UNDERSTANDING THE EQUINE DISTAL LIMB

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota

State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Studies examining health of the distal limb and lameness conditions are important for education and future research. It is hypothesized that changes to the external hoof would result in alterations to blood flow throughout the distal limb and changes to digital cushion thickness. To investigate these things, the following experiments (exp) were conducted. Exp 1: MRI images of the equine distal limb. All images had identified abnormalities to internal structures, and a lameness score assigned. Digital cushion thickness was measured, however no relationship of thickness and lameness was observed ($P \geq 0.12$). Exp 2: Trimming and shoeing is a routine procedure for maintenance of proper hoof health; therefore two exp at separate locations (NDSU and UMC) were conducted to examine digital cushion thickness, carpal joint circumference, and blood flow during this time. Specifically, measurements were obtained 24h post trimming and shoeing and periodically throughout an 8 wk period. No significant differences were identified in carpal joint circumference or digital cushion thickness at either location. Thermographic images identified changes in hoof temperature in bare and shod horses at both locations. Week by treatment interaction was significant at NDSU ($P=0.04$), with hoof temperature decreased in both treatment groups one week post trimming and shoeing. Shod horses remained below baseline throughout the 8 week period, and were significantly colder ($P=0.02$) than bare at 8 wk. Week by treatment interaction was also significant at UMC ($P<0.0001$), with decreased hoof temperature in both treatment groups 4 wks post trimming and shoeing, followed by shod horses increasing to baseline at 8 wk while bare remained colder. Exp 3: Transformative learning in undergraduate students. Undergraduate students enrolled in an Equine Science research course conducted four individual studies. Transformative learning was assessed throughout the course through reflection questions and discussions. It was determined that transformative learning was

achieved, however it was dependent on the particular student and their previous experience and knowledge. Overall, the current experiments provide further understanding of the distal limb. Further research should continue to place focus on those structures and mechanisms within the hoof which play an overall role in its proper function.

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This dissertation would not have been possible without the guidance and support of many people. My journey to where I am today has been a long process, but I have been abundantly fortunate to have the same people stick with me the whole way. Without them, this would not have been possible and they deserve all the acknowledgement.

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DEDICATION

To my son, Olly.

This little guy is the reason for everything I do. His energetic spirit and kind heart bring me joy every day. His hugs and snuggles are the light of my day. Having him in the midst of my graduate career has only encouraged me to keep going and has given me the drive and focus to be successful. Thank you for being my all little Ollyman!

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LIST OF ABBREVIATIONS

ave .... average

CJC .... carpal joint circumference

cm .... centimeters

CoP .... Center of pressure

CT .... computed tomography

DC .... digital cushion

DCT .... digital cushion thickness

DDFT .... deep digital flexor tendon

HPA .... hoof-pastern axis

LCJ .... left carpal joint

LD .... left dorsal

LL .... left lateral

LM .... left medial

max .... maximum

min .... minimum

mm .... millimeters

MRI .... magnetic resonance imaging

NDSU .... North Dakota State University

ºC .... degrees Celsius

os .... off side

PEL .... primary epidermal laminae

PD .... proton density

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CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Introduction

According to the USDA, horses in the United States are considered livestock; however, in contrast to most livestock species, horses are not used for food purposes. A horse's purpose and job within the United States has progressed from a working animal to where they are today as a performance animal (USDA, 2015b). Anything that prevents or hinders a horse from their purpose as a performance animal can create problems and become detrimental to the equine industry. To maintain performance, horses must be protected against things that may lead to lameness; however this is a large issue that the equine industry faces as it is the most common cause of lost performance. The distal limb can suffer from multiple complications that can lead to lameness and a potential loss in performance. Due to the variety of factors that can contribute to lameness in horses, it can be difficult to diagnose and become a large economic and welfare concern for the equine industry.

Lameness is a complicated condition with many possible causes. It has been defined as any alteration of a horse's gait, which can manifest in many ways that change performance and, ultimately, results in a complete loss of performance (Jeffcott et al., 1982). Lameness is considered a top medical problem in horses, with an annual incidence of 6.8% in horses ranging in age from 1 to less than 5 years, 6.2% in horses ranging from ages 5 to less than 20 years, and increasing to 9.9% in horses 20 years of age or older (USDA, 2015b). Furthermore, horse owners and industry professionals ranked leg/hoof problems (conditions leading to lameness) as a top priority for in-depth study focus (USDA, 2015b). Equine veterinarians rank musculoskeletal research as a top priority (89% of respondents), where four of the top five ranked diseases for research priority were lameness related (Seitzinger et al., 2002). Research focused on minimizing

lameness is essential as it is not only a welfare concern, but also an economic one as it is a leading cost for horse owners, with an estimate of $432 in veterinary costs, drugs, and care per lameness event (Seitzinger et al., 2002). This trend continues, with more recent data showing that 67.1% of operations had one or more resident horses with lameness issues in the previous 12 months (USDA, 2015a). Half of these horses (46.8%) had recovered and remained sound. However, 21.7% had improved but still showed signs of lameness and 15% showed no improvement (USDA, 2015a). Lameness has shown to be a long-term problem, with healing time anywhere from one week to over a year (USDA, 2015a).

Lameness is most commonly caused by problems in the foot (Turner and Stork, 1988; Hinchcliff et al., 2004). For centuries, the phrase "no hoof, no horse" has been used, yet there are many mechanisms of this important structure that are not fully understood (Mishra and Leach, 1983). Hoof imbalance is one example that has been implicated in the development of lameness (Balch et al., 1995; Wilson et al., 1998). Farriers are responsible for balancing a horse's hoof while trimming to ultimately prevent adverse effects that may cause injury to the horse or impair their performance (Heel et al., 2004). In a USDA 2015 study, 89.9% of operations provided routine hoof trimming to one or more horses in the previous 12 months. Almost half of operations (48.1%) provided basic shoes on all four hooves, and 27% provided basic shoes on two hooves (USDA, 2015a). The occurrence of trimming and shoeing horses is well documented and practiced; however information on how these procedures may affect structures within the distal limb is limited. Specifically, information in regards to effects on the digital cushion is unknown, and consequently warrants investigation.

The current review will describe distal limb anatomy and diseases associated with these structures, while also presenting background information on the domestication of the horse and

how hoof care has progressed along with it. Past research has focused on how trimming and shoeing affects the horse's hoof as well as the internal distal limb structures, which will be highlighted in this review. However, research has just begun to stress the importance for further studies examining one important internal structure, the digital cushion. This structure has been correlated to lameness incidences in dairy cattle and therefore should be considered in greater depth in equine research. Ultimately, this review will provide a framework and direction for future research to ultimately minimize the welfare and economic issues resulting from lameness in horses.

Distal Limb External Anatomy

Conformation of the equine hoof can determine shape, wear, flight of the foot, and distribution of weight; all things that can affect the horse's ability to remain sound. Incorrect balance, alignment and angles in the hoof may lead to excess stress on the internal structures, including tendons and ligaments, creating a potential for lameness. Furthermore, the hoof wall is an elastic and viscous structure, having the ability to alter under load and return to original shape when weight is removed (Johnston and Back, 2006). Abnormal weight distribution over time can lead to stresses on the foot potentially leading to injury or disease (Johnston and Back, 2006). The variation in applied stressors to the hoof and external hoof conformation from one horse's hoof to another can contribute to the reason why some horses can live their entire life with no foot problems while others seem to experience chronic foot problems (Bowker, 2003a).

The hoof is a highly keratinized epidermal structure; as well as being hard and insensitive to act as a barrier to protect the structures within the hoof capsule (Faramarzie et al., 2009). The hoof is made up of the wall, sole, and frog (Fig 1.1). The wall of the hoof is thickest at the toe, as this is the greatest point of friction, and thins as the wall progresses toward the heel where it is more elastic (Pollitt, 1992). It does not contain blood vessels or nerves, but instead is a product of continual cell proliferation of a single germinative layer of basal cells at the coronary band. These cells produce populations of daughter cells through mitosis that mature and keratinize, continually adding to the length of the proximal hoof wall.
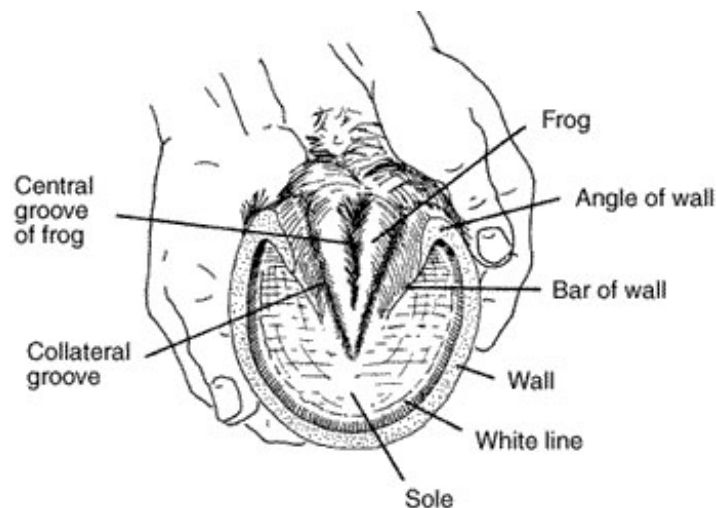
Figure 1.1. External hoof anatomy from the solar surface of the hoof (McClure, 1999)

The structure of the hoof consists of three main layers including the stratum externum (tectorium), stratum medium, and stratum internum (Fig 1.2). In addition, the corium underlies the hoof wall, consisting of tough connective tissues, nerves, and a network of arteries, veins, and capillaries (Pollitt, 1992). The corium provides nourishment to the hoof layers and connection to the inner structures. A basement membrane separates the corium from the overlying layers of the hoof. The stratum externum is a thin external layer of tubular horn covering the surface of the hoof wall. This layer is formed by the perioplic band epithelium at the junction of the skin and hoof wall; where it continues caudally over the heel bulbs to the

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periople. The stratum medium, the middle layer, comprises the bulk of the hoof wall including tubular and intertubular horn. The tubular horn is composed of a medullary cavity, which associates with the papillae of the corium at the proximal third of the hoof wall. The outer portion of the tubule is surrounded by keratinized epithelial cells, which combine with keratinized cells of the intertubular horn. The relative density of the tubules vary across the cross section of the hoof, with an increased number of tubules per unit area on the outer regions of the hoof and a decreased number on the inner hoof wall (Bertram and Gosline, 1987; Balch et al., 1997). This change in density may be due to different mechanical properties of the hoof wall such as dampening properties of the hoof wall during locomotion (Dyhre-Poulsen et al., 1994). The proximal portion of the stratum medium forms the coronary groove of the coronary corium, where many hair-like papillae fit into holes on the surface of the coronary groove. Together the coronary corium and the germinal epidermal cells are known as the coronary band. This layer is the main load support system, whereas the outer layer serves a "waterproof" function (Bowker, 2003b).

The stratum internum, also known as the stratum lamellatum, is the inner surface of the hoof wall consisting of keratinized primary epidermal laminae extending from the coronary groove to the ground surface. The primary epidermal laminae (PEL) serve to attach the wall to the underlying soft tissue, which is attached to the distal phalanx within the hoof capsule. Around the hoof wall perimeter there are approximately 600 PEL which aid in suspension of the distal phalanx, and each PEL has about 100 secondary epidermal laminae (SEL) (Stump, 1967). The relationship of the PEL and SEL increase the surface area which, in turn, may potentially reduce the tension per unit area on the inner hoof (Stump, 1967).
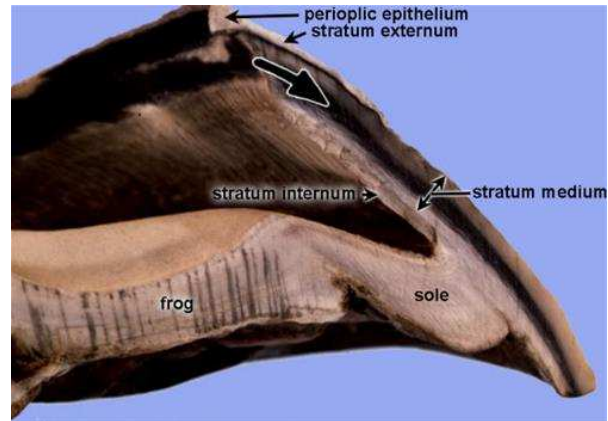
Figure 1.2. Three main layers of the hoof wall: stratum externum, stratum medium, and stratum internum (College of Veterinary Medicine Undergraduate Programs)

When viewing the solar surface of the hoof the sole and frog are evident (Fig 1.1). The sole of the hoof is comprised of keratinized epithelial cells and can be found in the area inside the white line (excluding the bars and frog); where the white line joins the sole to the stratum medium of the hoof and provides a barrier to prevent bacterial infiltration. The primary function of the sole is to protect the sensitive structures beneath it. The frog is a highly elastic structure of keratinized epithelial tissue, which comes into contact with the ground first as the hoof contacts the ground. It works along with the digital cushion, an internal structure directly above it, for assisting in blood flow and absorbing shock. This structure is prone to infection, therefore health of the frog should be a priority to horse owners for maintenance of a sound horse.

Proper conformation and balance of the hoof can be viewed externally; which includes examining for medial lateral balance, dorsopalmar balance, and proper break-over point (Trotter, 2004). If radiographs were taken of the foot, it is easy to visualize the alignment of internal structures. However, because radiographs are not taken routinely, it is important to read the external features of the foot that can accurately determine the location of P3 within the hoof capsule (Trotter, 2004). When viewed laterally, the external view of the horse's hoof pastern angle should form a straight line, where the dorsal aspect of the pastern should be parallel to the

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dorsal surface of the hoof wall (Figure 1.3, A). The angle formed with the ground should be 45-50 degrees in the front feet and slight more upright in the hind feet (50-55 degrees). When the hoof-pastern axis (HPA) is correct the foot breaks over properly. However, if both the pastern and hoof are too sloping the breakover point is slower and extra strain may be put on the tendons in the foot; where in contrast a too upright angle will cause the foot to break over faster and increase the concussion on the limb.

The changes in HPA are associated with two hoof-capsule distortions: the low or under-run heel associated with a broken back HPA, and the upright or club foot associated with a broken forward HPA (O'Grady and Poupard, 2003). This conformation of the hoof can easily be visualized externally. A broken back HPA (Fig 1.3, B) increases the concussion at ground impact as well putting strain on the dorsal aspect of the limb. This is often caused by excessive toe length and can be combined with a low heel/under-run heel. Often when a horse has a low heel they lack soft tissue mass at the back of the foot. In these cases, the foot is unable to properly dissipate energy when the hoof is loaded. Furthermore, these horses experience displacement of the distal interphalangeal and proximal interphalangeal joints promoting load bearing in the heel area of the foot and increased stress on the deep digital flexor tendon. A broken forward HPA (Fig 1.3, C) puts strain on the back of the pastern, which can lead to the heels growing long, where energy at ground impact during the landing phase of the stride will be transferred to the bones of the foot instead of soft tissues. Energy is not well dissipated here and extra stress can be detrimental to soundness (O'Grady and Poupard, 2003).

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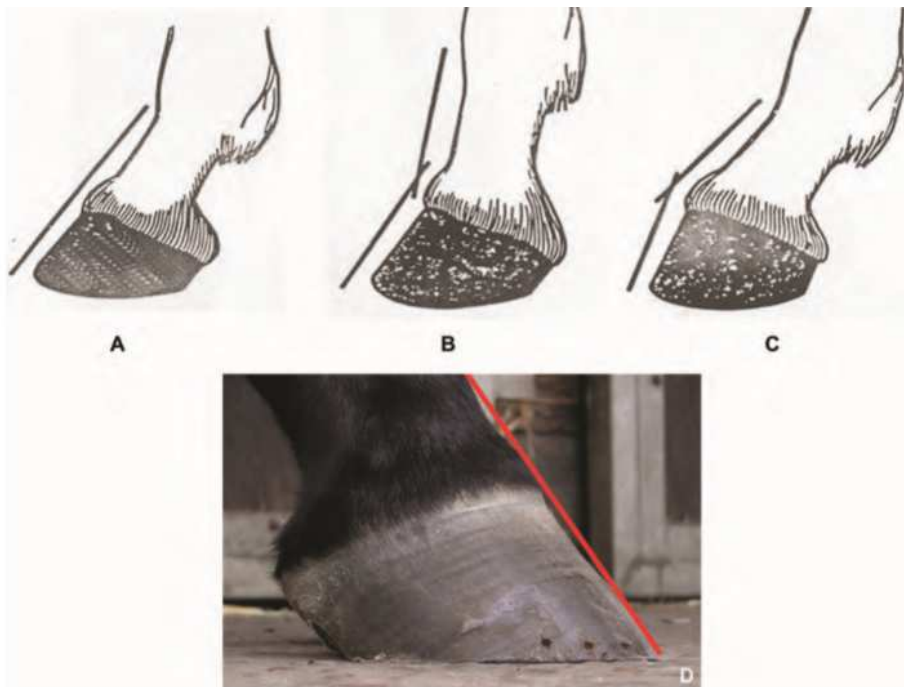
Figure 1.3. (A) An illustration of a correct parallel hoof pastern angle, (B) a broken back hoof pastern angle, and (C) a broken forward hoof pastern angle. (D) Picture of an actual hoof depicting a parallel hoof pastern angle along the red line (O'Grady and Poupard, 2003).

When the hoof is viewed from the bottom, the center of mass of the foot lies ½ to ¾ inch behind the apex of the frog (Trotter, 2004). Ideally, 66-75% of the bottom of the foot should lie caudal to this point to ensure that the frog and bars of the foot are more involved in weight-bearing at ground contact. This allows for proper energy dissipation and development of stronger tissues at the back of the hoof (Bowker et al., 1998). In addition, watching the foot land when the horse is moving toward you can determine mediolateral balance, where the foot should land flat from side to side, not first hitting the medial or lateral wall (Trotter, 2004). Horses with inward or outward limb deviations can have disturbances in this balance.

With each step, there is a load acting on the hoof which induces mechanical behavior of the hoof tissues. A study utilizing a force measuring horseshoe attached to the foot with a boot, investigated distribution of the vertical component of the hoof force in walking and trotting horses (Barrey, 1990). The mechanical loading was greater in the caudal area of the hoof than the

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cranial area after; therefore the heels and quarters take a prominent role in dampening concussion at ground impact. The hoof responds to modification during loading and ground impact, where it has been observed that horses during race training had a decrease in hoof circumference (Decurnex et al., 2009). These horses were also shod during their training period, potentially contributing to the results, as an attached shoe may impede hoof wall expansion. Another study found that race horses experience a reduction in hoof angle during galloping training (Peel et al., 2006). Furthermore, in an overloading situation, the heels sink and expansion at the heels stops; and in contrast, when the hoof is underloaded (lifted), the hoof contracts and the growth of the heels increases (Verschooten, 1993). Thus, exercise and management choices may have an effect on hoof conformation and function.

<center>Distal Limb Internal Anatomy and Associated Lameness Diseases</center>

Looking beyond the hoof wall and the external conformation of the digit to the internal structures can reveal new perspectives on what is causing certain lameness issues in response to the external conformation of the hoof (Fig 1.4) (Bowker, 2003a). For instance, the dermal and epidermal laminae, the distal phalanx, the digital cushion, the deep digital flexor tendon, and ligamentous connective tissues are important internal structures to consider as they all have significant roles in the anti-concussive mechanisms of the foot (Bowker et al., 1998). Overall, biomechanical stress to internal structures of the hoof may be responsible for chronic hoof problems and could also lead to increased severity in some lameness conditions (Bowker, 2003b).

Figure 1.4. Magnetic resonance image of a sagittal section of the equine distal limb. DC = digital cushion; DDFT = deep digital flexor tendon; DS = distal sesamoid bone; DP = distal phalanx; and L = laminar attachments.

The laminar corium consists of the dermal laminae (sensitive laminae) attached to the distal phalanx (Fig 1.5). The dermal laminae consists of living connective tissue filled with blood vessels and sensory nerves, which contain primary and secondary projections that fold together. Furthermore, the dermal laminae interdigitates with the epidermal laminae (insensitive laminae) on the solar corium on the internal surface of wall. This layer also contains primary and secondary projections (PEL and SEL). The dermal and epidermal laminar layers bind together strongly and if they become disturbed soundness issues can occur. Inflammation between the dermal and epidermal laminae, and subsequent failure of the attachment between the distal phalanx and the inner hoof wall is known as laminitis.
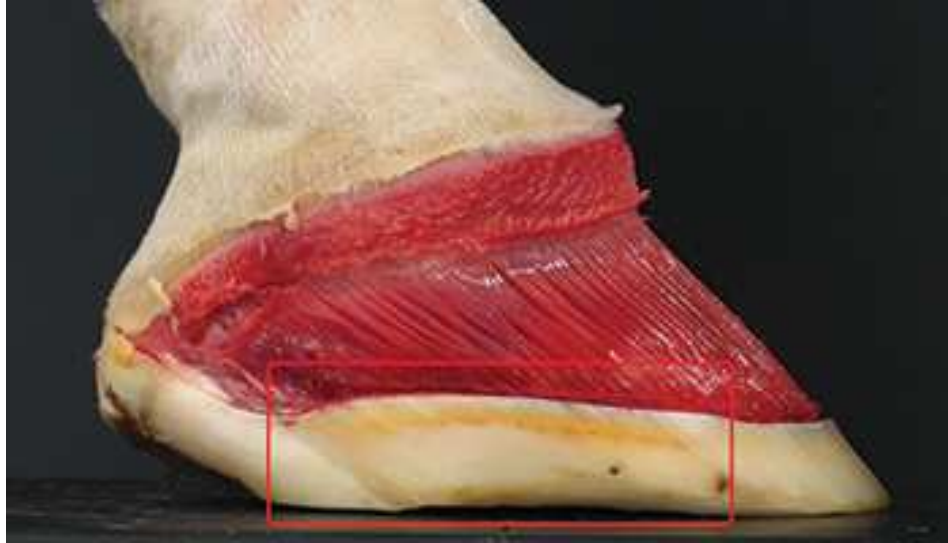
Figure 1.5. Image depicting the laminar corium consisting of the dermal laminae attached to the distal phalanx (Savoldi and Moss, 2013)

There are many causes of laminitis, which lends researchers to believe that this condition is complex and caused by several interacting factors (Hood et al., 1993). During the developmental phase and onset of laminitis there is vasodilation of the veins in the hoof, leading to clinical detection of the acute case, where the laminae become inflamed. Laminitic horses will develop a pronounced digital pulse in one or both front feet, along with the hoof wall surface temperature increasing rapidly (Hood et al., 1993; Pollitt and Davies, 1998). During the developmental phase and prior to the clinical appearance of laminitis, there is typically an issue with one or more of the following organ systems in the horse: gastrointestinal, respiratory, integumentary, and immume (Pollitt, 1999). However, the onset of laminitis may not always be evident prior to the acute phase. Once a horse has advanced past the acute phase of laminitis, there is clinical evidence of distal phalanx displacement (Fig 1.6). When the condition progresses to the point of the distal phalanx rotating away from the hoof wall, the horse enters the chronic phase (Stashak, 1987), which can be referred to as founder. It has been reported that a horse's ability to return to athletic soundness has an inverse relationship with the degree of bone rotation

from the distal phalanx (Stick et al., 1982). Due to the severity of the condition, chronic laminitis

has been reported as the most serious disease in the equine hoof, leading to loss of function and

poor welfare with an end result being of loss of performance and potentially euthanasia (Pollitt

and Davies, 1998; Bailey et al., 2004).
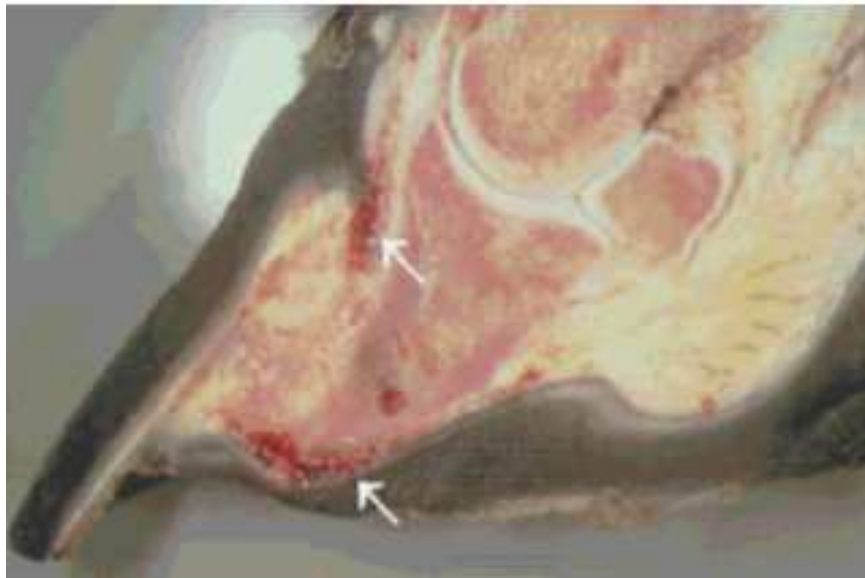
Figure 1.6. Sagittal view of an equine hoof with chronic laminitis, where inflammation in the laminar layers has caused the distal phalanx to separate from the stratum internum and point downward toward the sole. Arrows depict areas of hemorrhage and bruising at the coronet and sole. (Pollitt, 1999)

Risk factors associated with laminitis have been identified and can be utilized in

organizing future research examining this common and debilitating disease (Alford et al., 2001).

