct the model. This equation can be calculated by using the constant values presented in Table 3.3. When the constants are input, the final model was:

$$\text{Fawn age} = -108.03 + 0.2141 \times \text{HDC} + 0.1733 \times \text{HL} + 0.2526 \times \text{E} + 0.5787 \times \text{NG} + 0.0930 \times \text{Head}$$

Haskell et al. (2007) reported different growth rates from those reported by Haugen and Speake (1958), and showed that known fawn ages differed by as many as 10 days when using the morphometric estimates provided by Sams et al. (1996). Our RMSE values indicated that our strongest predictor, the hock to dewclaw (HDC) measurement, would predict within ± 4.03 days of the true age of the fawn. Our overall model, which incorporated the hock to dewclaw (HDC), hind leg (HL), ear (E), new hoof growth (NG), and head measurements, is comparable in accuracy with an RMSE value of 4.20. When applied, one would gain very little by the additional inputs needed to compute an estimate by the overall model if the single hock to dewclaw (HDC) measure is obtainable. However, our predictions are based on the 11 deer that we sampled. The degree of accuracy of our predictors must necessarily be evaluated with additional data sets which include captive and wild deer as well as deer from other regions of the whitetail's range.

It is likely that the model resulted in a marginally larger RMSE value than the single hock to dewclaw (HDC) predictor because this value incorporates the number of variables input into the model. Hock to dewclaw (HDC) is penalized as a predictor of age only by two variables—an

intercept and the actual hock to dewclaw (HDC) measurement. The overall model, however, is penalized for an intercept and 5 additional measurements. The hind leg (HL) measurement will also predict within 4 days of the true age with an RMSE equaling 4.74. Our RMSE values designated the new hoof growth developed by Haugen and Speake (1958) was the third best of our 17 individual predictors, as its RMSE value is 5.10. We criticized the subjectivity of this measurement specifically. However, the hock to dewclaw (HDC) and hind leg (HL) measurements that we found to be the strongest individual predictors can be variable as well. The least predictive measurements according to our models were the between the eyes (BE), front hoof (FH), forehead hair (FHH), and ear tip hair (EH) ($RMSE \geq 9.29$). Given the concerns about subjectivity of the new hoof growth measurement, we were encouraged to find that three alternative predictors were more precise in estimating age.

These values represent a population of 11 captive-bred fawns. These data indicate that there were many variables that appeared highly correlated with age and likely would be good predictors of age across the range of the species. This model will be strengthened by the addition of field-collected data and increased sample sizes, which should evaluate the specific variables we found to be strong predictors of age. It also should be tested in various regions to determine the spatial range of its applicability. These studies will determine if our model is a useful predictor of age, or if site specific models need to be developed for these variables across different ranges.

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Table 3.1. Weighted average correlations between fawn age and all 17 measurements calculated with the consideration of the number of observations from each fawn. These values were calculated with measurements collected at captive facilities in Clarke and Hancock Counties, Georgia in the summer of 2012.

Predictors	Description of measurement	Weighted r
Ear (E)	length of the ear	0.80
EyeToNose (EN)	distance from the eye to the tip of the rostrum	0.90
BetweenEyes (BE)	distance between the eyes	0.63
Head	distance from the base of the skull to the tip of the rostrum	0.88
EyeToJaw (EJ)	distance from the eye to the base of the jaw directly below the eye	0.81
SkullWidth (SW)	width of the skull at the widest point	0.86
FrontHoof (FH)	length of the front hoof posterior to the new hoof growth	-0.50
NewGrowth (NG)	new hoof growth	0.87
Tail	total length of the tail	0.78
HindLeg (HL)	total length of the hind leg	0.92
HockToDC (HDC)	length of the hind leg from the hock to the dewclaw	0.90
ForeheadHair (FHH)	middle of the forehead	0.02
EarTipHair (EH)	tip of the ear	0.20
BackHair (BH)	hair from the back along the spine	0.66
SpotHair (SH)	hair from the back within a spot along the spine	0.69
TarsalTuftHair (TTH)	hair from the middle of the left tarsal tuft	0.32
TailHair (TH)	hair from the tip of the tail	0.73

Table 3.2. Input values for each predictor in the linear mixed effects model developed from 11 captive white-tailed deer fawn in the summer of 2012. These fawns were housed and measured at captive facilities in Clarke and Hancock Counties. Root-mean-square error (RMSE) values indicate the residual number of days between average estimates and actual values for each model.