Horses that are at a greater risk for developing laminitis include those that have metabolic issues

(insulin resistance, equine metabolic syndrome, pituitary pars intermedia dysfunction), who are

considered overweight, are consuming feeds higher in sugars or consuming pastures with high

level of fructans, or are put on black walnut shavings. When horses consume a meal high in

starch or sugar, it may lead to an overflow of that starch/sugar reaching the hindgut where a

change in the microbial population can occur. The hindgut has a balance of microbial population

for fermentation of feed that was not digested in the small intestine. This change in microbial

population leads to fermentation and increase in lactic acid, where the pH decreases ultimately killing the microbes. Endotoxins are released into the bloodstream disturbing the delicate laminar layers in the foot. Ingestion of fructans can lead to this same fate. Fructans are found in cool season grasses and produced through photosynthesis occurring in the leaves of plants in the day light. Sensitive horses should be allowed to graze at night and early in the morning when fructans are low, and should avoid rich pasture in the spring. In addition, a seasonal pattern has been identified for laminitis, with the highest incidence around late spring and early summer in the United States (Treiber et al., 2006). During this time of high sunshine, pasture carbohydrate content contains a higher level of starches and fructans.

Those horses with metabolic issues, such as pony breeds, have an increased risk for developing laminitis. As a result of metabolic disease, such as equine metabolic syndrome, horses can experience insulin resistance. Normally, insulin is released from the pancreas as a result of high glucose, encouraging the tissues of the body to uptake glucose maintaining appropriate levels. In contrast, the tissues of the body in insulin resistant horses fail to respond to insulin leading to increased secretion by the pancreas and elevated levels of insulin in the body known as hyperinsulinemia. Hyperinsulinemia has been known to induce laminitis; where a study utilizing healthy Standardbred horses subjected to prolonged hyperinsulinemia developed laminitis within 48 hours of infusions of insulin and glucose compared to horses receiving a balanced electrolyte infusion for the same period (De Laat et al., 2010). A similar study completed in ponies with no known history of laminitis or insulin resistance produced similar results; with all horses receiving an insulin infusion developing laminitis within 72 hours, where laminitis was not detected in the control horses (Asplin et al., 2007). Potential mechanisms between insulin resistance and laminitis have been suggested, which include decreased amounts

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of glucose reaching the hoof tissues resulting in impaired glucose uptake by epidermal laminar cells and decreased peripheral vasodilation (Frank et al., 2010). It has been found that decreasing the risk of laminitis should come from a focus on preventative strategies, including: 1) improving insulin sensitivity through caloric restriction and increased exercise, and 2) minimizing risks in the diet such as grains and sweet feeds and restricting access to pasture during high risk times (Geor, 2008).

Another internal structure of the hoof that can play a role in lameness of the horse is the distal sesamoid bone, commonly referred to as the navicular bone. This is a small bone that can be found on the palmar/plantar aspect of the limb between the distal and middle phalanx. It is frequently associated with the lameness disorder of navicular syndrome. This bone provides a gliding surface at the point where the deep digital flexor tendon (DDFT) changes angles and continues down to attach at the distal phalanx (Wilson et al., 2001). As a result of this role, the bone experiences a compressive force during stance phase of movement (Wilson et al., 2001). Navicular syndrome and navicular disease are often used interchangeably. While some identify navicular disease as only affecting the navicular bone and its cartilage, navicular syndrome refers to a group of related conditions. This is an overarching term used to describe chronic and degenerative forelimb lamenesses associated with degenerative changes in the cartilage, bone, and surrounding tissues of the distal sesamoid bone (Rijkenhuizen et al, 1989). The soft tissue structures associated with the navicular bone include the collateral sesamoidean ligament and the impar ligaments. The collateral sesamoidean ligament is found on the proximal aspect of the navicular bone attaching the bone to the distal end of the short pastern bone. The impar ligaments are found on the distal aspect of the navicular bone which attach it to the coffin bone. Navicular bursa surrounds the bone to provide cushioning. A broader term that may be utilized to

categorize navicular syndrome is caudal heel syndrome, as associated structures are located at the back of the hoof. It is identified by bilateral lameness characterized by a toe first landing and a shortening of the anterior phase of the stride (Stashak, 1987).

Navicular syndrome is complex in nature and can be caused by biomechanical stress, circulatory disturbances, and genetic factors. Conformation of the horse's hoof can create imbalance and increased load on internal structures, as previously mentioned, where specifically horses with collapsed heels have been known to be susceptible to navicular syndrome. In these cases there is an increased passive load on the navicular bone from the deep digital flexor tendon resulting from an acute hoof angle (Wright and Douglas, 1993). Research completed by Wilson et al. in 2001 studied the compressive force exerted on the navicular bone in horses with navicular disease. They found that the peak stress exerted on the navicular bone was not significantly different in normal horses versus horses with navicular disease, although the stress on the navicular bone at mid-stance was different (Wilson et al., 2001). Therefore, it was concluded that horses with navicular disease might attempt to compensate for the condition by unloading their heels by contracting their deep digital flexor muscle, increasing the force in the deep digital flexor tendon. This will however increase the force on the navicular bone, which seems to be counter-intuitive to the horse, but could indicate other sources of pain in the hoof. This may result in a positive feedback loop mechanism that leads to the progressive and chronic nature of navicular disease (Wilson et al., 2001). A study investigating cases of navicular syndrome found that 78% of horses were bilaterally affected with no predominance for left or right limb (Wright, 1993). Furthermore, a broken foot/pastern axis was found in 75% of horses and mediolateral foot imbalance in 45% of horses (Wright, 1993). The movement of the affected

horses were also evaluated by the same study, which found that the cranial phase of the stride was decreased in 38% horses, with the caudal phase shorted in 16%.

Other risk factors for navicular syndrome outside of hoof conformation include horses with big bodies and small feet, overweight horses, and performance horses. One study investigating risk factors found that there was an increased risk in horses ages 4-9 years old with males at a greater risk (geldings greater than stallions); as well as Quarter Horses having a higher risk compared to other breeds (Ackerman et al., 1997). They also found that the horses participating in their trial had a poor response to therapy suggesting a poor prognosis. However, research is providing options to treat these horses. For example, a study has found that that use of heel wedges can reduce the force on the navicular bone benefiting horses with this disease (Willeman et al., 2010). Risk of navicular syndrome may also have a relationship to the shape of the navicular bone which subsequently influences biomechanical forces applied to it (Dik et al., 2001a,b). For example, the navicular bone of Finnhorses and Friesian horses tends to be straight or arched in shape at the proximal articular border; where these horses also have a lower incidence of developing navicular syndrome. In contrast, Dutch Warmbloods have a more concave shape at the same location on the navicular bone and have a higher incidence of development navicular syndrome (Dik and van den Broek 1995; Dik et al. 2001a). However, it has been mentioned that there has been little epidemiological research dedicated to investigating risk factors for navicular syndrome development (Dyson et al., 2010); therefore this is an area where further research is necessary.

A non-bony structure in the distal limb which is closely associated with some of the bony structures (distal phalanx and distal sesamoid bone) involved in the previously mentioned lameness conditions is the DDFT. This tendon allows flexion of the limb. It attaches to the deep

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digital flexor muscle above the carpus in the forelimb and hock in the hindlimb, running down the palmar or plantar aspect of the leg. At the distal portion of the limb it runs over the fetlock and the distal sesamoid, inserting into the back of the distal phalanx inside the hoof capsule. The tendon is comprised of long bundles of collagen filaments providing strength and the ability to stretch and contract. Injury to this tendon can occur as a result of strenuous exercise, where small strains or more severe tears can occur. These injuries can be diagnosed and monitored with the use of ultrasound to identify lesions and inflammation (Gillis, 1997). Horses with a diagnosed DDFT injury have varying outcomes which are dependent on injury severity, presence of concurrent injury to other structures in the foot, type of activity, and owner compliance with treatment recommendations (Lutter et al., 2015). A recent study reviewed horses whom were diagnosed with mild, moderate, and severe injury of the DDFT and treated medically by intrasynovial administration of cortiocosteroids and sodium hyaluronan, rest and rehabilitation, or both (Lutter et al., 2015). Of horses with mild, moderate, and severe injury, 21 of 29 (72%), 20 of 36 (56%), and 18 of 32 (56%), respectively, returned to use. Those treated with an intrasynovial corticosteroid injection as well as with rest and rehabilitation were able to return to use longer than those horses treated with no rest. Furthermore, horses in a western discipline were able to return to use longer than those in an English discipline. Rehabilitation protocols for return to exercise have been described, where advancing too quickly or too slowly can worsen the injury or result in loss of use (Gillis, 1997). The purpose of a controlled rehabilitation plan is to provide rest for reduction of inflammation and improvement of tendon gliding function, followed by a gradual increase in work load to increase strength over time (Gillis, 1997).

The digital cushion, another soft tissue structure in the distal limb, has not be studied extensively in terms of its potential association with lameness; although, anatomy and

composition of this structure have been described. The digital cushion lies between the lateral cartilages and above the frog and epidermal bars of the horse's hoof and is comprised of collagen, elastic fiber bundles, fibrocartilage, and adipose tissue (Bowker, 2003a). The digital cushion has been suggested as having a role in shock absorption when the hoof contacts the ground; along with being described as a blood pumping mechanism to encourage venous blood return from the digit upward to the leg (Bowker et al., 1998).

Furthermore, there are differences in digital cushion composition across and within breeds (Bowker et al., 1998). It can range in composition from adipose tissue and loose and elastic connective tissues, to primarily fibro-elastic and fibrocartilaginous connective tissues and elastic tissue with minimal adipose tissue, where differences in composition have been reported across and within breed. When investigating breed differences, feet examined from Arabians, Morgans, and Tennessee Walkers had digital cushions that consisted of fibro-elastic or fibrocartilaginous and elastic tissues. However, Thoroughbreds, Quarter Horses, and Standardbreds had digital cushions composed of fibrocartilaginous tissue with primarily adipose and elastic tissues (Bowker et al., 1998). In these breeds, it was also observed that the hind foot digital cushion, when compared to the forefoot, was composed primarily of adipose and elastic tissue (Bowker et al., 1998). The variability of the digital cushion observed within and between breeds could suggest that there is a potential genetic predisposition of certain breeds toward a fibrocartilaginous digital cushion (Bowker et al., 1998).

The composition of the digital cushion has been investigated across age as well, where changes in digital cushion composition from fat, elastic, and isolated collagen bundles to a stronger fibrocartilage are a normal progression seen in the equine foot with increasing age (Bowker et al., 1998). With this gradual development of the digital cushion's composition to a

stronger cartilage, the apparent health of the palmar foot may improve. Ultimately, horses that have a healthier palmar foot may also have less clinically evident chronic foot problems than those with an underdeveloped digital cushion (Bowker, 2003a). What is known about the digital cushion and its composition suggests that these connective tissues within the foot may be responsive and/or adaptive to various external stimuli; such as bodyweight, age, and forces at ground impact (Bowker et al., 1998).

<div align="center">History of Trimming and Shoeing</div>

Domestication of the horse over time has changed how the horse hoof should be cared for. Overall care of the hoof should focus on the balance of wear rate and growth rate of the hoof, keeping them as equal as possible. Horses in the wild move up to 20 miles per day, traveling on a variety of surfaces including hard ground (Mills and McDonnell, 2005). Moving on hard ground allows the hoof to wear, keeping it at a healthy, natural length. Therefore, under these natural conditions the wear rate equals the growth rate. Horses were first domesticated to carry or pull heavy loads over long distances causing excess stress on the hooves, where the wear rate then exceeded the growth rate (Mills and McDonnell, 2005). Furthermore, as horses were used for working purposes, they were exposed to environmental conditions and different ground surfaces that would cause breakage of the hoof as well as the excessive wear, thus creating a need for improved hoof care. Due to this, the need for a farrier, or hoof specialist, arose.

A farrier is a specialist in equine hoof care, requiring knowledge on hoof balance and proper trimming and shoeing. The history of the farrier is somewhat uncertain. It is known that the Egyptians and the Persians were the first to use horseshoes. They first made them out of woven grass tied to the horse's hoof, then progressed to using animal skins for a stronger surface on the bottom of the hoof. The Romans invented the "hipposandal" which was an iron sole

fastened to the horse's hoof with leather laces. After 400 AD, shoes became more like our modern shoes and started to be nailed to the hoof wall. It became more common to use shoes on horses in the military and, therefore, the military tended to have farriers on staff to keep their cavalry shod and sound (Fleming, 1877).

Horses in the U.S. are now used mainly for hobby riding purposes and performance with very few used for transportation, work, or military purpose. The change in use results in hooves that do not wear down as much as they grow. It is also common for horses to stand for long periods of time in soft, wet, or manure covered ground, which weakens the hoof. In these cases, there is no longer friction provided to keep the hoof trimmed down to a healthy length. The concern for wear versus growth, and hoof trimming and shoeing have resulted in the career of a farrier becoming an important and essential part of the U.S. horse industry.

Influence of Hoof Trimming

As previously mentioned, hoof trimming is a necessary practice as today's horse hooves are continually growing more than they are wearing down. The typical horse hoof grows ¼ inch per month. Many factors can contribute to the horse's hoof growth as well as hoof shape; these may include weight of the horse, diet, hydration of the hoof, trimming, shoeing, injury, or the ground conditions they are exposed to (Decurnex et al., 2009). Regardless of these factors, proper hoof care should be done regularly to prevent issues that may decrease performance and quality of life for the horse. Horses with hooves allowed to grow too long can have improper hoof angles leading to extra strain on their distal limbs (Clayton, 1990), as well as cracks or breaks in their hooves which can cause the horse to become sore. Hooves that grow unevenly can put a horse out of balance causing issues with distal limb structures and ultimately leading to lameness as previously described. Performance horses often have issues with hoof conformation

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and balance (Balch et al., 1995). Farriers are responsible for balancing a horse's hoof while trimming to ultimately prevent adverse effects that may cause injury to the horse or impair their performance (Heel et al., 2004), again emphasizing their critical role in the equine industry.

It has been known that a balanced hoof is required for a horse to have optimal performance and prevention of injury (Heel et al., 2004) and a well-balanced hoof should land flat or symmetrically (Grady and Poupard, 2001). However, research has found that horses have a preference for lateral asymmetrical landing in front and hind feet (Heel et al., 2004). Trimming these horses toward symmetry did not change their preferred way of landing. Trimming did, however, influence the duration of landing by shorting the landing in both front and hind feet (Heel et al., 2004). This does imply that the center of pressure (CoP) of the hoof moves toward the center of the foot quicker in these horses and can be thought to have a more positive influence on the load distribution for the internal hoof structures (Heel et al., 2004). Trimming has not been shown to affect the pattern of hoof-unrollment, which is a measure of how the hoof tracks from heel to toe. However, following trimming the intra-individual left/right symmetry was enhanced, suggesting that trimming aids in creating an equal load distribution within individual animal (Heel et al., 2004).

Hoof trimming is not only a practice done in the equine industry, but also an essential practice in the dairy cattle industry. Subsequently, the importance of hoof condition is significant. Research has investigated the effects of trimming in this species to manage claw disorders and prevent lameness issues (Ouweltjes et al., 2009). Overall, in agreement with equine studies, an importance of has been placed on understanding proper hoof shape and balance, aiming research toward prevention of poor hoof shape and care (Van der Tol et al., 2003).

Influence of Shoeing

As with trimmed and barefoot horses, there is also research on the center of pressure in shod horses. However, this research investigating the identification of CoP location in shod horses is inconsistent; where it has been found that CoP is at the mediodorsal quadrant in the front feet and laterodorsal quadrant in newly shod horses (Heel et al., 2005), moving cranially toward the point of the frog during stance phase in shod horses (Barrey, 1990), and the caudal portion of a shod hoof with medial and lateral wedges attached (Wilson et al., 1998). Different measurement techniques were utilized in all studies, therefore contributing to the differences seen between them. Regardless, all studies identified that the CoP is near the center of the shoe (Fig 1.7) stressing the importance of a well-balanced hoof.
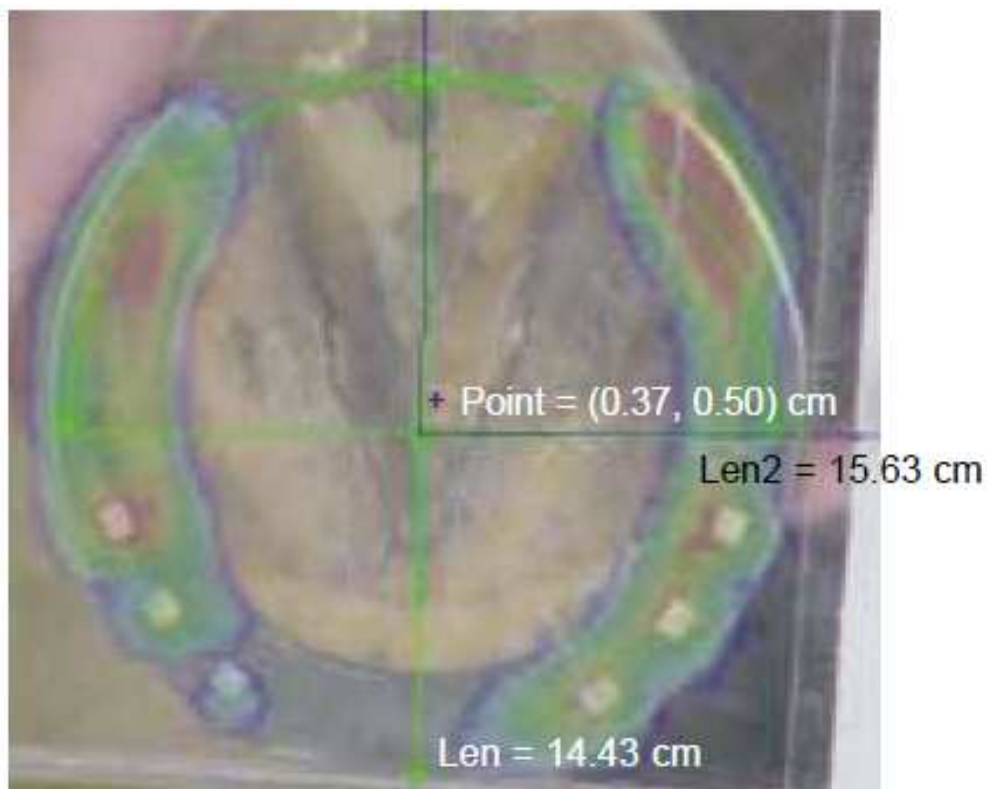
Figure 1.7. Digital image of the sole using Footscan frame at midstance. Location of center of pressure at coordinates (0.37, 0.50) cm. Len = shoe length, Len2 = shoe width (Heel et al., 2005).

Hoof-unrollment in shod horses has been identified differently between the front and hind feet. Research found that the front feet had an unrollment pattern that stayed along the sagittal hoof axis after a shoeing period and the hind feet tended to shift toward a lateral side unrollment (Heel et al., 2005). This indicates that the hind feet may have a greater ability to compensate for hoof changes that occur during a shoeing period (Heel et al., 2005). As the hoof growing between shoeing sessions, there is a change in hoof conformation where the length of the dorsal portion of the hoof wall will increase and the angle of the hoof will decrease. In barefoot horses, ground surface can compensate for some of this change, however this is not true in shod horses (Heel et al., 2005). Furthermore, maximal vertical ground reaction force has been found to increase when a horse is shod, indicating that these horses have a slight increase in loading of the forelimb (Willemen et al., 1998; Proske et al., 2017). These findings may help explain the differences seen in hoof disease between the front and hind feet, where the internal structures of the front feet more commonly suffer from loading-related disease such as navicular disease.

When investigating stride length between barefoot and shod horses, research has identified that stride length increased in shod horses with barefoot horses having a shorter mean stride length (Proske et al., 2017; Willemen et al., 1997). This may be due to changes in the pressure applied to the hoof. The location of the hoof due to this increase is then positioned at a further distance from the shoulder at ground contact, which may have adverse effects on joint flexion and balance (Willemen et al., 1997). The increase in stride length could also cause increase in inflammation to the distal limb joints; where research has identified that mean joint circumference increased in the carpal joint in shod horses when compared to barefoot horses (Proske et al., 2017). Overall, research has indicated that shod horses may experience changes in hoof morphology, which could create a gradual move toward lameness (Proske et al., 2017).

Pressure within the hoof between bare and shod horses has been measured, with differences identified. Negative pressure has been recorded in the digital cushion during ground contact and stance in a study using implanted pressure transducers, where pressure was recorded from heel contact with the ground till the hoof rolled over to the toe. The pressure measured in the digital cushion decreased rapidly after a 30ms delay during the stance phase, and remained low until the hoof started rolling over the toe for push off. This indicates that the pressure inside the digital cushion decreases when the horse's leg is weight bearing (Dyhre-Poulsen et al., 1994). When this was examined in shod horses fitted with standard iron shoes, the pressure curve had the same shape, however the decrease in pressure began later after hoof strike (50ms) and the pressure decrease was steeper. The low pressure also lasted a shorter amount of time in the shod horse. The lengthened delay in pressure in the shod horses could indicate that the shoe impedes hoof expansion, and without shoes the hoof wall can move freely (Dyhre-Poulsen et al., 1994).

The purpose of shoeing started with the goal of protecting the horse's feet from excessive wear as they were used for work and performance (Roepstorff et al., 1999); however, today, shoes can be used as a way to influence performance or they can provide therapeutic treatment of lameness conditions (Heel et al., 2005). Specifically for treatment purposes, shoes with heel wedges have been shown to significantly reduce the force that is exerted on the navicular bone by the deep digital flexor tendon in navicular syndrome (Willemen et al., 1999), as well as decreasing the medial and lateral toe and heel pressure (Rogers and Back, 2003). Therapeutic shoes reduce pressure on the navicular bone as well as reduce strain on the deep digital flexor tendon; further supporting the use of these shoes in horses with navicular lameness. As the use of shoes become a more common practice, increased data on shoeing is crucial to understanding how a horse can adapt to shoes.

Potential Association of Digital Cushion and Performance

Originally there were two traditional theories for how the hoof dampens the ground impact related to energy redistribution and dissipation from the 1800s. These theories were the depression theory (Coleman et al., 1805; Peters et al., 1883) and the pressure theory (Clark, 1809; Lungwitz, 1883) where both of these theories indicate that the digital cushion plays a fundamental role in energy dissipation. The depression theory emphasizes that the downward movement of the middle phalanx into the digital cushion will force the lateral cartilages out. The pressure theory suggests that the frog pushes up on the digital cushion when the hoof contacts the ground, moving the lateral cartilages outward while the digital cushion serves as a shock absorber. Both theories state that blood is pumped from the foot at impact and that the digital cushion has positive pressure, absorbing energy before the outward deflection of the cartilages (Bowker, 2003a).

In contrast, as technology has advanced, negative pressure has been recorded in the digital cushion during ground contact and stance in a study using implanted pressure transducers, indicating that the pressure inside the digital cushion decreases when the horse's leg is weight bearing (Dhyre-Poulsen et al., 1994). Furthermore, it was reported that during the vertical loading period, digital cushion displacement occurs in patterns consistent with palmar displacement of the second phalanx, indicating the digital cushion plays a passive role in the equine foot (Taylor et al., 2005). This displacement pattern of the digital cushion is also inconsistent with the pressure and depression theories, further supporting the negative pressure reported by Dhyre-Poulsen et al. in 1994.

Due to the finding of measured negative pressure in the digital cushion, Robert Bowker proposed a hemodynamic flow hypothesis, which suggests the negative pressure is created by the

outward movement of the hoof cartilage (Fig 1.8). This outward movement allows blood to move from under the distal phalanx to the rear portion of the hoof through microvessels in the lateral cartilages. This dissipates the energy caused by the impact on the ground. Through the development of this theory, Bowker observed that horses with good feet have more blood vessels in the lateral cartilage of their hooves than those that had histories of foot problems (Bowker, 1998). The digital cushions in those horses also were made of cartilaginous material instead of elastic tissue. This theory plays a large role in providing the hoof with nutrients for development of stronger tissues and for proper energy dissipation during ground impact.
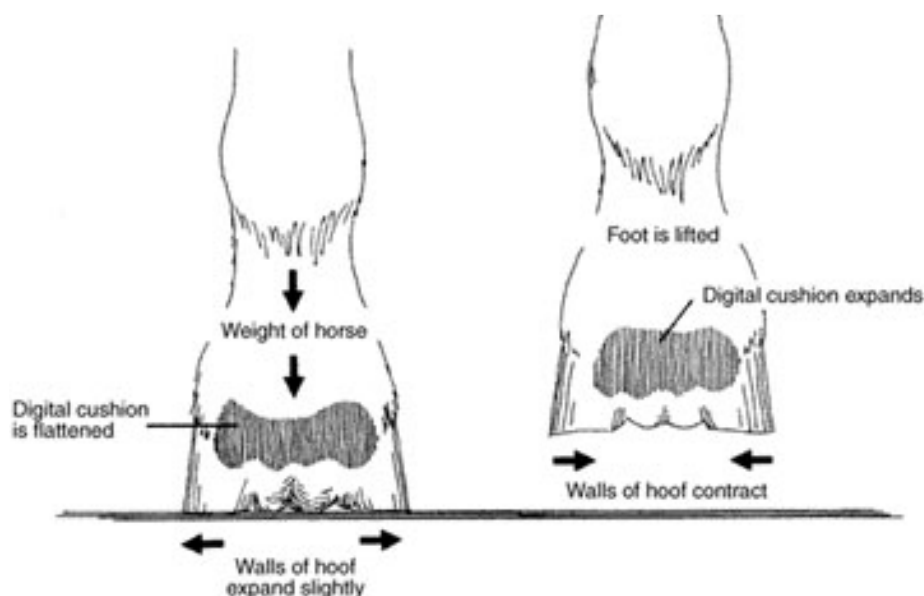
Figure 1.8. Effect of weight bearing and non-weight bearing on the distal limb, specifically on the digital cushion (McClure, 1999)

Therefore, if there is inefficient energy dissipation in the hoof when it is loaded there is the potential for adverse effects in the strength and support of the foot (Bowker et al., 1998), which can gradually lead to lameness conditions. Farriers are encouraged to practice trimming techniques that optimize the mechanism described by hemodynamic theory. This includes

trimming with a short breakover and keeping the frog on the ground, where the frog and back of the hoof are responsible for the weight of the horse promoting the growth of stronger tissues.

Similar to horses, lameness is one of the most significant welfare issues of high producing dairy cows in North America, as well as being a financial concern (Oikonomou et al., 2014). Although there are limited studies regarding the digital cushion in horses, this structure has been studied in dairy cattle. In dairy cattle, it has been observed that digital cushion thickness has a high association with body condition score (BCS), where an increase in BCS was paired with an increase in digital cushion thickness. A low BCS has also been associated to increased incidence of lameness. Therefore, researchers have identified that a thin digital cushion may be a strong predictor of lameness (Bicalho et al., 2009) and further investigation into this relationship is warranted. These studies suggest that a well-developed digital cushion is necessary to prevent contusions that may lead to lameness (Bicalho et al., 2009), where cattle with a larger digital cushion have feet that are biomechanically resilient and less prone to lameness (Gard et al., 2015).

Research has found the potential to minimize lamenesses by maximizing digital cushion surface area as well as the volume of the second and third phalanges, making cattle more resilient to their environment (Gard et al., 2015). A recent study found that cattle maintained and exercised on alternative terrain of dirt, stones, and grass had increased volume and surface area of their digital cushion when compared to cattle in grass paddocks and not encouraged to exercise. This increase in the volume and surface area of the digital cushion and distal phalanges could have a positive effect on hoof health, which in turn could potentially make cows less susceptible to lameness (Gard et al., 2015).

The use of thermography allows researchers to identify localized inflammation, where the thermal pattern that is seen in a thermography image is determined by the circulatory pattern and relative blood flow of the surface (Turner, 2001). Another study completed in dairy cattle utilized infrared thermography to investigate the association between digital cushion thickness and sole temperature, where it was hypothesized that digital cushion thickness may be associated with early signs of inflammation measured by increased sole temperature (Taylor et al., 2005). Sole temperature decreased as digital cushion thickness increased, supporting the association of the digital cushion with sole temperature (Taylor et al., 2005). Dairy cattle are found to be the most productive when they are pain free, which means further research that can aid in the prevention of lameness is necessary to maintain health and production (Gard et al., 2015). This has direct and parallel implications for the health and welfare of horses.

It has been identified that digital cushion thickness was greater in barefoot horses compared to shod horses, suggesting that applying shoes may decrease digital cushion thickness (Proske et al., 2017). While the digital cushion plays a role in vascular exchange throughout the distal limb as well as a role in energy dissipation in the hoof as it is loaded, changes in thickness have the potential to disturb this mechanism (Dyhre-Poulsen et al., 1994). When a horse is shod, the lack of frog and sole interaction may hinder these important roles of the digital cushion. Overall, inefficient energy dissipation may gradually produce lameness conditions, and this association of digital cushion thickness and lameness should be investigated.

Conclusion

The distal limb is a complex structure that requires proper care to prevent adverse effects that can lead to potential lameness. Both trimming and shoeing have shown to have an effect on multiple variables such as center of pressure and stride length; however further understanding on

how a horse responds and adapts to these changes in hoof balance during this time of trimming and shoeing is required. Furthermore, structures such as the digital cushion have not been investigated as thoroughly as other internal structures; and has been shown to be important in dairy cattle. Future research that explores the digital cushion in horses is essential in investigating and understanding the effect trimming and shoeing may have on the multiple structures within the equine distal limb as well as changes that can ultimately affect their performance. Therefore, two studies were designed to examine the digital cushion. The first study focused on identifying potential associations of digital cushion thickness and lameness (Chapter 2), and the second focused on potential changes in digital cushion thickness during a time of trimming and shoeing (Chapter 3). The hoof has been described as an adaptable structure with many working parts, where changes to just one structure can cause damage in other areas. Research on the digital cushion during times of lameness and during a period of trimming and shoeing can begin to help us understand how this structure changes and adapts.

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CHAPTER 2. ASSOCIATION OF THE EQUINE DIGITAL CUSHION WITH LAMENESS AND ANATOMICAL CHANGES OF THE DISTAL LIMB

Abstract

Lameness caused by distal limb pain is a concern in the equine industry, and diagnosis can be difficult. Magnetic resonance imaging (MRI) has proven to be a valuable tool for detecting changes and irregularities in structures of the distal limb. Although research has examined many parameters associated with distal limb lameness, investigation of the digital cushion is limited. The objectives of this study were to measure digital cushion thickness and assess its relation with lameness and anatomical changes in structures of the distal limb. To meet these objectives, medical records were used from 20 mature, stock-type, western performance horses that presented to the Texas A&M Veterinary Medical Teaching Hospital for lameness, and underwent MRI of the bilateral distal front limbs. Severity of lameness was ascertained from the medical record and the foot with a higher lameness score was identified as the primary side (PS) and the other side as the off side (OS). Images were reviewed using DICOM viewing software and distal limb structures scored for severity of abnormalities. Images generated from a PD sagittal series were selected to determine digital cushion thickness, with the thickest measurement selected for analysis. Digital cushion thickness was defined by drawing a parallel line along the distal-interphalangeal joint surface of the navicular bone through the deep digital flexor tendon and digital cushion to the corium cunei. Measurement of digital cushion thickness (mm) was then determined along the parallel line from the palmar surface of the deep digital flexor tendon to the corium cunei. Data were analyzed using the MEANS procedure of SAS and Pearson correlations were estimated using PROC CORR of SAS. Additionally, data were analyzed using PROC GLIMMIX of SAS fitting gender as a fixed effect and age and digital

cushion thicknesses as covariates. A p-value ≤ 0.05 was considered significant. Mean value for

PS lameness score was 2.7 and OS lameness score was 1.3. Mean values the same for PS digital

cushion thickness and OS digital cushion thickness (1.49 cm $\pm$ 0.04). No correlations were

identified of digital cushion thickness with abnormalities of distal limb anatomical structures.

Digital cushion thickness also was not significantly related to lameness score ($P\geq0.12$); however,

the sample size was small where standard errors were high. Evaluation of a larger sample size

has the potential to determine more definitively whether an association with lameness and digital

cushion thickness exists.

Introduction

Foot pain is a large issue in the equine industry, and furthermore, lameness is a top

concern for horse owners and veterinarians. Diagnosis of these conditions is a vital part to

managing healthy, sound horses. Advanced techniques have allowed for improved diagnosis and

provide more detail to identify pathological changes involved in horses suffering from foot pain.

To view the internal structures of the hoof non-invasively, researchers can utilize magnetic

resonance imaging (MRI), computed tomography (CT), radiography, and ultrasonography. MRI

has advantages that these other imaging techniques do not have (Dyson et al., 2003). MRI

displays detailed images of both bone and soft tissue with high contrast resolution, and sections

can be made in any plane (Whitton et al., 1998). Radiographs and CT are able to image both

bone and soft tissue, but compared with MRI the soft tissue images are poor (Whitton et al.,

1998), which is not as beneficial when examining many of the internal structures of the foot.

Data has shown that MR images are different in horses with and without foot pain, where

changes to multiple structures can be detected and damage across these structures can occur at

the same time (Murray et al., 2006). Researchers have utilized MRI to investigate anatomical

abnormalities associated with navicular disease and laminitis, two common lameness-causing diseases in horses (Dyson and Murray, 2007; Murray et al., 2003). Changes in the bone are subtle in the early stages of navicular disease, but changes in the soft tissues can be detected earlier; therefore, MRI is the preferred imaging modality for early detection before the disease advances (Ross et al., 1997). Soft tissues of the hoof can also be examined with the use of an ultrasound; however, it can be difficult to position the transducer in a way that allows identification of subtle pathology (Denoix et al., 1996). Thus, the use of MRI allows for diagnosis of multiple irregularities in the structures of the distal limb that cannot be diagnosed through other means (Dyson et al., 2003).

One specific soft tissue structure contained in the hoof capsule is the digital cushion. The digital cushion lies between the lateral cartilages and above the frog and epidermal bars of the horse's hoof and functions to dissipation impact energy as the foot contacts the ground. When the horse is moving correctly, the heel lands first allowing the frog to make contact with the ground and the hoof wall to expand. This increases the volume inside the hoof and stretches the deep digital flexor tendon, thus decreasing the pressure within the digital cushion at this time (Dyhre-Poulsen et al., 1994). This produces an increase in venous blood flow through the caudal foot where the negative pressure enables to the vasculature to be refilled (Bowker et al., 1998). Taylor et al. (2005) reported that during the stance phase there is displacement of the digital cushion, which occurs in patterns consistent with response to palmar displacement of the second phalanx, indicating the digital cushion is playing a passive role in the equine foot (Taylor et al, 2005). Bowker's hemodynamic flow theory states that this negative pressure is created by the outward movement of the hoof cartilage while simultaneously the impact energies force venous blood throughout the lateral cartilages, providing further negative pressure as a vacuum action

draws blood up from the solar surface of the hoof (Bowker et al., 1997).

The composition of the digital cushion plays a role in the health of the horse's foot as well as its ability to proper dissipate energy. The digital cushion is comprised of collagen, elastic fiber bundles, fibrocartilage, and adipose tissue (Bowker, 2003). Changes in digital cushion composition between breeds, between fore and hind foot, and with age have been identified. Anything that alters the normal composition of the digital cushion could have the potential to disrupt the normal function of this structure. Based on studies of composition, it has been stated that as the digital cushion develops to a stronger cartilage, the health of the palmar foot improves (Bowker, 2003). Additionally, taking into account the function of the digital cushion, it has been hypothesized that disturbances in this mechanism could transfer greater energies to other portions of the distal limb, potentially resulting in lameness (Bowker et al., 1997). In dairy cattle, it has been identified that digital cushion thickness was a strong predictor of lameness, with thinner digital cushions being found in lame animals (Bicalho et al., 2009). However, studies to examine this same association in horses have not been done. Therefore, understanding this relationship can provide veterinarians with new information on hoof anatomy and deepen the understanding of lameness prevention and treatment. Specifically, it is vital to execute research in this area to aid in the maintenance of a healthy palmar foot to reduce the incidence of lameness conditions and improve the overall welfare of the horse.

The objective of this study is to investigate the relationship of digital cushion thickness and lameness. Specifically, the objectives are to measure thickness of the digital cushion through the use of MRI records and assess its relation with anatomical changes in the structures of the distal limb. The research hypothesis is that digital cushion thickness will be inversely associated with lameness causing disorders of the distal limb.

Materials and Methods

Medical Records

Medical records were analyzed from 20 mature, stock-type, western performance horses that had presented to the Texas A&M Veterinary Medical Teaching Hospital for lameness, which responded to palmar digital perineural anesthesia and had undergone MRI of the bilateral distal front limbs. The severity of lameness was ascertained from the medical record and the foot with the higher lameness score was identified as the primary side (PS) and the other side as the off side (OS).

Image Analysis

Standardized MRI acquisition parameters were utilized at the imaging facility. Soft tissue structures and the navicular bone medulla were evaluated on proton density (PD, non-fat suppressed) and short *tau* inversion recovery (STIR, fat suppressed) weighted spin echo images in the transverse, sagittal, dorsal, and dorsal/oblique planes. Navicular bone surfaces were evaluated in 3-dimmensional T1-weighted fat suppressed gradient echo images (fast low angle shot, FLASH) reconstructed in the transverse, sagittal, dorsal, and dorsal/oblique planes.

A board certified veterinary radiologist reviewed the images in a randomized order using DICOM viewing software. The radiologist scored abnormalities of the navicular bone, distal aspect of the deep digital flexor tendon, distal sesamoidean impar ligament, collateral sesamoidean ligament of the navicular bone, and navicular bursa as previously described by Murray et al. 2006 (Table 2.1).

Table 2.1. MRI grading for abnormalities of distal limb structures (adapted from Murray et al., 2006)

Structure	Grade	Description
Deep digital flexor tendon (DDFT)	0	Uniform low signal intensity patterns with clear margins
	1	Small areas of mildly increased signal intensity, covering areas of less than 1mm^2 and/or very mild irregularity of the tendon surface
	2	Areas of moderately increased signal intensity incorporating less than one-third of the tendon area in transverse sections and/or moderate irregularity of the tendon margins
	3	Areas of increased signal intensity involving more than one-third of the tendon are in transverse sections and/or marked disruption of the tendon margins
Navicular bone flexor	0	Clear fibrocartilage layer over entire surface, smooth chondro-osseous margins, uniform cortical thickness and smooth endosteal surface
	1	Mild irregularities in the fibrocartilage thickness and signal intensity and/or slightly irregular chondro-osseous margin and/or irregularity and loss of definition to the endosteal surface of the cortex
	2	Moderate loss of signal definition at site of fibrocartilage with defects in the flexor surface of the cortex and/or moderate irregularity and loss of definition to the endosteal surface of the cortex
	3	Severe fibrocartilage loss, large defects in the flexor surface of cortex, severe irregularities in the endosteal surface with extensions into medulla
Navicular bone distal	0	Smooth indentation into cortical surface, uniform cortical thickness, smooth endosteal surface
	1	Slightly irregular indentations into cortical surface, mild variability in cortical thickness and/or slightly irregular endosteal surface
	2	Irregular defects into the cortex with moderate variability in cortical thickness, endosteal irregularity and proximal linear extensions of mineralization into the medulla
	3	Severe, large defects in the cortex, surrounded by irregular mineralization, distal border fragments, severe irregularity to the endosteal surface with marked extensions of mineralization into medulla
Navicular bone dorsal	0	Clear articular cartilage layer over entire surface, smooth chondro-osseous margins, uniform subchondral bone thickness and smooth subchondral/cancellous junction
	1	Mild irregularities in the articular cartilage thickness and signal intensity and/or slightly irregular chondro-osseous margin and/or slightly irregular subchondral/cancellous junction

Table 2.1. MRI grading for abnormalities of distal limb structures (adapted from Murray et al., 2006) (continued)

Structure	Grade	Description
	2	Moderate loss of signal definition in articular cartilage with osteophyte formation and/or defects in the subchondral bone
	3	Severe articular cartilage loss, osteophytes, large defects in the subchondral bone, severe irregularities in the subchondral/cancellous junction with extensions into medulla
Navicular bone proximal	0	Smooth indentation into cortical surface immediately dorsal to insertion of collateral sesamoidean impar ligament, uniform cortical thickness, smooth endosteal surface
	1	Slightly irregularity of cortical surface, mild variability in cortical thickness and/or slightly irregular endosteal surface
	2	Moderate irregularity cortical surface, enthesiophyte formation with moderate variability in cortical thickness, endosteal irregularity
	3	Severe, marked cortical irregularity and enthesiophyte formation, severe irregularity to the endosteal surface with marked extensions of mineralization into medulla
Navicular bone medulla	0	Uniform high signal intensity on PD weighted images with low signal intensity on STIR images. Clear definition from cortex.
	1	Less uniform high signal intensity on PD weighted images with some signal heterogeneity. No alteration or mild focal, or very mild generalized increase in signal intensity on STIR images
	2	Mild-to-moderate signal heterogeneity on PD weighted images and/or moderate localized or generalized increase in signal intensity on STIR images
	3	Marked alterations in signal intensity on PD weighted images and/or generalized or focal marked alteration in signal intensity on STIR images
Distal sesamoidean impar ligament (DSIL)	0	Symmetrical, uniform distribution of low signal intensity interspersed with uniformly distributed areas of higher signal intensity (consistent with synovial in-pouching between fiver bundles). Smooth margins. Smooth cortical surface at site of insertion on P3 and origin on navicular bone. Close apposition between distal palmar border of DSIL and dorsal surface of the DDFT on distal axial midline.
	1	Mild asymmetry in signal homogeneity and/or slight irregularity to palmar margins and/or origin/insertion.
	2	Obvious asymmetry in signal homogeneity and/or irregularity of palmar margins and/or irregularity at origin/insertion. Indication of mild adhesion formation in abaxial, middle and proximal regions of the DSIL.
	3	Marked asymmetry in fiber pattern, defects in margins with marked evidence of adhesion formation and poor separation from DDFT, enthesiophytes at origin and/or insertion

Table 2.1. MRI grading for abnormalities of distal limb structures (adapted from Murray et al., 2006) (continued)

Structure	Grade	Description
Collateral sesamoidean impar ligament (CSL)	0	Homogeneous signal intensity, symmetrical shape and size, clearly defined margins. Smooth cortical surface at insertion on navicular bone
	1	Mild alterations in signal homogeneity, mild asymmetry or alteration in shape/size and/or slight irregularity of margins. Some evidence of adherence of axial part of CSL to DDFT in proximal region of the navicular bursa
	2	Moderate signal heterogeneity, marked enlargement, obvious asymmetry or alteration in shape/size and irregularity of margins. Adherence of abaxial areas of CSL to DDFT.
	3	Marked alterations in signal intensity, loss of structural definition of ligament with difficulty separating from adjacent structures. Extensive adhesion formation.
Navicular bursa	0	Homogeneous fluid signal without marked distension
	1	Distension with strands of soft tissue crossing bursa
	2	Soft tissue clearly evident with pockets of fluid signal
	3	Bursa full of soft tissue/adhesions, with only fluid present as distension abaxially
Digital cushion	0	Heterogeneous moderate signal intensity with slightly irregular pattern of linear and focal increases and decreases in signal representing vasculature
	1	Focal loss of pattern
	2	Focal or linear loss of pattern, increased or decreased signal intensity on PD weighted images
	3	Generalized increase or decrease in signal with loss of vascular pattern and/or defects

Digital Cushion Measurement

Images were reviewed using DICOM viewing software and distal limb structures scored for severity of abnormalities. Images generated from a PD sagittal series were selected to determine digital cushion thickness, with the thickest measurement selected for analysis. Digital cushion thickness was defined by drawing a parallel line along the distal-interphalangeal joint surface of the navicular bone through the deep digital flexor tendon and digital cushion to the corium cunei (Fig 2.1). Measurement of digital cushion thickness (mm) was then determined

along the parallel line (Fig 2.1) from the palmar surface of the deep digital flexor tendon to the

corium cunei.