Variable(Predictor) ^a	n	Intercept			Covariate			Random			RMSE
		Est (β_0)	t	pval	Est (β_1)	F	pval	int (b_0)	slope (b_1)	Wald test	
Ear (E)	156	-75.7814	-18.76	< 0.0001	1.1368	623.7	<0.0001	25.0093	-	-	6.81162
EyeToNose (EN)	155	-95.6488	-23.94	<0.0001	1.5008	1016.98	< 0.0001	36.6300	-	-	6.98678
BetweenEyes (BE)	156	-113.2100	-8.52	<0.0001	3.0263	98.47	<0.0001	28.2777	-	-	10.1103
Head	162	-57.3159	-11.34	<0.0001	0.4857	234.88	<0.0001	13.3376	0.000223	0.3014	7.6993
EyeToJaw (EJ)	155	-66.5398	-13.11	<0.0001	2.0308	295.13	<0.0001	17.1612	-	-	7.44712
SkullWidth (SW)	156	-155.4900	-21.16	<0.0001	2.5789	568.12	<0.0001	13.5147	-	-	6.16269
FrontHoof (FH)	157	91.1473	6.26	<0.0001	-4.3034	26.72	<0.0001	65.5054	0.0314	0.4328	12.1827
NewGrowth (NG)	157	-1.9611	-2.60	0.0225	3.6005	304.13	<0.0001	0.0323	0.243	0.0407	5.10366
Tail	127	-56.5498	-15.54	<0.0001	0.6185	479.26	<0.0001	22.3545	0.001005	0.196	6.94379
HindLeg (HL)	136	-120.0800	-29.80	<0.0001	0.5259	1333.05	<0.0001	15.5220	0.000029	0.4171	4.73948
HockToDC (HDC)	135	-142.4200	-35.75	<0.0001	0.8028	1789.42	<0.0001	11.3395	0.000243	0.1042	4.03085
ForeheadHair (FHH)	126	1.5129	0.27	0.7865	1.1690	6.22	0.0140	0	-	-	9.40572
EarTipHair (EH)	124	2.9551	0.61	0.5430	3.5810	6.33	0.0138	4.7023	-	-	9.29809
BackHair (BH)	128	-14.7983	-5.08	<0.0001	1.7890	122.68	<0.0001	11.6971	-	-	7.12874
SpotHair (SH)	128	-27.8832	-7.59	<0.0001	2.5310	150.36	<0.0001	13.3843	-	-	6.97162
TarsaTuftHair (TTH)	127	-4.1327	-0.90	0.3685	0.9170	18.52	<0.0001	6.4384	-	-	8.94076
TailHair (TH)	126	-18.0721	-5.46	<0.0001	1.0980	110.73	<0.0001	9.2902	-	-	7.1966

^aSee table 3.1 for descriptions of measurements

Table 3.3. Input values for the overall linear mixed effects model developed from 11 captive white-tailed deer fawn in the summer of 2012. These fawns were housed and measured at captive facilities in Clarke and Hancock Counties. A root-mean-square error (RMSE) value indicates the residual number of days between average estimates and actual values for estimates predicted by this model.

Effect(Predictor) ^a		Estimate	F Value	t Value	pval	Random	RMSE
Intercept	β_0	-108.03		-16.66	<.0001	6.9236	4.2008
HockToDC (HDC)	β_1	0.2141	15.23	3.9	0.0002	-	
HindLeg (HL)	β_2	0.1733	27.32	5.23	<.0001	-	
Ear (E)	β_3	0.2526	23.42	4.84	<.0001	-	
NewGrowth (NG)	β_4	0.5787	7.35	2.71	0.0130	0.2364	
Head	β_5	0.0930	6.78	2.6	0.0105	-	

^aSee table 3.1 for descriptions of measurements

CHAPTER 4

SUMMARY AND CONCLUSIONS

The goals of this project were to better understand wild deer and their management through research on captive deer. The unique setting of captivity provides the basis for obtaining information that could not be obtained in a field setting. Specifically, I determined the efficacy of certain modifications to a previously developed deer-training apparatus (DTA) for future vision and sensory perception research and provide recommendations for future studies with the DTA. I also developed a model to estimate age of neonatal fawns in multiple research and management contexts.

I created a design to retrofit the original DTA with 14” computer monitors that could display different stimuli, therefore broadening the number and types of experiments that could be conducted using the device. These modifications involved writing a new program for the TECO SG2 Programmable Logic Smart Relay, which controlled the timing of the commands to the device. In a two-phase training period, I successfully trained two deer. With novel deer, I expect that researchers will be able device to train and collect data from captive deer in future studies. Potential topics for these future studies include determining the limitations of deer’s color vision capabilities, precision of their visual acuity, ability to detect motion, ability to distinguish patterns and textures, and other aspects yet to be defined.

Estimating age of individuals is important in managing wildlife populations and in wildlife research. Currently, there are no accurate methods to determine age of neonatal white-tailed deer from birth to 30 days postpartum. The ability to estimate age of fawns would provide

insight as to when fawns are susceptible to predation, disease, and other instances of age-specific survival. In addition, conception and parturition dates could be determined without the lethal collection of the does while parturient. In creating model for neonatal fawns parsimony was my top priority, so that the model was applicable in a field setting and easily conducted. I created two linear mixed effects models. One was a separate model for each predictor, whereas another was a stronger predictor that incorporated a combination of variables to best predict fawn age. The separate linear mixed effects models are appropriate in situations where the inputs of the combined linear mixed effects model could not be obtained. For example, if only the hind leg of a depredated fawn remains, a separate linear mixed effects model can still provide an estimate of age. A full model was the best predictor for the morphometrics, while the re-scaling of hair measurements made a reduced model the only considerable model for that predictor. If all five morphometrics cannot be obtained, age can still be estimated by a number of individual measurements. These results offer two methods by which one may arrive at an age estimate for fawns between one and 30 days old.

My experiments provided results that can immediately be applied in future endeavors. Future researchers can move forward with vision research utilizing the DTAs with the computer program and modifications I evaluated in Chapter 2. I also created a viable technique to determine age of neonates that can be used in field and captive settings. This technique is flexible in that there is an alternative model if all the necessary samples are not obtainable.