Figure 2.1. MR image generated from a PD sagittal series of the equine distal limb. The line represents the location for digital cushion thickness measurement identification.

Statistical Analysis

To analyze the data, the MEANS procedure of SAS (v. 9.4, SAS Institute Inc., NC) and

Pearson correlations were estimated using PROC CORR of SAS. Additionally, data were

analyzed using PROC GLIMMIX of SAS fitting gender as a fixed effect and age and digital

cushion thicknesses as covariates. A P-value ≤ 0.05 was considered significant.

Results

The mean value for PS and OS lameness score was 2.7 and 1.3 respectively (Fig 2.2).

The mean values were the same for PS digital cushion thickness and OS digital cushion

thickness (1.49 mm ± 0.04) (Fig 2.3). No correlations were identified of digital cushion thickness with abnormalities of distal limb anatomical structures and digital cushion thickness was not significantly related to lameness score ($P \geq 0.12$).
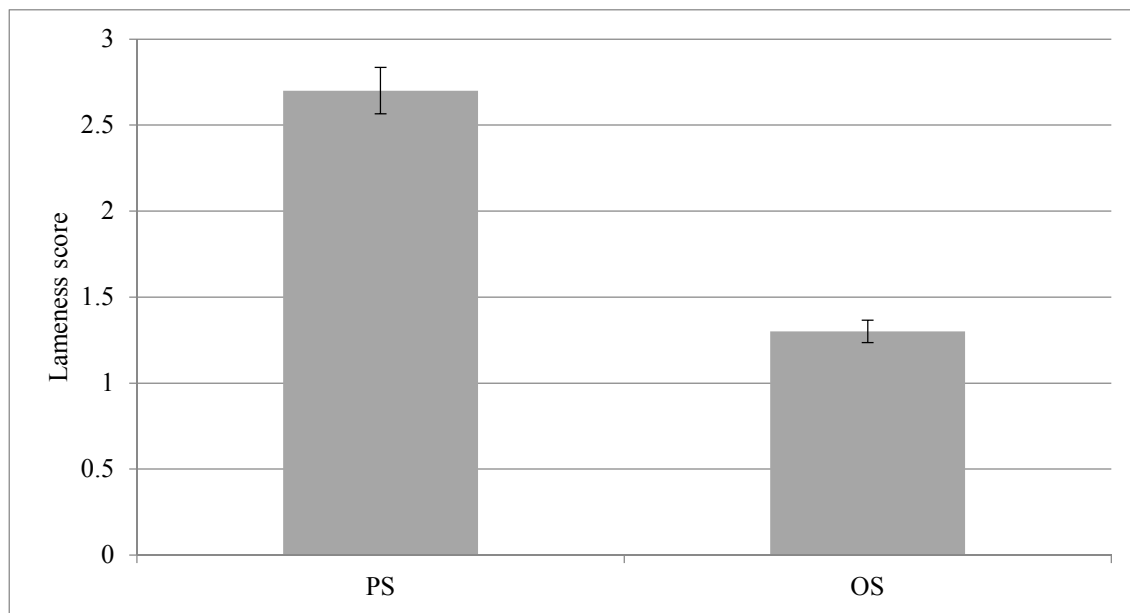
Figure 2.2. Mean value of PS and OS lameness score determined from the medical records.
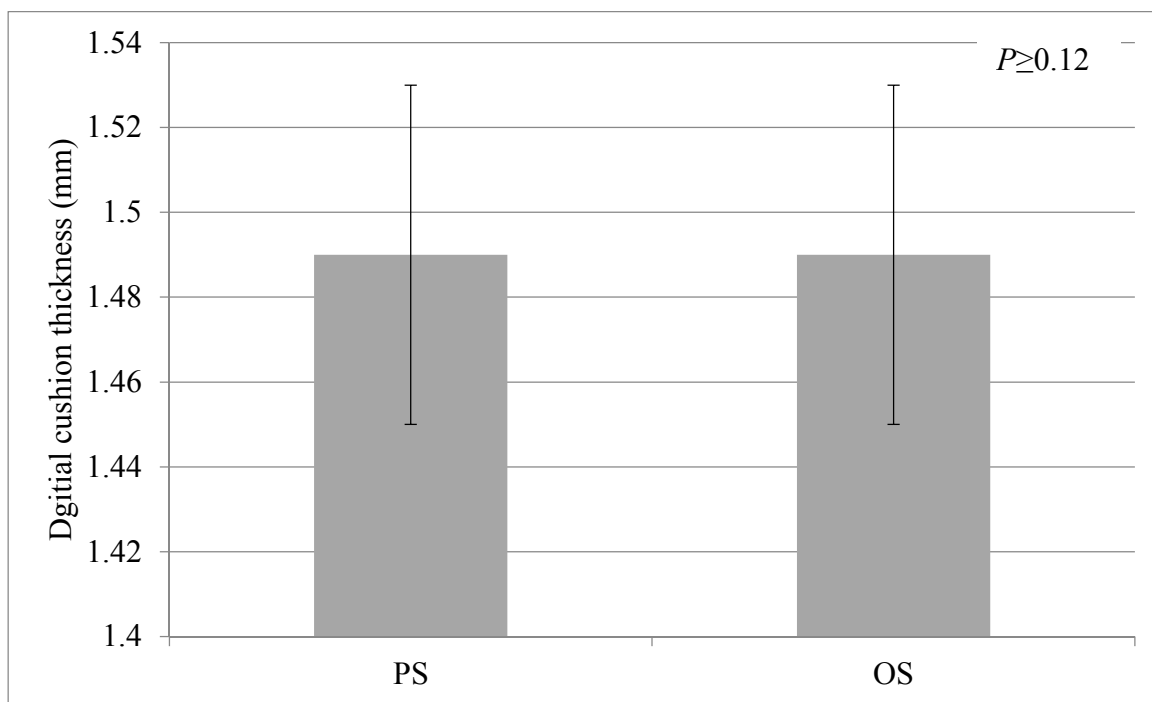
Figure 2.3. Mean values for PS and OS digital cushion thickness.

Discussion

Digital cushion thickness was not significantly related to lameness score (P≥0.12); however, the sample size in this study was small while standard errors were high. Previous data has shown that MR images are different in horses with and without foot pain, where changes to multiple structures can be detected and damage across these structures can occur at the same time (Murray et al., 2006). The current study identified abnormalities and changes in distal limb structures in lame animals, however when investigating potential relationship to digital cushion thickness, no correlation was observed. Lameness was present in both the PS and OS, therefore a true non-lame leg control was not present. In addition, horses in the current study were of a mature age and their digital cushions have had the time to develop to a stronger cartilage (Bowker, 2003); therefore potentially making it difficult to detect changes in digital cushion thickness.

Results from previous studies using ultrasound and a transcuneal approach to measure digital cushion thickness (mm) identified that mean value (± S.E.) for the digital cushion of the front foot ranged from 0.96 ± 0.03 (Gunkelman and Hammer, 2017) to 1.41 and 1.43 ± 0.03 in bare horses and 1.26 ± 0.03 in shod horses (Proske et al., 2017). Results from this study identified higher digital cushion measurements (1.49 ± 0.04) but was similar to Proske et al. (2017). This could be due to a difference in location of digital cushion thickness measurement when using ultrasound versus MR images. When data was re-examined using the more forward location of digital cushion thickness measurement similar to the ultrasound measurement from Gunkelman and Hammer (2017), mean values were more closely related (0.9 mm ± 0.04).

In summary, although this small sample did not identify a change in digital cushion thickness with lameness score, identification of proper digital cushion measurement location

using MRI should be further investigated. Future research should also allow for a true non-lame control for comparison. Furthermore, evaluation of a larger sample size has the potential to determine more definitively whether an association with lameness and digital cushion thickness exists.

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CHAPTER 3. INFLUENCE OF SHOEING AND TRIMMING ON TEMPERATURE, DIGITAL CUSHION THICKNESS, AND CARPAL JOINT CIRCUMFERENCE IN MATURE HORSES

Abstract

Horses' hooves are maintained through routine trimming and shoeing. However, alterations to the external hoof can affect internal structures, including those which play a role in vascular exchange such as the digital cushion. Thermography images can be used as a method of noninvasive determination of relative blood flow. Therefore, the objective of this study was to determine effects of trimming and shoeing on carpal joint circumference, digital cushion thickness, and hoof temperature; with the hypothesis that shoeing would impede hoof wall expansion leading to decreased blood flow within the hoof. To meet this objective, two experiments were conducted; Experiment 1 (Exp 1) at North Dakota State University (NDSU) and Experiment 2 (Exp 2) at the University of Minnesota – Crookston (UMC). Exp 1 utilized 12 mature, stock-type horses. Horses were randomly assigned to one of two treatments: hooves trimmed and left barefoot (bare, n=6) or hooves trimmed and both forefeet fitted with metal shoes (shod, n=6). Exp 2 utilized 10 mature horses of varying breeds, where again horses were randomly assigned to one of two treatments: hooves trimmed and left barefoot (bare, n=5) or hooves trimmed and both forefeet fitted with metal shoes (shod, n=5). Carpal joint circumference (cm) was measured on all horses using a soft tape measure. Measurements of digital cushion thickness (mm) were obtained from both forelimbs using ultrasound and a transcuneal approach. Thermography images of each front hoof were obtained in a climate controlled facility utilizing a FLIR T420 thermography camera (Vetel Diagnostics, San Luis Obispo, CA). Images were taken from the right and left dorsal view, as well as the right and left lateral and medial view at a

distance of 60 cm. Baseline measurements were obtained one week prior to farrier work in Exp 1 and the day prior to farrier work in Exp 2. Data was again collected at 24 h, 4 wk, and 8 wk post trimming and shoeing in both experiments. Additional thermography images were obtained in Exp 1 at 1 wk and 2 wk. Images were analyzed using thermo-analysis software, where each hoof at each view was divided in half on a transverse plane and average, minimum, and maximum temperature of the area from coronary band to middle of the hoof wall was recorded. The distal portion of the hoof was not utilized to minimize effects of the attached cold shoe/nails in shod horses. Data were analyzed in SAS (v. 9.4, SAS Institute Inc., NC) using the PROC MIXED procedure. Significance was set at $P \leq 0.05$. In Exp 1, no difference was identified in carpal joint circumference between treatment groups for the left ($P=0.63$) forelimb; whereas a tendency was seen in the right ($P=0.09$) forelimb. There was no significant change in digital cushion thickness from the left hoof between bare and shod horses over the 8 week period ($P=0.29$); however the right hoof digital cushion was greater at 4 wk in shod compared to 24h and 8 wk ($P \geq 0.02$). When examining the temperature of the distal limb, a significant week by treatment interaction identified ($P=0.04$). In Exp 2, mean carpal joint circumference remained similar throughout the duration of the trial. Overall, there was no significant difference identified in digital cushion thickness between bare and shod horses ($P \geq 0.68$) across the 8 week period. Temperature of the distal limb was not different between bare and shod horses; however, week by treatment interaction was significant ($P<0.0001$) with hoof temperature decreasing from baseline in both bare and shod horses 4 weeks post trimming and shoeing followed by shod horses increasing toward baseline at week 8. Overall, data indicates that changes in hoof temperature can be detected for 8 weeks following trimming and shoeing, with decreases in hoof temperature suggesting a decrease in blood flow.

Introduction

The structures of the hoof are comprised of the hoof capsule, sole, frog, digital cushion, ungual cartilages, and the deep digital flexor tendon. Farriery assumes a vital role in maintaining the health of the foot and preserving the integrity of those hoof structures (O'Grady, 2009). Hooves continually grow to replace hoof lost to wear and tear at the ground surface. However, for today's horse in typical management conditions, growth rate of the hoof exceeds wear rate resulting in excess hoof. Additionally, this wear can become uneven and unbalanced. Therefore, to maintain hoof health, regular trimming to achieve proper length and balance is required. This routine procedure is extremely important as it can influence a horse's overall soundness. To further protect the hoof from uneven wear leading to an unbalanced hoof, a horse can also be fitted with metal shoes (Roepstorff et al., 1999). However, this original purpose for shoes has expanded into numerous farriery techniques; and shoeing is currently also being used to influence performance or serve as a therapeutic aid to prevent and/or treat lameness (van Heel et al., 2005). Shoeing should be considered an extension of a properly trimmed hoof (O'Grady and Poupard, 2001), where conversely, improper shoeing may predispose a horse to lameness issues (Moyer and Anderson, 1975).

Both trimming and shoeing can affect the way in which the foot lands, the duration of time at the stance phase of the stride and the breakover point, overall foot function, and injuries related to the hoof (O'Grady and Poupard, 2001). Furthermore, the specific objectives of trimming include facilitating breakover and ensuring protection of the solar surface while also providing palmar and plantar heel support (O'Grady and Poupard, 2001). When compared to barefoot horses, shod horses have been shown to have changes in their gait kinematics (Willemen et al., 1997; Proske et al., 2017). Shod horses also experience an increase in the

mechanical load of the lower limb (Moyer and Anderson, 1975), which may lead to joint stress and strain on distal tendons. Solar loading distribution has been shown to change following trimming and shoeing, with a significant increase in contact surface area in a trimmed foot due to increased uniformity of bearing wall contact with the ground and increase in contact of the peripheral sole, the frog, and the bars. Furthermore in a shod horse, research has identified that the load distribution pattern was restricted to the shoe surface (Hood et al., 2001).

Importance on the external hoof through trimming and shoeing is essential, as what is altered on the exterior has an influence on the internal structure of the foot (O'Grady and Poupard, 2001). One internal structure that has recently gained attention is the digital cushion. The digital cushion plays a role in vascular exchange throughout the distal limb as well as a role in energy dissipation in the hoof as it is loaded. When a horse is weight bearing, pressure is exerted on the hoof wall, frog, and digital cushion leading to expansion within the hoof. It has been suggested that horses should land heel first with the back third of the frog making contact with the ground (Bowker, 2003). This increases the ability of energy dissipation within the hoof as well as achieves proper development of the tissues in the back of the hoof, which primarily includes the digital cushion. Through this mechanism, the tissues of the digital cushion become stronger, proper energy dissipation is achieved and allows for adequate blood flow through the hoof, and a decrease in strain/stress on internal structures is observed (Bowker, 2003).

Thickness of the digital cushion has not been researched extensively, however it has been hypothesized that changes in thickness have the potential to disturb the mechanism of energy dissipation (Dhyre-Poulsen et al., 1994). Previous studies completed in cattle have found an association of a thin digital cushion to lameness (Raber et al., 2004); with another study completed in horses finding a decreased digital cushion thickness potentially linked to the

application of steel shoes (Proske et al., 2017). Furthermore, when a horse is shod, the lack of

frog and sole interaction may hinder these important roles of the digital cushion (Bowker, 2003).

These factors can lead to inefficient energy dissipation and may gradually produce lameness

conditions.

While shoeing has been shown to limit the interaction of the frog and solar surfaces at the

point of ground contact (Bowker, 2003), it has also been shown to limit the expansion of the

hoof wall at the same time. The unshod hoof expands in response to loading during the stance

phase, whereas shoeing can impede this (van Heel et al., 2004). This may interfere with the

mechanism of circulation through the hoof, where vessels in the foot are filled with arterial blood

when the horse lifts the limb and when the hoof is loaded capillaries are compressed pushing

blood back up the limb (Bowker, 1998). Thermographic images have proven to be a valuable

non-invasive technique to visualize the circulatory pattern and relative blood flow throughout the

horse's limb (Turner et al., 1986), potentially providing a better understanding to how blood flow

may differ in barefoot and shod horses.

Overall investigation on how trimming and shoeing may affect the health of the equine

hoof is essential for proper foot care. More specifically, identifying potential changes in digital

cushion thickness which could effect on energy dissipation within the hoof as well as looking for

alterations in blood flow in the distal limb can ultimately lead to recommendations for horse

owners on the care of their horse's feet. Therefore, two experiments were designed to investigate

the overall objective of the effects of trimming and shoeing on the distal limb in mature riding

horses.

Materials and Methods

All animal procedures were approved by North Dakota State University (NDSU) and the University of Minnesota – Crookston (UMC) Institutional Animal Care and Use Committees.

Experiment 1

Horses and Treatments

Twelve mature, stock-type horses were assigned to the study at NDSU. All horses were of varying age (range 6-19 years), height, and body weight; with adequate body condition score. Horses were sound at the time of the study, with no known history of chronic lameness conditions. Horses were ridden regularly during the weekdays throughout the trial as part of a university teaching program. In addition, all horses were managed similarly, where they were housed in a climate controlled barn overnight in individual 10'x10' box stalls and turned out in group paddocks daily with ad libitum access to hay and water.

Horses were randomly assigned to one of two treatments: 1. Hooves trimmed and left barefoot (bare, n=6) or 2. Hooves trimmed and both forefeet fitted with standard metal shoes (shod, n=6). Within treatments, each horse was randomly assigned to one of three groups, so that each group consisted of two shod horses and two bare horses. Farrier work and data collection was completed in groups, with each group on a separate day. All horses had regular hoof care prior to the study, where they were maintained on an 8 wk trimming schedule. None of the horses on the trial had been shod during the previous three months. The same farrier was used for all treatments, ensuring the same routine was followed.

Carpal Joint Circumference Measurements

Carpal joint circumference (cm) was measured on all horses using a soft tape measure. The location of the tape measure was standardized to surround the carpal bones just distal to the

accessory carpal; where measurements were obtained by one trained individual throughout the duration of the trial to ensure consistency. Horses were positioned to stand square and have equal weight bearing on both front feet during carpal joint measurements.

Digital Cushion Measurements

Digital cushion thickness (mm) was measured on all horses. To obtain this measurement, ultrasound images were obtained from both the left and right forelimb using a transcuneal approach as previously described (Gunkelman and Hammer, 2017).

Figure 3.1. Ultrasonic image obtained using a transcuneal approach. Solid line illustrates the area of digital cushion thickness measurement. DC = digital cushion; DDFT = deep digital flexor tendon.

Thermographic Images

Prior to imaging, front limbs of each horse were examined, and any dirt and debris removed. After limbs were prepared, a minimum of 30 min were provided to allow skin temperature to return to baseline. During this acclimation period, horses were housed in 10'x10'

box-stalls to minimize activity. All thermographic images were obtained in a climate-controlled barn.

Images were obtained using a FLIR T420 thermography camera (Vetel Diagnostics, San Luis Obispo, CA) (Fig 3.2). Images of the front feet were taken from the following views: right and left dorsal view [right dorsal (RD) and left dorsal (LD)], as well as the lateral and medial view of each hoof [right lateral (RL), left lateral (LL) and right medial (RM), left medial (LM)]. Images from the carpal joint were taken from the cranial view [right carpal joint (RCJ) and left carpal joint (LCJ)]. All hoof images (RD, LD, RL, LL, RM, LM) were taken from a distance of 60 cm, while carpal joint images (RCJ and LCJ) were taken from a distance of 100 cm.

Images were analyzed using a thermo-analysis software (Research IR, FLIR, Wilsonville, OR), where each hoof at each view was divided in half at a transverse plane and the average (ave), minimum (min), and maximum (max) temperature of the area from the coronary band to the middle of the hoof wall was recorded (Fig 3.2). The most distal portion of the hoof was not utilized to eliminate artifact effects from the shoe/nails in the shod horses. Carpal joint images were also analyzed for ave, min, and max temperature.
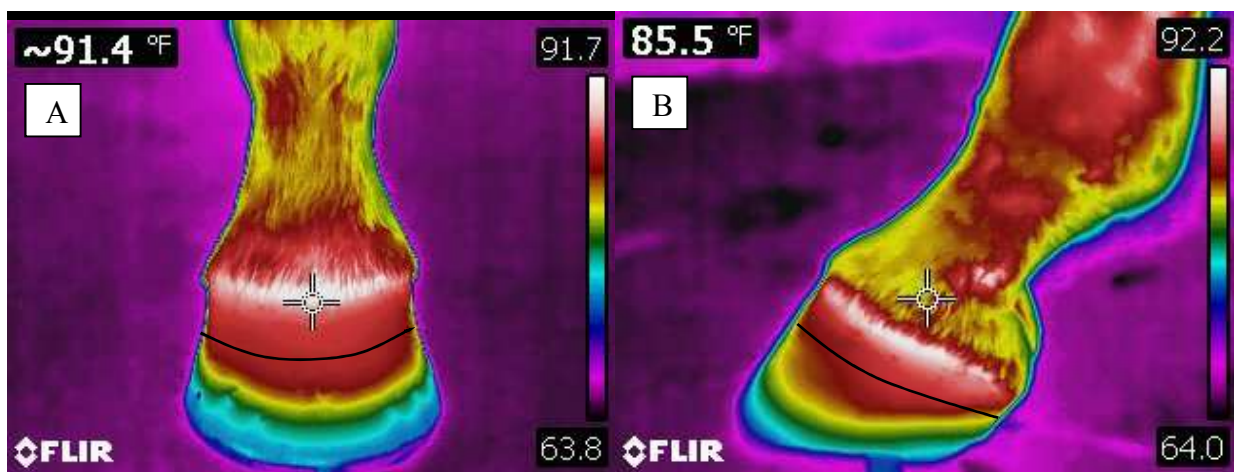
Figure 3.2. Thermography image of the dorsal view (A) and medial view (B) of the hoof. Line across each hoof depicts where the hoof was divided on a transverse plane.

Baseline measurements of digital cushion thickness, carpal joint circumference, and thermographic images were obtained on all horses prior to farrier work using the techniques described above for each respective measurement. Baseline measurements were obtained one week prior to farrier work. Horses in both treatment groups were trimmed, and horses in the shod group were fitted with standard metal shoes on both forefeet. Digital cushion thickness, carpal joint circumference, and thermography images were obtained 24 h following farrier work and at week four and eight at both locations. Additional thermography images were taken at week one and two on all horses. All data was collected by the same trained individual throughout the trial to ensure consistency.

–1 wk	Farrier	24h	1wk	2wk	4wk	8wk
• Baseline measurements (DCT, CJC, Thermo)	• Bare (n=6) • Shod (n=6)	• DCT • CJC • Thermo	• Thermo	• Thermo	• DCT • CJC • Thermo	• DCT • CJC • Thermo
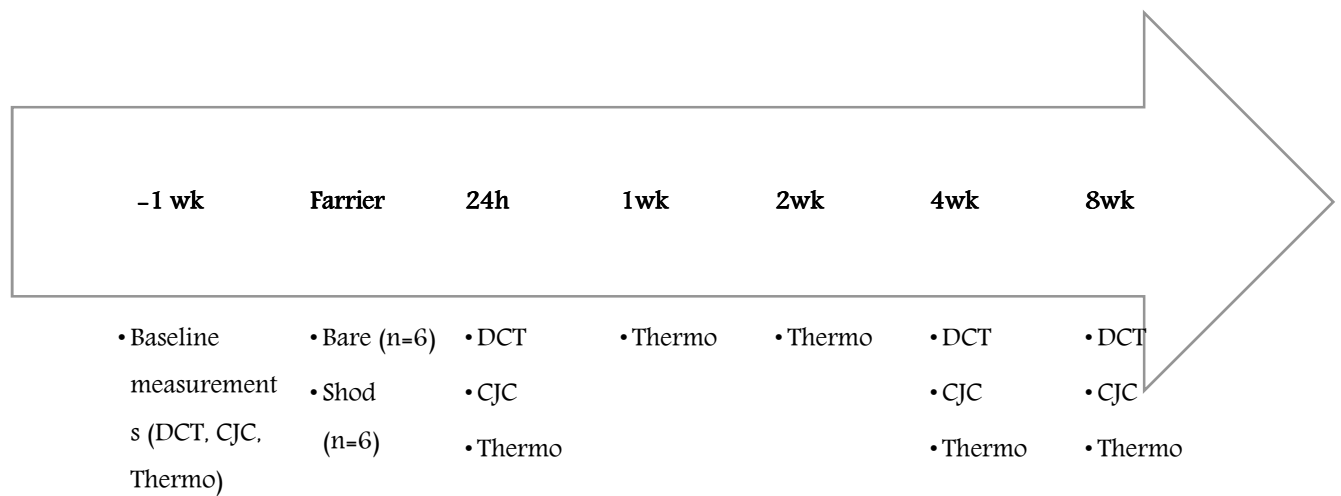
Figure 3.3. Project timeline (DCT = digital cushion thickness, CJC = carpal joint circumference, Thermo = thermography images)

Experiment 2

Horses and Treatments

Ten mature horses of various breeds were assigned to the study at UMC. All horses were of varying age (range 7-27 years), height, and body weight; with adequate body condition score. Horses were sound at the time of the study, with no known history of chronic lameness

conditions. Horses were ridden regularly during the weekdays throughout the trial as part of a university teaching program. In addition, horses were housed in a climate controlled barn overnight in individual 12'x12' box stalls and turned out in group paddocks daily with ad libitum access to hay and water.

Horses were randomly assigned to one of two treatments: 1. Hooves trimmed and left barefoot (bare, n=5) or 2. Hooves trimmed and both forefeet fitted with metal shoes (shod, n=5). Within treatments, horses were randomly assigned to two groups, so that each group consisted of a combination of shod horses and bare horses (group 1: bare n=2, shod n=3; group 2: bare n=3, shod n=2). Farrier work and data collection was completed in groups, with each group on a separate day. All horses had regular hoof care prior to the study, where they were maintained on an 8 wk trimming schedule. None of the horses on the trial had been shod during the previous three months. The same farrier was used for all treatments, ensuring the same routine was followed.

Carpal Joint Circumference Measurements

Carpal joint circumference (cm) was measured on all horses using the same method as previously described in Exp 1.

Digital Cushion Measurements

Digital cushion thickness (mm) was measured on all horses using the same method as previously described for Exp 1.

Thermographic Images

Thermography images were obtained using the same method as previously described for Exp 1.

Sampling Timepoints

Baseline measurements of digital cushion thickness, carpal joint circumference, and thermographic images were obtained similar to Exp 1; however, baseline measurements were obtained 24 h prior to farrier work. Horses in both treatment groups were trimmed by the farrier assigned to the trial, and horses in the shod group were fitted with metal shoes on both forefeet. Digital cushion thickness, carpal joint circumference, and thermography images were obtained 24 h following farrier work and again at week four and eight (Figure 3.4). All data was collected by the same trained individual throughout the trial to ensure consistency.

–24h	Farrier	24h	4wk	8wk
• Baseline (DCT, CJC, Thermo)	• Bare (n=5) • Shod (n=5)	• DCT • CJC • Thermo	• DCT • CJC • Thermo	• DCT • CJC • Thermo
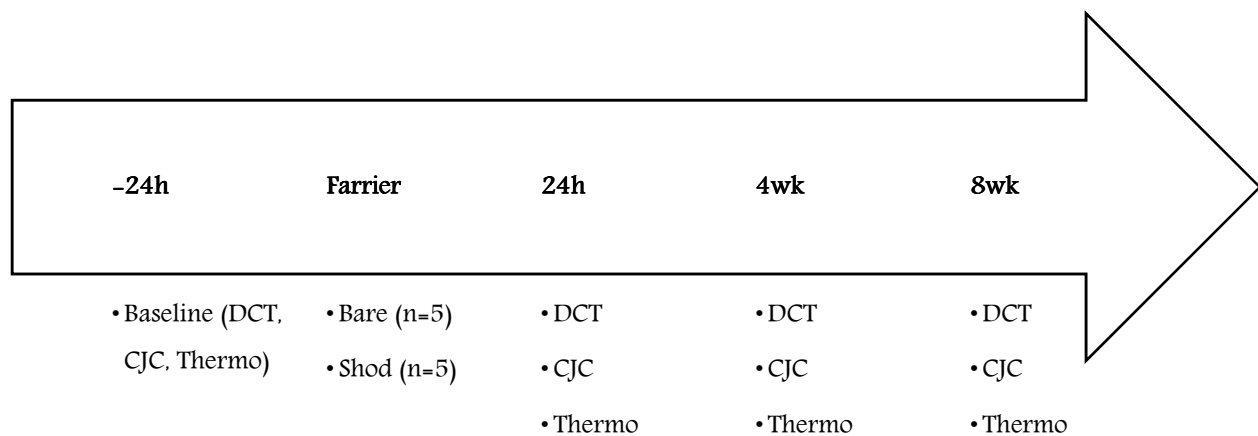
Figure 3.4. Project timeline (DCT = digital cushion thickness, CJC = carpal joint circumference, Thermo = thermography images)

Experiment 1 and 2

Statistical Analysis

Data were analyzed in SAS (v. 9.4, SAS Institute Inc., NC) using the PROC MIXED procedure. Fixed effects fitted in the model included group, sex, age, anatomical view, week, and treatment. Baseline measurements were set as a covariate. Two and three-way interactions were tested and removed if $P>0.20$, except for week*treatment which was kept regardless of P-value. Significance was set at $P\leq0.05$.

Results

Experiment 1

Carpal Joint Circumference

Mean carpal joint circumference remained similar in the left carpal joint between bare and shod horses (*P*=0.63; Fig 3.5). The right carpal joint in bare horses tended to have a decreased carpal joint circumference in comparison to shod horses (*P*=0.09; Fig 3.5). Mean values for left and right carpal joint circumference in bare horses were 31.82 ± 0.13 cm and 31.84 ± 0.26 cm, respectively. Mean values for left and right carpal joint circumference in shod horses were 31.92 ± 0.14 cm and 32.18 ± 0.27 cm, respectively.
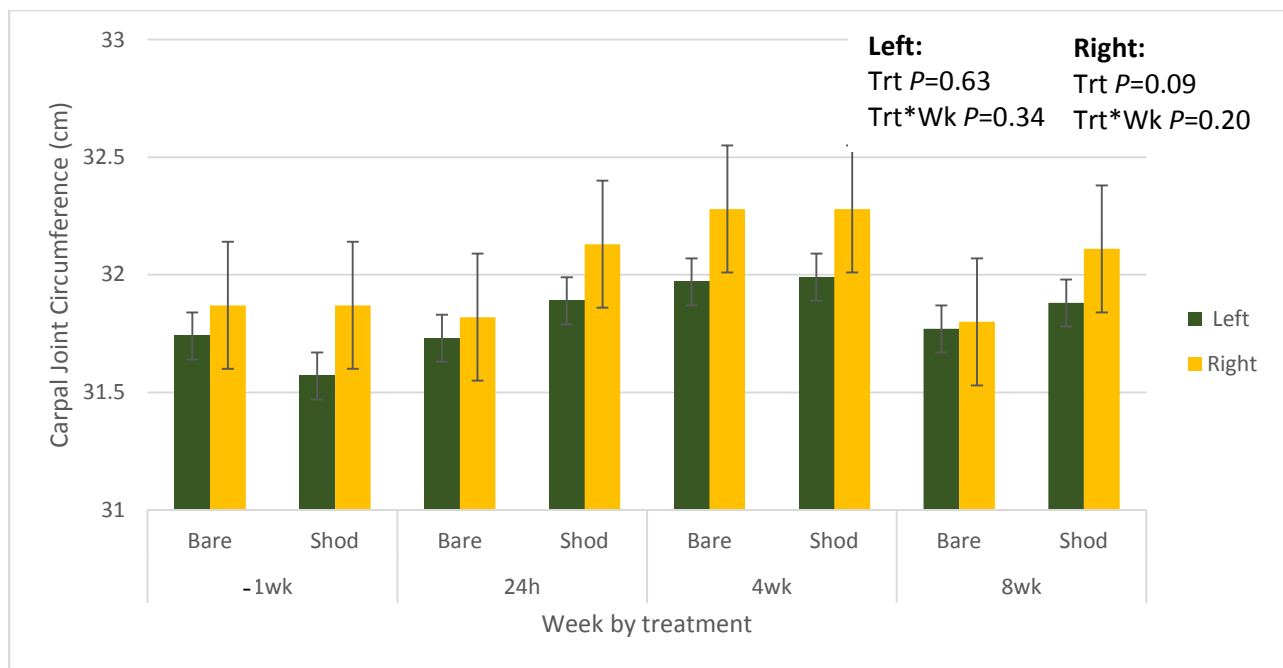
Figure 3.5. Comparison of carpal joint circumference (cm) in bare and shod horses across an 8 week period following trimming and shoeing.

Digital Cushion

Overall, there was no significant difference identified in digital cushion thickness between bare and shod horses for either the left (*P*=0.89) or right (*P*=0.63) hoof. Average digital

cushion thickness from the left hoof was 9.27 ± 0.47 mm in bare horses and 9.17 ± 0.49 mm in shod horses, with average digital cushion thickness from the right being 8.86 ± 0.32 mm in bare horses and 9.1 ± 0.32 mm in shod horses.

A week by treatment interaction was identified (Fig 3.6), with the right digital cushion thickness in shod horses increasing (P=0.02) at week 4 compared to 24h and 8 which did not differ. From week 4 to week 8, the right digital cushion thickness in shod horses decreased significantly (P=0.02). Digital cushion of the left hoof in shod horses remained similar at all time points. In week 4, bare and shod horses were significantly different from each other; where bare horses had a decreased digital cushion thickness compared to shod horses (P=0.02).
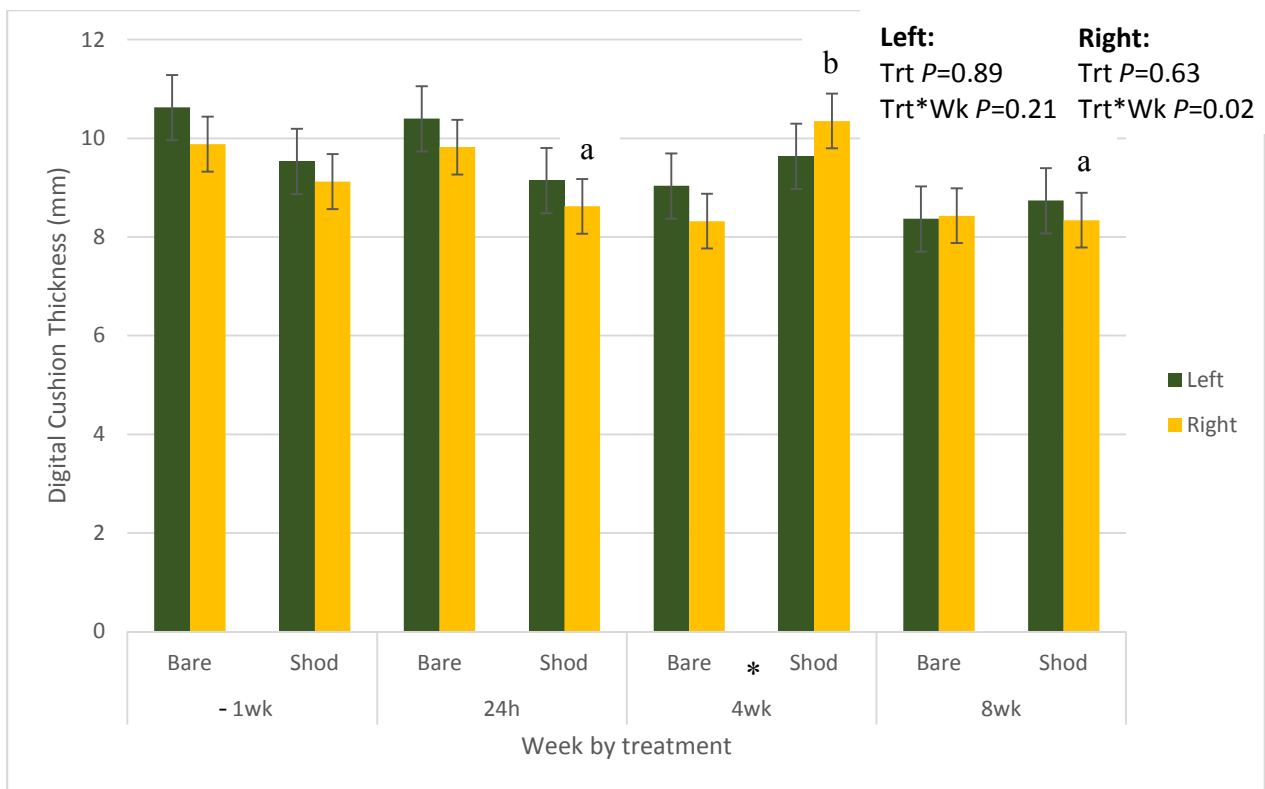
Figure 3.6. Comparison of digital cushion thickness (mm) in bare and shod horses across an 8 week period following trimming and shoeing. Columns with differing superscripts differ by P<0.05. Weeks with asterisks (*) bare vs shod differ by P<0.05.

Thermographic Images

Overall, images of the carpal joint (LCJ and RCJ) were significantly cooler than those of the hoof in both the left and right forelimb ($P<0.0001$); with all hoof images (RL, RM, RD, LL, LM, LD) being similar (Fig 3.7).
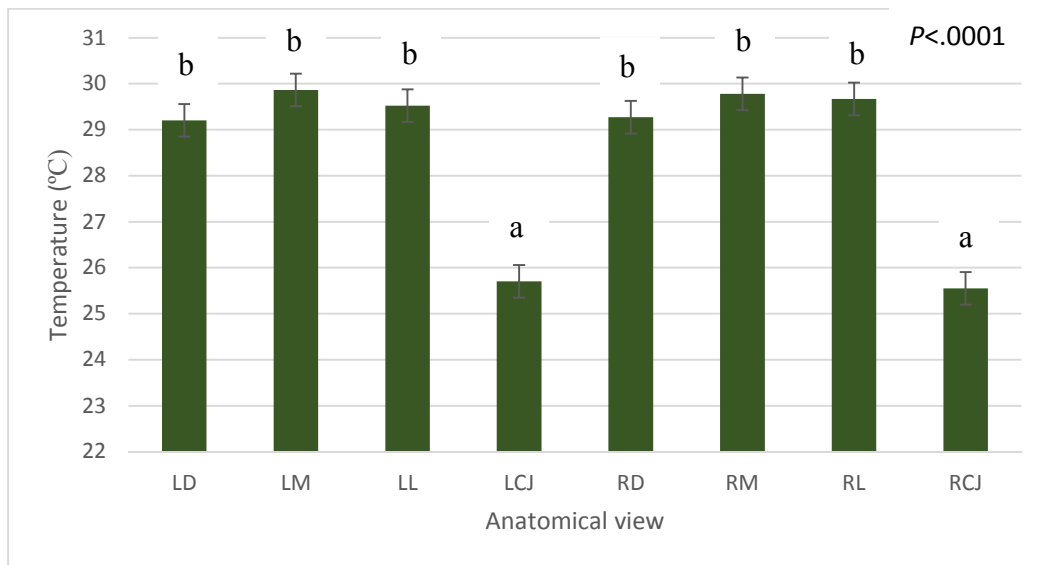
Figure 3.7. Average temperature (ºC) of hoof views (RL, RM, RD, LL, LM, LD) and carpal joint (LCJ, RCJ) as determined by thermography in horses. Columns with differing superscripts differ by $P<0.05$.

No difference in average temperature of the hoof was identified between bare (28.55 ºC) and shod (28.59 ºC) horses ($P=0.90$). However, there was a week by treatment interaction ($P=0.04$; Fig 3.8) with hoof temperature decreasing in both bare and shod horses one week post trimming and shoeing. Bare horses returned to baseline at week 4 before decreasing again by week 8. Shod horses remained below baseline throughout the 8 week period, and were significantly colder ($P=0.02$) than bare at week 8.
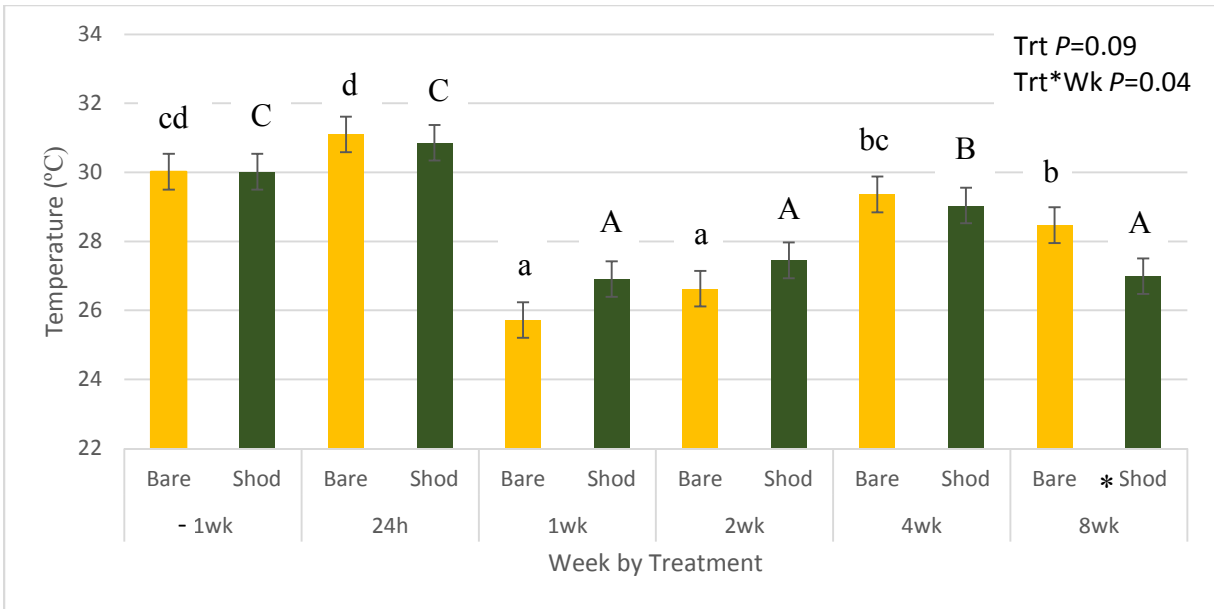
Figure 3.8. Average temperature (ºC) of the hoof in bare and shod horses across an 8 week period following trimming and shoeing. Columns within treatment (a, b = bare; A, B = shod) with differing superscripts differ by *P*<0.05. Weeks with asterisks (*) bare and shod differ by *P*<0.05.

Hoof temperature of horses within groups were different (*P*<.0001), where group two had significantly higher temperatures than groups one and three. Group three had the lowest average hoof temperature (Fig 3.9).
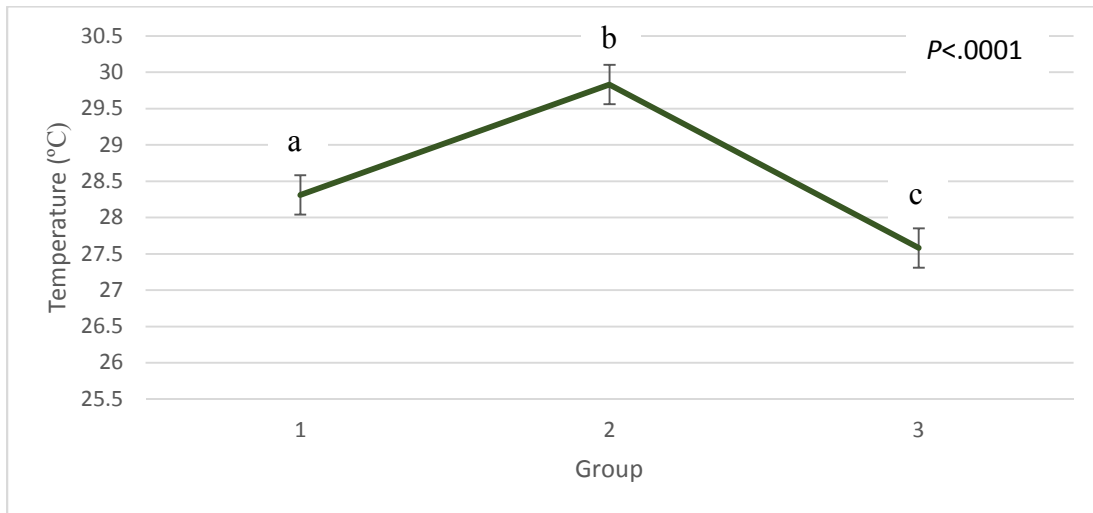
Figure 3.9. Average temperature (ºC) of the hoof between three groups of horses. Group with differing superscripts differ by *P*<0.05.

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Experiment 2

Carpal Joint Circumference

Mean carpal joint circumference remained similar between treatments in both left and right carpal joints ($P \geq 0.87$), as well as throughout the duration of the trial (Fig 3.10). Mean values for left and right carpal joint circumference in bare horses were 32.77 ± 0.07 cm and 32.62 ± 0.05 cm, respectively. Mean values for left and right carpal joint circumference in shod horses were 32.80 ± 0.12 cm and 32.63 ± 0.07 cm, respectively.
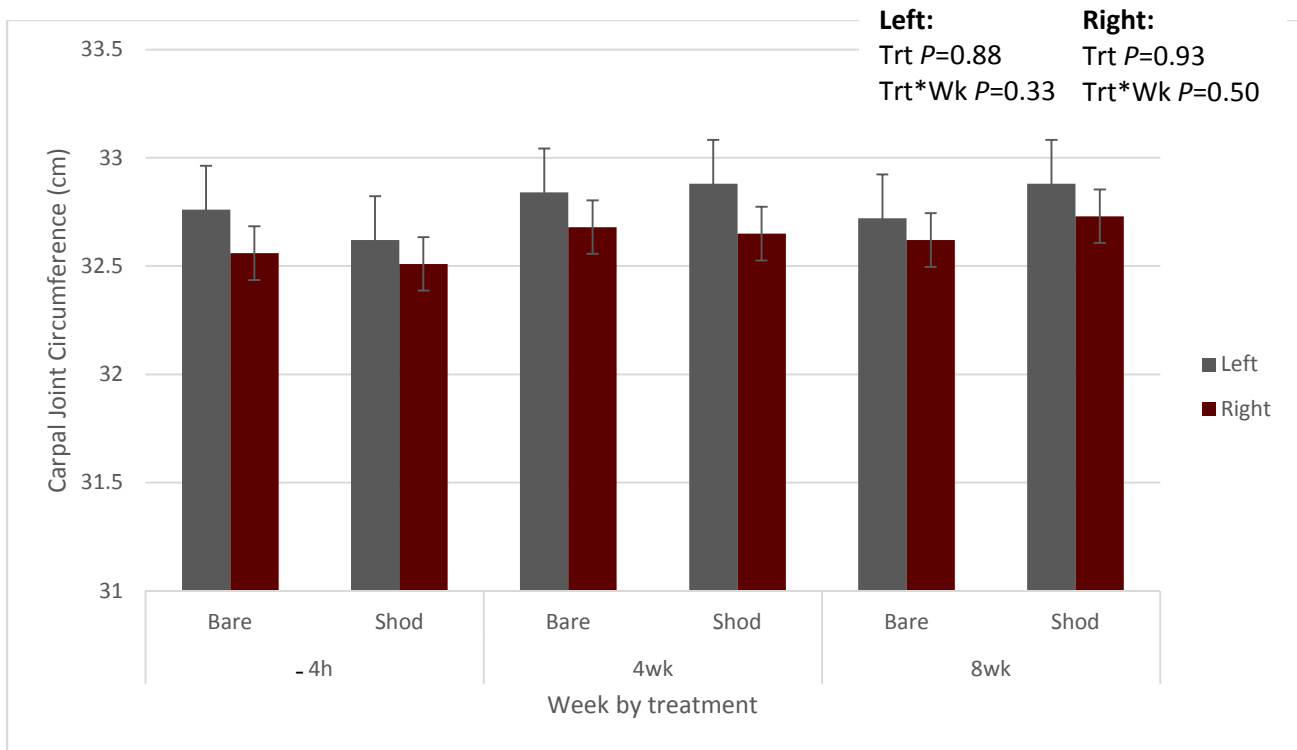
Figure 3.10. Comparison of carpal joint circumference (cm) in bare and shod horses across an 8 week period following trimming and shoeing.

Digital Cushion

Overall, there was no significant difference identified in digital cushion thickness between bare and shod horses for either the left ($P=0.84$) or right ($P=0.53$) hoof. Mean digital cushion thickness in bare horses for left and right was 9.66 ± 0.69 mm and 9.25 ± 0.46 mm,

respectively. Mean digital cushion thickness in shod horses for left and right was 9.49 ± 0.77 mm

and 9.82 ± 0.65 mm, respectively. Furthermore there was no significance seen between

treatments across the 8 week period (Fig 3.11).
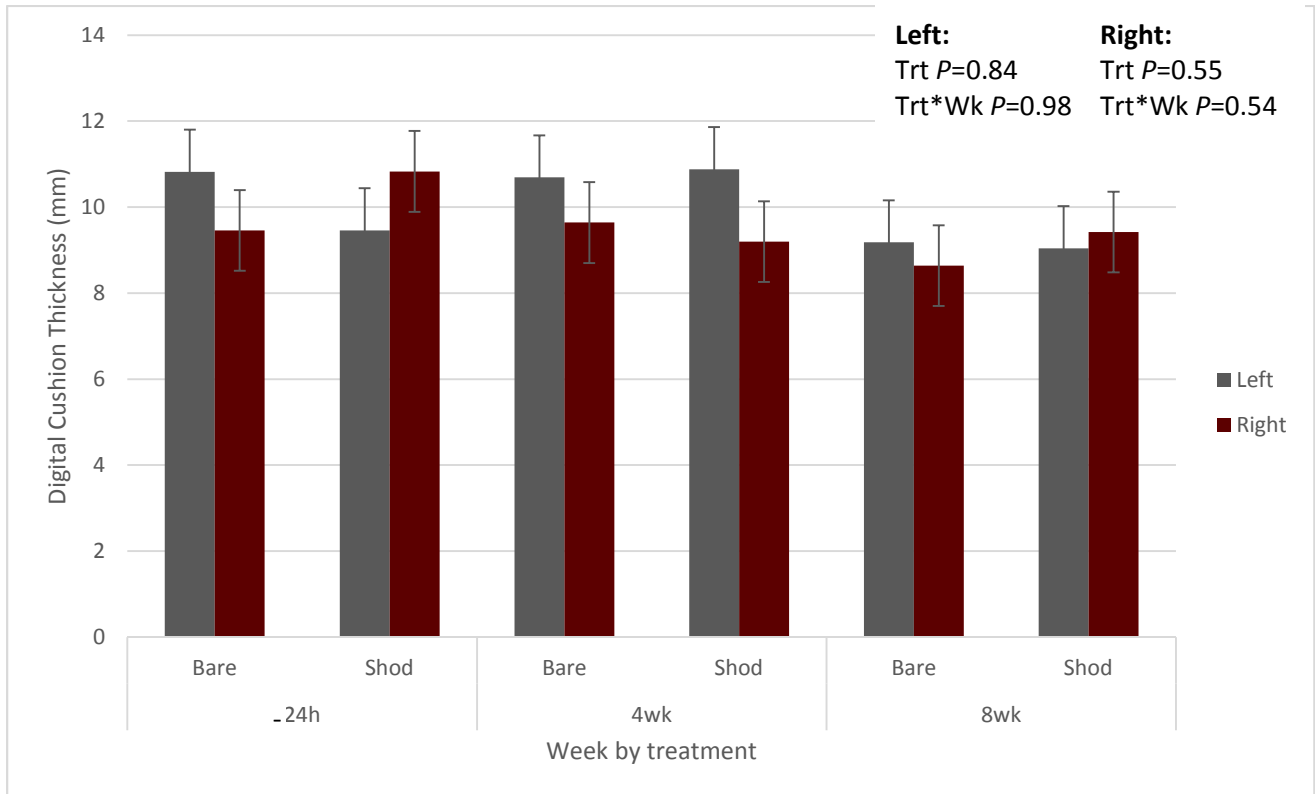
Figure 3.11. Comparison of digital cushion thickness (mm) in bare and shod horses across an 8 week period following trimming and shoeing.

Thermographic Images

When examining thermography images of the carpal joint and hoof, hoof views tended to

be warmer than the temperature of the carpal joints (LCJ and RCJ) (P=0.08; Fig 3.11). The

temperature of all hoof images (RL, RM, RD, LL, LM, LD) were similar (Fig 3.12).
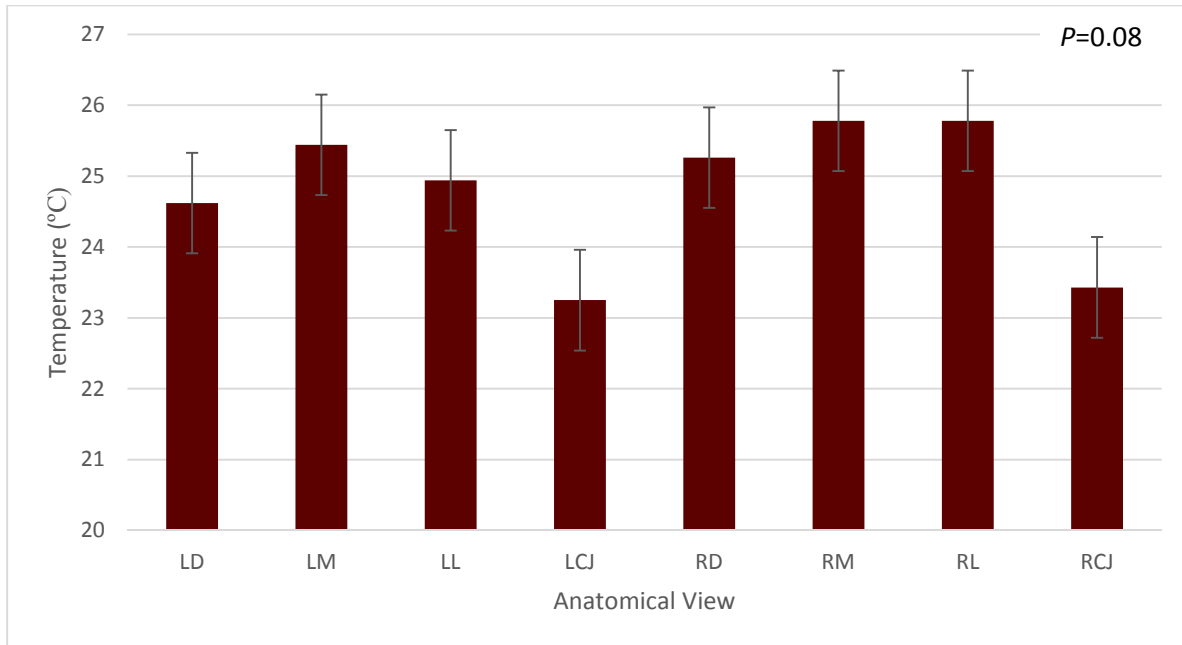
Figure 3.12. Average temperature (ºC) of hoof views (RL, RM, RD, LL, LM, LD) and carpal joint (LCJ, RCJ) as determined by thermography in horses.

No difference in temperature of the hoof was seen between bare and shod horses (*P*=0.24); with bare horses having an average temperature of 25.23 ± 0.51 ºC and shod horses having an average temperature of 24.4 ± 0.39 ºC. Week by treatment interaction was significant (*P*<0.0001; Fig 3.13); at baseline (week -1), bare and shod horses were not different; however, hoof temperature decreased from baseline in both bare and shod horses 4 weeks post trimming and shoeing, followed by shod horses increasing to baseline at week 8 while bare remained colder. Shod horses were cooler (*P*<0.0001) than bare at week 4 but warmer (P=0.02) than bare at week 8 (Fig 3.13).
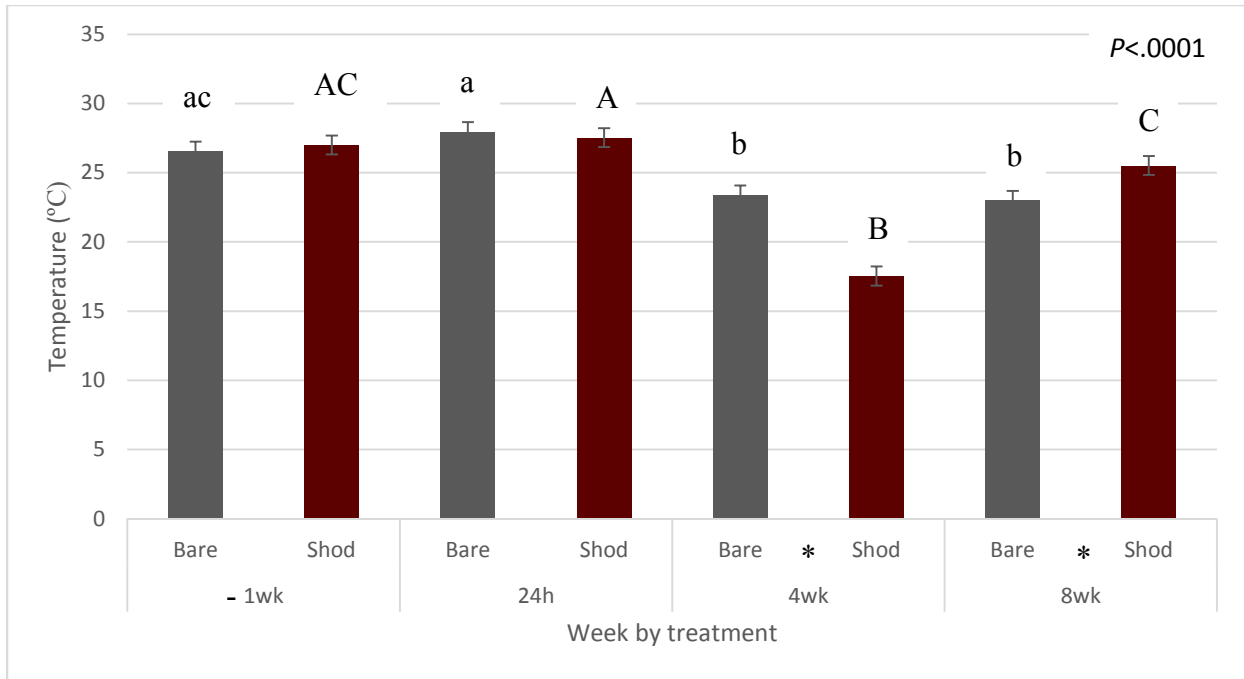
Figure 3.13. Average temperature (ºC) of the hoof in bare and shod horses across an 8 week period following trimming and shoeing. Columns within treatment (a, b = bare; A, B = shod) with differing superscripts differ by *P*<0.05. Weeks with asterisks (*) bare and shod differ by *P*<0.05.

<div align="center">Discussion</div>

Carpal Joint Circumference

No significant change in carpal joint circumference was identified between bare and shod

horses in Exp 2; however a tendency was observed in the right carpal joint for bare horses to

have a decreased carpal joint circumference in comparison to shod horses in Exp 1. It is

hypothesized that the left carpal joint was greater due to inflammation of the joint; with the left

side seeing increased inflammation from the common practice of a rider mounting on the left

side. It has been reported that significant pressure is put on the withers when a rider is mounting

(Geutjens et al., 2008); however further investigation is needed to determine whether this

pressure is also seen on the distal limb.

It has been determined that approximately 67% of the damping of impact vibrations are at the interface between the hoof wall and the distal phalanx (Willemen et al., 1999). Impact vibrations at the distal and proximal interphalangeal joints were only 6%. In comparing bare and shod hooves, the amplitude at the hoof wall was 15% higher in those that were shod. However, this difference was not noticed at the level of the first phalanx and metacarpus. Therefore, the effect of shoeing on the amplitude of impact vibrations at the level of the metacarpophalangeal joint was suggested as minimal (Willemen et al., 1999). Although vibrations at the level of the carpus were not measured, it is likely that minimal impact vibrations reach this level. Thus, inflammation at the level of the carpus due to alteration in impact vibrations resulting from shoeing are unlikely.

A previous study completed by Proske et al. (2017) observed a gradual increase in mean joint circumference in shod horses suggesting regional inflammation at the area of the carpal joint. The authors reported a mean joint circumference of 30.15 ± 0.33 cm at day 0 of the trial in barefoot horses, with a gradual increase once those horses were shod reaching a maximum circumference of 31.0 ± 0.33 cm at the end of a 6-wk shoeing period. This is in contrast to the current findings, where mean carpal joint circumference was higher than what was reported in Proske et al. (2017) ranging from 32.57 ± 0.10 cm to 32.83 ± 0.17 cm in bare horses and from 31.92 ± 0.14 cm to 32.80 ± 0.19 cm in shod horses. Differences between the results may be due to difference in study design and exercise intensity. All horses underwent a period(s) of being barefoot and shod in the Proske et al. (2017) study. In addition, horses were on a 6 week trimming and shoeing schedule, whereas the current study allowed an 8 week period. Furthermore, Proske et al. (2017) utilized controlled exercise, where all horses were exercised on a linear dirt track three times a week for the duration of the study. This is in contrast to Exp 1 and

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2, where horses were exercised during the weekdays as part of a university program. The amount, duration, and intensity of exercise was not recorded.

Digital Cushion

Exp 2 saw no significant changes in digital cushion thickness between bare and shod horses; however Exp 1 identified an increase in the right digital cushion thickness in shod horses at 4 wk of the trial, followed by a decrease at 8 wk. This again is in contrast to a previous study where digital cushion depth was found to be greater in barefoot horses when compared to shod horses over a period of 6 weeks; however as previously mentioned this study utilized a switchback design which is significantly different from the current experiments (Proske et al., 2017). The technique in which digital cushion thickness was obtained was similar to this current study. Regardless of the similar technique, measured digital cushion thickness was vastly different between the two studies. Between the current experiments, mean digital cushion thickness in bare horses ranged from 8.86 ± 0.32 mm to 10.23 ± 0.66 mm and in shod horses from 9.1 ± 0.32 mm to 9.79 ± 0.62 mm. Proske et al. (2017) identified a thickness of 14.1 ± 0.03 mm and 14.3 ± 0.03 mm in the two barefoot phases, with a thickness of 12.6 ± 0.03 mm in horses during the shod phase.

In the current experiments digital cushion measurements were obtained from the superficial frog, where the digital cushion was visualized lying dorsal to the frog and proximal to the deep digital flexor tendon. Measurements from Proske et al. (2017) potentially included the deep digital flexor tendon within their measurements, explaining the increased thickness in digital cushion between their study and the current experiments. The ultrasound technique used in Exp 1 and Exp 2 to measure digital cushion thickness follows what is described by

Gunkelman and Hammer in 2017, where average digital cushion thickness measurements were similar (9.9 mm, bare; 8.7 mm, shod).

To understand the importance that digital cushion thickness may have in regards to hoof health it is important to understand the mechanism of energy dissipation through the hoof. It is known that the foot gradually changes and adapts to the forces applied to it (Bowker et al., 1998); and if restriction of the foot during a loading period is present, preventing it from adapting to its fullest, there is potential for the foot to have reduced strength. The interaction of the frog and the sole of the hoof with the ground surface is essential for development of a stronger digital cushion (Bowker, 2003). Furthermore, it has also been reported that the nailing and adhesion of a shoe in a loaded hoof could impede the expansion of the hoof wall, recorded by a large change in pressure (Dyhre-Poulsen et al., 1994). Therefore, this may alter energy dissipation throughout the hoof, requiring adaptation to the applied forces.

However, research has not made a direct correlation of digital cushion thickness to digital cushion strength. It is known that the composition of the digital cushion changes from fat, elastic, and isolated collagen bundles to a stronger fibrocartilage as a normal progression with increasing age (Bowker, 1998). Through stimulation of the solar surface and frog as a horse ages, the fibrocartilage begins to form distally and progresses proximally toward the distal sesamoid bone. This change in composition to a stronger fibrocartilage has been reported to be completed around age five in horses (Bowker, 1998). A study completed in two-month-old calves found that exercise on an alternative terrain of dirt, stone, and grass increased the volume and surface area of the digital cushion compared to calves housed in grass paddocks with no exercise (Gard et al., 2015). No studies investigating digital cushion thickness in young horses has been completed. Therefore, it is possible that further attention on the digital cushion should be concentrated on the

horse's stage of maturity, with the main focus in young, growing horses where composition of the digital cushion is still developing. It is possible that this is a crucial time to allow the digital cushion an opportunity to form into stronger fibrocartilage.

Thermographic Images

Heat in the limb detected via a thermography camera typically follows the routes of major vessels; where the dorsal view of the limb including the metacarpus/metatarsus, fetlock, and pastern are relatively cool as they are positioned away from the major blood supply (Turner, 2001). The warmest area of the limb thermographically includes the arteriovenous plexus of the coronary and laminar corium just proximal to the hoof wall, with the coronary band being the warmest area of the foot (Turner, 2001). The images from Exp 1 and Exp 2 follow what would be expected when analyzing thermographic images the hoof and forelimb.

Turner (2001) states that a difference of 1 ℃ between two anatomically symmetric regions indicates a significant change; and more specifically, a difference of more than 1 ℃ between hooves is also significant. No known studies have investigated changes in temperature between bare and shod horses using thermography of the distal limb; however a previous study used thermographic images to identify changes in limb temperature in horses with podotrochlosis (Turner et al., 1983). It was not stated if the horses in this study were barefoot or shod, although horses with podotrochlosis are regularly treated with therapeutic shoeing (Ostblom et al., 1984; Willemen et al., 2010). Though there was no comparison between bare and shod horses made, it is interesting to note that this study found that following exercise horses diagnosed with podotrochlosis did not have an increase in limb temperature to the same degree as those whom were clinically normal. They suggest that this failure to increase in temperature may be related to low arterial blood flow (Turner et al., 1983; Love, 1980). As previously mentioned, the nailing

and adhesion of a shoe in a loaded hoof could impede the expansion of the hoof wall, which has been recorded as a large change in pressure (Dyhre-Poulsen et al., 1994). During ground impact the hoof wall expands allowing negative pressure within the digital cushion. This produces an increase in venous blood flow through the caudal foot where the negative pressure enables to the vasculature to be refilled (Bowker et al., 1998). With less expansion of the hoof wall there is potential for decreased blood flow through the cartilages in the foot, as well as less energy dissipated correctly resulting in more energy being transmitted to bone and ligaments. Eventually, a threshold will be reached and clinical signs of lameness will be apparent.

In Exp 1, there was a week by treatment interaction with hoof temperature decreasing in both bare and shod horses one week post trimming and shoeing. Bare horses returned to baseline at week 4 before decreasing again by week 8. Shod horses remained below baseline throughout the 8 week period, and were significantly colder than bare at week 8. Similar results were seen in Exp 2. However hoof temperature decreased from baseline in both bare and shod horses 4 weeks post trimming and shoeing; followed by shod horses increasing to baseline at week 8. Bare and shod horses were also significantly different from each other at week 4 and at week 8; where shod horses were cooler than bare at week 4 but warmer than bare at week 8. It is suggested that there are slight differences between Exp 1 and Exp 2 due to the variation between locations. A separate farrier was used between the two experiments, therefore there may be difference associated with the way in which horses were trimmed and shod. Horses between the two experiments were housed and managed at different locations. Although management practices were similar, small variations may have an influence such as exercise routine, footing in paddocks and stalls, time spent in stalls and turnout, environmental temperature changes, etc. Thermography is a useful tool but requires a controlled environment for optimal accuracy

(Turner, 2001). Regardless, it can be determined that there are temperature changes following trimming and shoeing and further investigation eliminating these variations is needed to determine what the changes indicate.

It is hypothesized that the observed changes in temperature from the current experiments are potentially due to changes in blood flow due to alterations to the hoof during trimming and shoeing. Trimming has been known to influence the duration of landing by shorting the landing in both front and hind feet, implying that the center of pressure (CoP) of the hoof moves toward the center of the foot quicker in these horses and can be thought to have a more positive influence on the load distribution for the internal hoof structures (Heel et al., 2004). Additionally, alterations in in hoof expansion from the application of shoes may have an effect on the blood flow mechanism throughout the hoof as described earlier. It has been established that the load distribution pattern in the shod horse is restricted to the shoe surface (Hood et al., 2001). During a regular shoeing period of 8 weeks, hoof angle decreases and horses compensate for this change by increasing the loading on the distal interphalangeal joint leading to increased strain on the navicular area and the deep digital flexor tendon (Moleman et al., 2006).

The use of thermography may indicate inflammatory, vascular, or physiological responses to changing conditions. It can provide insight into processes which affect blood flow to the feet (Turner et al., 1983). Energy dissipation in the hoof and the blood flow mechanism are closely related; therefore when one is insufficient there is potential flaw in the other. Although thermography is a simple, noninvasive method in detecting emitted heat from the limb, it is unable to confirm what the observed change indicates.

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Implications

It is understood that there are multiple changes occurring at the time of trimming and shoeing including conformation changes, stride kinematics, and solar surface contact with the ground. Ideally, during trimming a farrier should trim the foot so that it lands heel first (Bowker 1998), allowing the tissues of the foot to function optimally for dissipation of impact energy and participate in the blood flow mechanism through the foot. Furthermore, the back of the foot has the largest surface area for ground impact, therefore allowing a larger surface area to support the hoof at ground impact can minimize stresses on the foot (Bowker, 1998). Excess hoof wall at the end of the trimming period may prevent optimal hoof and ground interaction. If the back part of the foot and the frog do not touch the ground, the energy at impact is transmitted to the bones and other tissues of the foot resulting in insufficient energy dissipation and ultimately lameness (Bowker, 1998). Further research on the importance of hoof contact with the ground and subsequent effects on internal structures and blood flow are required.

In the present experiments, no significant changes were identified in digital cushion thickness and carpal joint circumference between bare and shod horses over the 8 week trimming and shoeing period. However, significant changes were detected in hoof temperature. In both experiments there was a decrease in temperature in both bare and shod. In Exp 1, this decrease was then followed by a gradual increase. However, in Exp 2 only shod horses increased at 8 wk with bare remaining cooler. Thermography provides researchers a noninvasive way to detect emitted heat (Turner, 2001), however it is uncertain whether this detected change is suggesting localized inflammation or potential changes in blood flow, especially when examining the foot. Further research to identify what the detected changes in temperature during trimming and shoeing indicate is warranted. This may eventually lead to further information on the effects on

energy dissipation within the hoof as well as proper blood flow in the distal limb, ultimately providing information for horse owners and industry professionals to guide proper management decisions.

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CHAPTER 4. TRANSFORMATIVE LEARNING IN UNDERGRADUATE STUDENTS

Introduction and Literature Review

Transformative learning was first introduced by Jack Mezirow in 1978 to help explain how adults changed the way they interpreted their world (Baumgartner 2012; Taylor, 2008). The theory attempts to explain how our expectations, framed within cultural assumptions and presuppositions, directly influence the meaning we derive from our experiences. To fully understand transformative learning, it is best to explore the initial views of Jack Mezirow's original theory, as well as the refinements made to the theory through years of research and additional thoughts. This theory is often utilized and associated with adult education, where it is assumed that as we enter adulthood we have gained a store of meanings, beliefs, and values which are a result of socialization (Elias and Merriam, 2005). The process of learning then is considered a construction of new meaning to these experiences.

However, at what point is one considered an adult? For example, the age of 18 is considered a legal definition of adult in the United States. Or does the term of being an adult begin once an individual has assumed the social roles and responsibilities expected of one? The term adult may be best considered when one is clearly in a differing role from that of a child. Elias and Merriam (2005) describe a child as one that is dependent on others for their care and at a stage of development considered more physical (learning to walk) and/or cognitive (learning to talk). Whereas an adult's development has to do more with social roles (learning to be a worker) and psychosocial tasks (Elias and Merriam, 2005). The social context of today's world has fostered a new stage of "emerging adulthood", where it is defined as the period at which a young person between the age of 18-25 years are allowed a "prolonged period of independent role exploration", being not yet an adult but beyond adolescence (Arnett and Tanner, 2000). This

review will first describe the evolution of the Mezirow's transformative learning theory, progressing to where it is today. Furthermore, this review will describe the usefulness of transformative learning in today's students and instructors.

Transformative Learning Theory

Mezirow's most recent description of transformative learning can be defined as the process of effecting change in a frame of reference, which are structures of assumptions through which we understand our experiences (Mezirow, 1997). A frame of reference is composed of two dimensions: habits of mind and a point of view (Mezirow, 2000). Habits of mind include a broad, abstract, habitual way of thinking and acting which is influenced by assumptions; whereas a point of view is the complex of feelings, beliefs, judgements, and attitudes we have regarding a specific individual or group. A point of view more easily changes through reflection and problem solving, while habits of mind are considered more durable. Mezirow (2000) states that "one can try on another's point of view, however one cannot try on someone else's habit of mind". A perspective transformation leads to "a more fully developed frame of reference… one that is more inclusive, differentiating, permeable, critically reflective, and integrative of experience" (Mezirow, 1996).

Specifically when considering the adult population, it is assumed that they have obtained numerous experiences in which have helped in defining their life. Furthermore, these experiences shape our views and perceptions, where we often reject ideas that fail to fit our preconceptions. However, change is continually around us and we cannot always be assured of what we know, therefore learning to have a critical viewpoint is essential (Taylor, 2008). This involves learning "how to negotiate and act upon our own purposes, values, feelings, and meanings rather than

those we have uncritically assimilated from other" (Mezirow, 2000). Transformative learners may move toward a frame of reference that is more inclusive and integrative of experience.

Development of Transformative Learning

Mezirow first described transformative learning as a cognitive, rational process. The early development of transformative learning began with Mezirow's study of United States women returning to education or the workplace after an extended period of time out of school or out of employment (Mezirow, 1978a). This was a qualitative study which recognized factors that may interfere with or aid in a woman's progress into a re-entry college program. This study followed 83 women from New York, New Jersey, San Francisco, and Washington whom were divided into four groups including: re-entry into a university after an extended period out (51 women), entering a college center for counseling (8 women), first semester community college (16 women), or an assistance program for women re-entering the workforce (14 women). Furthermore, Mezirow followed up with a nationwide phone and mail surveys from additional programs and colleges serving the same purpose. It was identified from these studies that the experience for women returning to school caused them to examine their assumption about who they were and how they were as products of sociocultural expectations of women at the time. From the findings of these studies, Mezirow (1978b) established the 10 phases of personal transformation, which is now utilized as a major element of understanding transformative learning (Table 4.1).

Table 4.1. Mezirow's (1978b) Ten Phases of Transformative Learning (Kitchenham, 2008)

Phase 1	A disorienting dilemma
Phase 2	A self-examination with feelings of guilt or shame
Phase 3	A critical assessment of epistemic, sociocultural, or psychic assumptions
Phase 4	Recognition that one's discontent and the process of transformation are shared and that others have negotiated a similar change
Phase 5	Exploration of options for new roles, relationships, and actions
Phase 6	Planning a course of action
Phase 7	Acquisition of knowledge and skills for implementing one's plans
Phase 8	Provisional trying of new roles
Phase 9	Building of competence and self-confidence in new roles and relationships
Phase 10	A reintegration into one's life on the basis of conditions dictated by one's perspective

Mezirow describes the beginning of transformative learning as a disorienting dilemma which is brought about when there is a significant life event triggering a puzzling time in our lives. Research may suggest that a certain time point may initiate the process, however there can be an accumulation of experiences over time that come together and lead to a transformation (Mezirow, 1978b). This moment leads to a self-examination (phase 2) where one may question themselves. At that point, an individual goes onto phase 3 where they experience a personal assessment of what they have been undertaking prior to the initiation of this process through critical reflection. The succeeding steps (phase 4-6) follow a pattern for the start of making improvements on the initiating disorienting dilemma. One must recognize that one's discontent and the process of transformation are shared, which for example means that another individual may experience the same issue and be undergoing a similar pattern in changing it. From there, one must explore options for change and plan a course of action. The remaining steps (phase 7-10) include acquiring the knowledge and skill needed for the change to take place, working toward trying out new roles, becoming confident in oneself and gaining the ability to carry out that role, and finally re-integrating that role as a new perspective in one's life.

The early influences on Mezirow's theory included Kuhn's (1962) paradigm, Freire's (1970) conscientization, and Habermas's (1971, 1984) domains of learning (Kitchenham, 2008). The key ideas from Kuhn's paradigm provided a basis for Mezirow's transformative learning. Ideas included perspective transformation, frame of reference, meaning perspective, and habit of mind. Key points from Freire included the disorienting dilemma, critical self-reflection, as well as habit of mind. Freire (1970) appreciated traditional education, where the instructor would provide information to students. However, some find that this form of education can make the students dependent on the teacher for knowledge, not drawing on and developing critical thinking abilities. Freire described stages of consciousness growth: 1) intransitive thought, 2) semitransitive, 3) critical transitivity (Freire, 1973). The first and what is considered the lowest stage is intransitive thought, is where one feels that their lives are out of their control. The second stage involves some thought and action for change, but only addresses one problem at a time. The highest level is apparent in individuals who think globally and critically about their situations and take action when change is required. This last stage clearly had an influence on Mezirow and his phases of transformative learning. Finally, Habermas's domains of learning provided ideas for the learning processes, perspective transformation, meaning scheme and perspective. Habermas (1971) proposed three domains of learning: the technical, the practical, and the emancipatory. He describes technical learning as learning focused on a routine; being specific to a task and governed by rules. Practical learning involves learning that follows social standards. Lastly, emancipatory learning is focused on being meditative for learning; where the learner utilizes self-reflective and experiences self-knowledge. Mezirow examined Habermas's three domains leading to his term of perspective transformation, meaning "the emancipatory process of becoming critically aware of how and why the structure of psycho-cultural

assumptions has come to constrain the way we see ourselves and our relationships, reconstituting this structure to permit a more inclusive and discriminating integration of experience and acting upon these new understandings" (Mezirow, 1978b). This description following what Mezirow describes in his 10 phases of transformative learning (Table 4.1).

Furthermore, as Mezirow became more established in the original theory, he expanded the view of his described perspective transformation with the ideas of Habermas in mind. He related the emancipatory process to self-directed learning to form three revised types of learning. Habermas's (1971) three types of learning (technical, practical, and emancipatory) then became instrumental, dialogic, and self-reflective as seen in Figure 4.1 (Mezirow, 1985). Learners ask how they could best learn the information (instrumental), when and where this learning could best take place (dialogic), and why they are learning the information (self-reflective). These three types of learning are the meaning perspective and meaning schemes, which are central to the overall perspective transformation. Mezirow describes a meaning perspective as the structure of cultural and psychological actions which are integrated with our past experiences to transform a new experience (Mezirow, 1985). In contrast, a meaning scheme is the collection of belief, concepts, and feelings which shape a particular interpretation (Mezirow, 1994). A meaning perspective is considered a general frame of reference encompassing specific meaning schemes (Kitchenham, 2008).
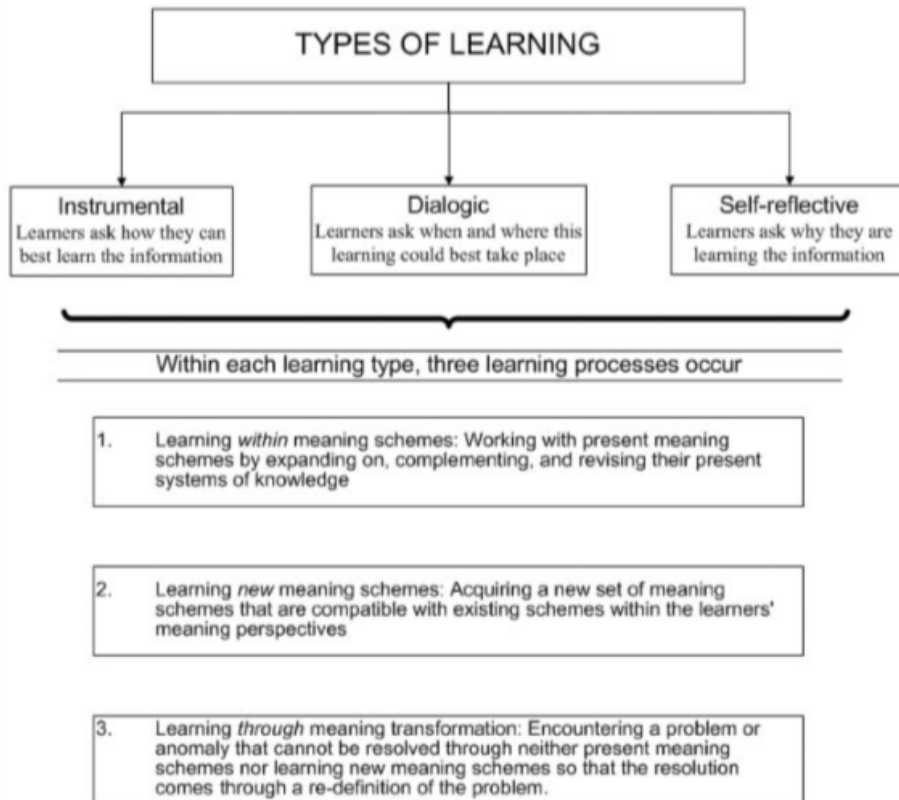
Figure 4.1. Diagram of Mezirow's (1985) types of learning (instrumental, dialogic, self-reflective) within his Transformative Learning Theory, as well as the three learning processes within each learning type (Kitchenham, 2008)

Mezirow's three learning types of instrumental, dialogic, and self-reflective all have three learning processes within them, including: learning within meaning schemes, learning new meaning schemes, and learning through meaning transformation (Fig 4.1). Learning within meaning schemes involves learners working with what they already know by expanding on, complementing, and revising their current knowledge. Learning new meaning schemes that are compatible with existing schemes. Learning through meaning transformation requires an individual to become aware of problems and specific assumptions on which an insufficient meaning scheme is based and from there transform the meaning.

Years later, Mezirow (1991) revised his original 10 phases of transformative learning to add an additional phase, which is to alter present relationships and building new relationships. This phase occurs between phases 8 and 9. The purpose of this additional phase is to focus on critical self-reflection, where Mezirow describes meaning as individualistic. Learning is found inside the learner and the instructor rather than just though external thoughts. The description of transformative learning was then further identified by Mezirow as an enhanced level of awareness of the context of one's beliefs and feelings, a critique of their assumptions and premises, an assessment of different perspectives, a decision to disprove an old perspective in favor a new one or making a combination of old and new, an ability to take action based on new perspectives, and a desire to fit the new perspectives into one's life (Mezirow, 1991).

Critical Reflection

Transformative learning has been and can be studied in multiple difference environments, such as classrooms and in workplaces. However, transformation is focused in the individual person (Merriam and Bierema, 2014), where critical reflection can lead to transformative learning. Ultimately to make "meaning" is to make sense of one's experience. In interpreting the meaning, we guide decision-making, where "meaning" can become "learning". Reflecting on our learning allows us to correct distortions in our beliefs and errors in our thought processes. Specifically, critical reflection is an evaluation of our assumptions based on our beliefs. Learning can defined as the process of making a new or revised interpretation of the meaning of an experience, guiding subsequent understanding, appreciation and action. However, what we think and fail to think, are greatly influenced by our expectations and our set of assumptions that structure the way we interpret our experiences. Mezirow (1995) explains three types of reflection including content reflection, process reflection, and premise reflection (Fig 4.2). Critical

reflection goes beyond simply reflection of one's actions but includes making related conditions of their origins. Specifically, content reflection involves thinking back to what was done, where process reflection is the consideration and examination of the cause of actions and whether there are other factors involved. Premise reflection is the overall view of why we perceive, think, feel, or act as we do. Premise reflection leads to a meaning perspective, whereas the others lead to a meaning scheme.

Mezirow (1996) further explains that critical reflection involves objective and subjective reframing. Objective reframing can be described as being critically reflective when involved in communicative learning, such as being engaged in a task-oriented problem solving situation or when hearing a point of view from another person. In contrast, subjective reframing involves self-reflectively assessing your own ideas and beliefs, requiring one to look inward rather than outward (Brookfield, 2002).
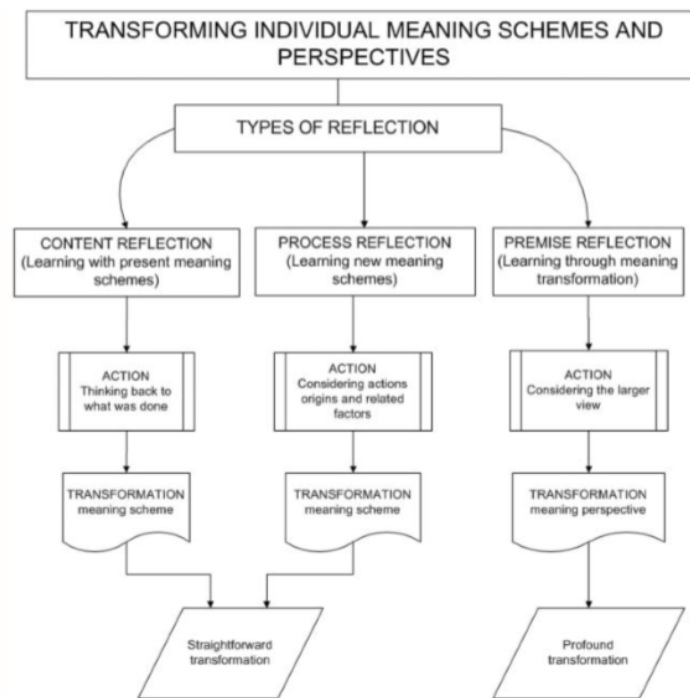
Figure 4.2. Diagram of Mezirow's three types of reflections (content, process, and premise) and their meaning (Kitchenham, 2008)

Facilitating Transformative Learning

Educators must help learners become aware and critical of their own assumptions, as well as others. Learners should practice in recognizing frames of reference and using their imagination to redefine problems from a different perspective, as well as assisted in participating effectively in discourse. Assessing transformative learning can be difficult. However, when assessing transformative learning, it is important to consider that the process does not always follow the ten-phase model by Mezirow. Learners may experience each phase of the model as it is written, while others may skip a phase or return back to one. Others may experience one phase in a more noticeable manner than another (Dewane, 1993; Taylor, 1997). A qualitative study completed by Lytle (1989) found that nursing students had individual experiences; where some experienced presence and absence of some phases of transformative learning or completed them in a differing sequence, while others experience all ten phases.

One may also consider the transformation needed as an instructor, where the educator should be active in the learning process. The educator should serve as a facilitator and should create a learning environment that encourages critical reflection and communication. The rewards of teaching toward transformative learning are great, but also demand a lot of work for both instructor and students (Taylor, 2006). The mind frame for an instructor in higher education should be focused on the transformation of students' perceptions on learning and in their way of thinking, rather than simply acquiring new skills and information (McGonigal, 2005).

Conclusion

Transformative learning has undergone many changes throughout the years, with primarily concepts from Jack Mezirow but also with emphasis from other scholars (Table 4.2). One area of criticism from other scholars however has been that there is a lack of social action

with a disproportional emphasis on personal transformation within Mezirow's theory. However, the goals of adult education include "helping learners to be self-guided, self-reflective, and rational and helping them to establish communities of discourse in which these qualities are honored and fostered" (Mezirow, 1991). Mezirow (2000) states that transformative learning begins from a personal disorienting dilemma, whereas social constructivists like Freire view learning as an active social and culture process (Freire, 1973). Mezirow (2000) claims however that becoming mindful of other's perspectives can eventually lead a person to social action.

Table 4.2. Summary of the progression of Mezirow's transformative learning theory (adapted from Kitchenham, 2008)

Year	Important Event
1978	▪ The initial 10 phases of transformative theory were made by Mezirow
1981	▪ Mezirow adapted Habermans's (1971) three domains of learning: technical, practical, and emancipatory
1985	▪ The theory was expanded to include instrumental learning, dialogic learning, and self-reflective learning ▪ Mezirow defined meaning scheme and meaning perspective ▪ The three learning processes were established: learning within meaning schemes, learning new meaning schemes, and learning through meaning transformation
1991	▪ Mezirow added an additional phase to the transformative learning theory, stating that present relationships may be changed with new relationships built ▪ Three types of reflection were described: content, process and premise
1995	▪ Critical self-reflection
1998	▪ Explanation of objective and subjective reframing
2000	▪ Explanation of habits of mind and points of view
2003	▪ Mezirow provided a clear definition for transformative learning theory

Application in the Classroom

I have gained many teaching experiences throughout my graduate program. Some of which have been in a formal classroom setting, where lecturing and note taking are primary tools utilized. But in addition, I have gained extensive experience teaching undergraduate students in a

non-formal setting. This section will focus on how transformative learning takes place in a non-traditional classroom setting.

Course Objectives

One example of a non-traditional classroom setting is an undergraduate research course. The objectives of undergraduate research in animal sciences are 1) to learn the application of the scientific method including hypothesis development, experimental design, research methods, data collection and analysis, and interpretation of results, and 2) aid in making decisions about post-baccalaureate career options. Basic requirements are described in the syllabus (Appendix C); however, due to the nature of the course there is opportunity as an instructor to personalize the course to the students enrolled. Students enrolled specifically in equine research credits are expected to participate in each stage of a research project.

Four students were enrolled in equine research credits in the spring semester of 2018. Each of the four students coming into the course had vastly different experience levels in research, with some having very little knowledge about the process to others having more extensive hands on experience in other areas of research. However, some students with less research experience, had more advanced horse knowledge and handling skills, which gave them adequate tools for the course. Within the equine undergraduate research course, students were provided a project of their own, as well as expected to aid in other student projects during the semester. This allowed them to learn the research process through multiple projects, with a higher responsibility with one specific project. Studies included: 1) Thermography of the equine hoof immediately following trimming, 2) Thermography of the equine hoof immediately following shoeing, 3) Acclimation of the equine distal limb temperature following exposure to extreme cold, and 4) Effect of external therapeutic wraps on the temperature of the equine distal

limb. Data from study one and study two were combined and included in Appendix A. Data from study three is included in Appendix B. Data from study four was not included. Students had an integral role in learning the background information related to the presented projects, engaging in data collection, analyzing data, interpreting results, drawing conclusions based on data, and writing a research paper to describe the above. Furthermore, the students were encouraged to understand the purpose of the research and how it has an impact on the equine industry. Throughout the process, students were expected to actively reflect on their experience through journaling and class discussions. Outside of the scope of the syllabus, goals set for students included:

1) The ability to commit themselves to their work, taking responsibility for each aspect of the research they are participating in.

2) The ability to gain a sense of ownership for their work, where they are able to become "experts" in their topic of research.

3) The ability to engage in understanding the purpose of their work to further encourage the first two goals.

With these goals in mind, transformative learning can more easily be observed and achieved. Mezirow states that to underdo transformative learning, students must engage in critical reflection on their experiences, leading to a perspective transformation. To facilitate this, instructors must offer opportunities within a course that can aid in achieving that goal. Therefore, students in this course were provided the following:

1) Opportunities for critical thinking

    a. Specific examples related to research course include: reading research articles followed by a subsequent in-class discussion on those articles

2) Reflection opportunities on their own experiences

    a. Specific examples related to research course include: journaling on their experience throughout conducting their research project as well as participating in other student projects, further journaling related to overall thoughts on research; journaling was both prompted by reflection questions as described in the next section as well as left open ended for student interpretation on their own experience

3) Reflection opportunities on each other's experiences

    a. Specific examples related to research course include: in-class discussions on the research projects with discussion facilitated by the instructor

4) Opportunity to bring about a change in their thinking

    a. Specific examples related to research course include: open ended reflection questions (as described in the next section) to guide students toward connecting their previous experiences and knowledge to what they have learned throughout the course, one-on-one meetings with the instructor to discuss this topic and potential change in thinking ("transformation")

In addition to setting opportunities for students to gain a sense of transformative learning, the instructor must consider specific goals for achieving the same thing. As an instructor, even in a non-traditional classroom setting, there should be objectives set for teaching information, engaging students, and assessing student understanding. The specific objectives as an instructor of a research course include:

1. Teach students background information required for understanding the purpose of the planned research projects through the following:

- Pre-test and post-test (Appendix D)

- Reading and subsequent discussion of research papers

- Hands-on experience

2. To engage students in critical thinking through the research experiences achieved through:

    - Discussion groups with other students in the course and with the instructor

    - Reflection questions throughout the research process

    - Student reflection journals to describe their experience

3. Identify whether students are undergoing some form or level of transformative learning through observations and student reflections

Reflection Questions

Reflection questions can often be structured or be left open ended to let the students share what they feel is important. Therefore questions given to students are described as prompt questions where students are encouraged to answer in whatever format they see fit. Example prompt questions utilized in the research course are below, where some are written in a structured format while others are left open ended for interpretation by the student.

Structured reflection questions: (example responses in Appendix E)

1. What is your expectation of research in general? This semester?

    - What past experiences made you draw upon these expectations?

2. What hypothesis do you derive for your project? The other projects?

3. Describe your experience while doing your research project?

    - How do these experiences align with your expectations? Explain.

4. How will your experiences this semester affect your future research experiences?

- What application could this have? For you? For horse owners? Equine industry

  professionals?

Open ended reflection questions: (example responses in Appendix E)

1. My experience this semester taught me _____.

2. My previous knowledge was transformed because _____.

3. The biggest take away message from my research experience is _____.

4. I can use what I learned throughout the semester to _____.

Challenges Affecting Transformative Learning

Throughout teaching this specific course, I was faced with many challenges which had an effect on assessing transformative learning in students. However, I consider this the disorienting dilemma described by Mezirow, which initiates transformative learning for me as an instructor. I was able to learn from each challenge and I consider each valuable for future teaching endeavors. My first challenge was discovering that the population of students can be a large factor in their level of transformation. Drawing on previous knowledge, skills, and experiences are an essential components to undergoing transformative learning. However, when students are dramatically diverse in their previous knowledge and experiences, the transformation also looks dramatically different. For example, students in this equine undergraduate research course were vastly different. Two students had previous experience in research projects, where prior to the course they had read research articles, learned the research process, interpreted data, and synthesized graphs and prepared an overall research article. However, their knowledge on horse handing and background information related to the research topic was minimal. In contrast, the other two students were very experienced horse handlers and had previous knowledge about the research topic. However, they had no experience with the research process prior to the course. This

created a very dynamic and diverse population of students. The solution to this challenge comes from knowing how to ask questions during group discussions and reflection opportunities that properly guide the learning process for each student. This is very achievable and effective with a classroom size of just four students. Using prompt questions as written above can help encourage students to share what they know and what they don't know, what they have learned and what they haven't learned. Furthermore, in group discussions, the students are able to learn from each other, as they can build off each other's strengths and weaknesses. Ultimately, as an instructor, understanding that transformative learning is individual to each student is crucial; where throughout a course each student may reach a different level of transformation.

The second challenge I encountered was fully engaging students. It is assumed that when an instructor presents information in an interactive and engaging way that students will respond positively. However, just because the instructor is passionate about the topic does not indicate that students will be as well. The difficulty in teaching truly comes when students are lacking a need for knowledge and/or skill in that subject. Through this, I also found that transformative learning is not always obtainable if a student is not fully engaged, or when they do not have the drive to learn. Throughout the research course, students began to disengage when the hands-on experiences were minimal (when research projects were completed). The students struggled to create meaningful reflections and were less interested in the data and the writing portion of the research process. To best overcome this challenge and what I find as the best solution is to help students find a relatable reason to learn. Part of this entails knowing your students and guiding course topics in a direction that may lead to them finding their interest. This may not always be the direction the instructor has planned, but being flexible in course expectations can be beneficial when considering individual students. One-on-one discussions with the students

enabled me find their specific connection to the project, encouraging them to reflect on that in their writing. One goal to consider in transformative learning is that it should be a learning process of making meaning of one's experience.

The third challenge is one of the last phases of Mezirow's transformative learning theory; building competence and self-confidence in new roles and relationships. While instructors are providing new information and knowledge to their students, there is also a level of personal development to consider. Again, with the diverse group of students, this process was very dissimilar among the course. The solution to this is often dependent on the student, but should be properly facilitated by the instructor. Critical reflection and self-directed learning are necessary to becoming confident in oneself. Instructors can facilitate by encouraging students to commit themselves to their work, take responsibility for their learning, and as a result gain a sense of ownership for their work, where they can be considered the "experts". Students required facilitation in the areas they had less previous experience; which may have been during reading scientific articles, data collection, analyzing data, constructing graphs, etc. The process of transformative learning looks different in each student, as well as being different from start to end.

Teaching Philosophy Transformation

Being faced with these described challenges through teaching non-formal education courses and through studying the transformative learning theory, has guided transformation in my own teaching philosophy. Teaching experiences have allowed me to critically reflection on my teaching and build a proper framework for my personal teaching philosophy. Each experience I have as an instructor has contributed to some form of transformation to my personal teaching philosophy. However, specifically in teaching the undergraduate research course, with

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the intentional focus on utilizing the transformative learning theory, I have made vital

transformations to my teaching philosophy that were not as apparent in previous experiences.

The format of this research course certainly contributes to this; however the greatest

contributor is going into the semester with the focus of being an intentional instructor. This first

and foremost changed my teaching philosophy, where being an intentional teacher is considered

a priority. I set goals for myself in addition to those set for my students; and continually critically

reflected on those throughout the semester. Individuality of the students was one challenge

mentioned above, and also one of the most influential challenges. Students being diverse in their

previous knowledge and experiences, creates a transformation that also looks dramatically

diverse. Working through this challenge altered my teaching philosophy to become more student

centered, where integrating meaningful reflections is essential to the learning process. As

Mezirow's transformative theory states, in undergoing a transformative, one should build

competence and self-confidence in new roles and relationships. This is the ultimate goal of

transformative theory. In teaching it is important to remember that this transformation may look

different in each and every student; but much can be accomplished when one strives to be an

intentional instructor, focused and set on goals, and working toward building self-confidence in

new knowledge and skills. With these things in mind, I have constructed a personal teaching

philosophy which accurately describes what I believe in today.

Personal Teaching Philosophy

William Arthur Ward states that "The mediocre teacher tells. The good teacher explains.

The superior teacher demonstrates. The great teacher inspires." When reading this statement I am

reminded that as teachers we should aim to inspire those we teach; and as an individual

passionate about teaching, my philosophy is to strive to go beyond telling and instead work

toward explaining, demonstrating, and ultimately inspiring each and every student. Furthermore, Mesirow defines learning as 'the process of making a new or revised interpretation of the meaning of an experience, which guides subsequent understanding, appreciation and action'. He describes learning as a transformative process. Utilizing these resources has allowed me to create a base for my own teaching goals and principles. I believe that to be successful in anything we do, whether it be education or non-education, we should consider what our goals are and establish something to aim for. With this concept, the goals I have set include: (1) encourage students to be passionate about learning and find an application for it, (2) allow students to experience learning in a variety of ways, and (3) inspire students to ask questions and gain further understanding beyond what is taught to them. These are laid out as guidelines for my teaching as well as my student's learning.

I find it necessary for those in the education field to approach the art of teaching with the primary focus of student understanding. Being an effective teacher requires the ability to not only provide students with the required information but also allow them to engage in that information to make it relatable in their everyday life. During the years I have had in education, through being a student as well as being an instructor, I have gained experience focused on my own interests and goals, further teaching me the information and skills I use today for my own personal and professional development. Therefore, I find it important that students are able to have the same experience through their education.

Students are individuals, and a typically class is made up of a group of these individuals, each with differences in their goals. Therefore it is necessary for instructors to utilize all their tools to engage each individual student to the best of their ability. It is beneficial for students to be exposed to multiple forms of learning, where they can learn to adapt and thrive in diverse

situations. As an instructor, I enjoy utilizing multiple forms of teaching, where application of many methods in the classroom can aid in engaging students. The use of standard teaching techniques to present information through lecturing and note taking in essential. But beyond that, it is important to encourage problem solving and critical thinking. The goal here is to require students to take control of their own learning. Learning takes place in the mind, where it cannot be seen. Therefore it may be difficult to assess if students are not require to be involved in the classroom. This may come from engaging students in projects, collaboration, and interactive learning on a daily basis. Beyond school, students may be faced with many situations in which these skills are essential; hence, utilizing these tools in the classroom can provide students not only knowledge and understanding of material required of the course, but additionally skills for outside the classroom later in life.

As instructors we must understand that the effectiveness of teaching is dependent on many variables; which include the students, the environment, and the information. Each classroom or group of students we teach are uniquely different and should be assessed in their own way. To keep instruction effective, it is vital to create an environment where each and every student feels confident and encouraged, which can lead to student-centered learning. This includes students having the ability to engage in asking and answering questions, while expressing their own thoughts and views. Learning can be enhanced through this form of interactive environment, as well as this participation and involvement for those in the classroom outside of just the instructor.

Finally, due to the uniqueness that each classroom presents it is essential that instructors have a way to gage student understanding. Utilizing evaluations is a useful technique to determine the effectiveness of instruction. As previously mentioned each class, each student, and

each semester poses new challenges; and if instructors are not always striving for more then why should we be expecting that from our students? What is expected from them, should also be expected of ourselves. Overall, for teachers, understanding the steps of blooms taxonomy can help spark new ideas and inspiration for the diverse situations that we are put in. Knowledge, comprehension, application, analysis, synthesis, and evaluation are all key to successful teaching and utilizing these skills is essential for working toward student learning.

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CHAPTER 5. GENERAL CONCLUSIONS AND FUTURE DIRECTIONS

Results from these studies serve to provide vital information to horse owners, veterinarians, and those involved in the equine industry. The studies contribute to our understanding of the equine distal limb, with specific focus on the hoof. Lameness is considered a top medical problem in horses with most lameness issues caused in the foot, as well as leg/hoof problems being ranked as a top priority for research. Furthermore, investigation on how trimming and shoeing may affect the health of the equine hoof is essential for proper foot care. More specifically, identifying potential changes in digital cushion thickness to identify potential effects on energy dissipation within the hoof as well as proper blood flow in the distal limb can ultimately provide recommendations to horse owners on the care of their horse's feet.

In Chapter 2, the association of the digital cushion and anatomical changes of the distal limb were evaluated. MRI images of the equine distal limb from lame animals were assessed for abnormalities, and measurements of digital cushion thickness were obtained. No relationship of digital cushion thickness to anatomical abnormalities or lameness was identified. However, sample size was small and standard errors were high. In addition, lameness scores were determined in both front limbs meaning that there was no non-lame control present. Although no significant relationship was identified between digital cushion thickness and lameness, further research using a proper non-lame leg control for comparison is required before concrete conclusions can be made.

Chapter 3 discusses potential alterations that may occur in the equine distal limb during a period after trimming and shoeing. Horses' hooves are continually growing, therefore trimming and shoeing is a routine procedure for maintenance of proper hoof health. However, what is done to the external hoof can have an effect on the internal structures, thus it is important to identify

potential changes to the hoof during this time so we can better manage our horses for optimal health. Two experiments (exp) in separate locations were conducted, where measurements of carpal joint circumference, digital cushion thickness, and temperature of the distal limb were obtained.

In Exp 1, no significant difference was identified in digital cushion thickness between bare and shod horses. Carpal joint circumference tended to be different in the right leg, where bare horses had a decreased carpal joint circumference in comparison to shod horses. When examining the temperature of the distal limb, a significant week by treatment interaction was identified with hoof temperature decreasing in both bare and shod horses post trimming, followed by a gradual increase toward baseline. In Exp 2, no significant results were seen in carpal joint circumference nor in digital cushion thickness between bare and shod horses. Temperature of the distal limb was not different between bare and shod horses; however the week by treatment interaction was again significant. Hoof temperature decreased from baseline in both bare and shod horses post trimming and shoeing followed by shod horses increasing toward baseline. Overall, data from the two experiments indicate that changes in hoof temperature can be detected for 8 weeks following trimming and shoeing, with decreases in hoof temperature suggesting a decrease in blood flow. In addition, shoeing has been suggested to restrict hoof wall expansion as well as energy dissipation throughout the hoof as it is loaded. Although the current study did not show changes to the digital cushion, further investigation is needed to determine how this restriction might affect loading of the digital cushion. Regardless of the conclusions made, horse owners can benefit from further education on the horse's hoof allowing an educated decision on whether a horse should be shod or remain unshod.

Chapter 4 focused on transformative learning in undergraduate students enrolled in an Equine Science research course, where these students conducted four studies. In addition to the research, throughout this course, transformative learning was assessed through the use of pre-test and post-test assessments, reflection questions, and discussions with the instructor as well as the other students. It was determined that transformative learning was achieved, however it was considered dependent on the particular student and their previous experience and knowledge. Drawing on previous knowledge, skills, and experiences are essential components to undergoing transformative learning. Students performed well on the post test, where they provided more correct and detailed answers. However, where students showed dissimilarities in their transformation was in the research component. Those students who came into the course with previous experience in research reached a greater understanding of data analysis and scientific writing; whereas those students with little research experience gained an initial understanding of these concepts, but had more difficulties in attaining an in-depth understanding. Overall, in examining transformative learning, my teaching philosophy has also transformed to become more student focused and goal oriented.

Appendixes A and B describe two smaller scale projects completed by the students in the undergraduate research course, however each provide valuable information as supporting data to this dissertation. Appendix A describes changes in distal limb temperature immediately after trimming and shoeing through the use of thermography; where horses in the bare group had a significantly higher hoof temperature overall than horses in the shod group. Additionally, over a 12 hour period, those horses in the bare group exhibited increasing hoof temperature over time, while those in the shod group exhibited decreasing hoof temperatures over time. This study works in conjunction with Chapter 3, where hoof temperature was first examined 24 hours after

trimming and shoeing. However, although it was seen that bare horses increased in hoof temperatures and shod horses decreased within the 12h after trimming and shoeing, after one week both bare and shod horses had decreased temperatures when compared to baseline which continued until four weeks. Although it cannot be determined exactly what these changes indicate, both studies suggest temperature changes which may relate to differences in blood flow between bare and shod horses, both immediately following trimming and shoeing and over an 8 wk period.

The objective of Appendix B was to identify how distal limb temperature changes after exposure to extreme cold. When utilizing a thermography camera, a 10-20 minutes acclimation period has been suggested, however no other studies have identified how that acclimation period changes in extreme temperatures. This study found that neither the hoof nor pastern were able to return to their baseline temperatures after a 2 hour period of acclimation. Thermographic images have proven to be a valuable non-invasive technique to visualize the circulatory pattern and relative blood flow throughout the horse's limb; however many factors need to be considered to produce a reliable image. As extreme cold is common in this location, adjustments in acclimation time should be made when utilizing thermography for research or applied purposes.

Future Directions and Implications

The present data encourages research in the area of lameness and overall importance to hoof health. Diagnosis of lameness conditions is a vital part to managing healthy, sound horses. Utilizing advanced imaging techniques are essential for improved diagnosis and identification of pathological changes in the limb. Although no difference was identified in digital cushion thickness in either Chapter 2 or Chapter 3, there are multiple factors that should be considered. In Chapter 2, it is possible that no difference was seen in digital cushion thickness due to identified

abnormalities suggesting lameness in each image. In Chapter 3, there were many variables to consider. Exercise was not controlled, therefore horses may have experienced different amounts and intensity of work. Also, temperature variations on each day should be evaluated as thermography readily detects changes in external environment. Lastly management practices between and within locations should be considered. Overall in further research, focus should be placed on controlling variation such as exercise and management practices. Additionally, a non-lame leg should be a priority as well as a stronger sample size.

MRI images are an ideal way to investigate digital cushion thickness, as it provides a clear image of bone and soft tissues within the hoof capsule. However, although there are benefits with using MRI in comparison to other techniques, it is a costly technique which is not available to all horse owners. Using an ultrasound can also aid in visualizing internal structures of the distal limb, as well as thermography to investigate changes in blood flow and localized areas of inflammation. Furthermore, differences in digital cushion thickness in horses that are shod versus those that are unshod should be further examined. Variation in obtaining digital cushion thickness with an ultrasound is high as a clear image can be difficult to achieve. Therefore, identifying more precise markers of identification could create less variability in this measurement. Additionally, utilizing advanced technologies such as an MRI could provide ideal images for accurately measuring the digital cushion.

One possible approach for future research would be through a long-term study investigating the changes in digital cushion thickness in young horses. The tissue composition of the digital cushion has been investigated across age, where changes in digital cushion composition from fat, elastic, and isolated collagen bundles to a stronger fibrocartilage are a normal progression seen in the equine foot with increasing age. With this gradual development

of the digital cushion's composition to a stronger cartilage, the apparent health of the palmar foot may improve. However, management strategies may have an effect on this development. A study completed in dairy cattle found that those animals maintained and exercised on alternative terrain of dirt, stones, and grass had increased volume and surface area of their digital cushion when compared to those in grass paddocks and not encouraged to exercise. This increase in the volume and surface area of the digital cushion and distal phalanges could have a positive effect on hoof health, which in turn could potentially make cows less susceptible to lameness. The digital cushion in young horses may be more susceptible to remodeling in response to environmental conditions and would be interesting to investigate. Additionally, many horses in the industry are shod at a young age, and the potential alterations to hoof wall expansion in these horses should also be considered. Future studies investigating digital cushion thickness in bare and shod horses should focus on young, growing horses during the time of digital cushion development.

These future directions for research have the potential to provide earlier identification for lameness conditions, as digital cushion thickness could suggest strength of the hoof. Early intervention toward developing a stronger hoof could make those horses less susceptible to lameness. Furthermore, these studies have the potential to provide information to help guide management decisions.

APPENDIX A. THERMOGRAPHY OF THE EQUINE HOOF IMMEDIATELY FOLLOWING TRIMMING AND SHOEING

Abstract

Horses' hooves require routine trimming and shoeing for maintenance of a healthy hoof. However, alterations to the external hoof can affect normal hoof function. As the foot contacts the ground, movement of the hoof aids in blood flow through the distal limb. Thermography can be used for determination of relative blood flow. The objective of this study was to examine the immediate effects of trimming and shoeing on the hoof. To meet this objective, eight mature, stock-type horses were utilized. Treatment groups included horses trimmed and left barefoot (bare, n=4) and horses trimmed and fitted with standard iron shoes (shod, n=4). Prior to the trial, horses in the shod group were shod during the previous 8 wks, and horses in the bare group were barefoot during the previous 8 wks. Prior to farrier work, baseline measurements of the front feet were obtained using a thermography camera (FLIR T420, Vetel Diagnostics, San Luis Obispo, CA). Images were taken from the right and left dorsal view, as well as the right and left lateral and medial view at a distance of 60 cm. Following baseline measurements, farrier work was completed; with horses trimmed and those in the shod group fitted with shoes. Images were then taken at 15, 30, 60, 180, and 720 min post-trimming or shoeing. Between measurements, horses remained in box-stalls to minimize activity. All thermographic images were obtained in a climate controlled facility. Images were analyzed using thermo-analysis software (Research IR, FLIR, Wilsonville, OR). Each hoof at each view was divided in half on a transverse plane and average, minimum, and maximum temperature of the area from the coronary band to the middle of the hoof wall was recorded. The distal portion of the hoof was not utilized to minimize effects of the attached cold shoe/nails in shod horses. Data were analyzed in SAS (v. 9.4, SAS Institute Inc.,

NC) using the PROC MIXED procedure. Model included fixed effects of age, sex, time, hoof view, and treatment. Significance was set at $P \leq 0.05$. Treatment was significant ($P<.0001$) with horses in the bare group having a significantly higher hoof temperature overall (27.53ºC ± 0.19) compared to horses in the shod group (25.82ºC ± 0.19). Time by treatment interaction was also significant ($P<.0001$) with increasing hoof temperatures over time in bare horses (25.40 ºC to 30.49 ºC ± 0.45), whereas shod horses had decreasing hoof temperatures over time (26.70 ºC to 25.22 ºC ± 0.45). Thus, it can be determined that changes in hoof temperature immediately following trimming and shoeing are present and indicate a potential relationship to differences in blood flow between bare and shod horses.

<div align="center">Materials and Methods</div>

All animal procedures were approved by the North Dakota State University (NDSU) Institutional Animal Care and Use Committee.

Horses

For thermographic evaluation of the hoof following trimming and shoeing, eight mature stock-type horses from NDSU were utilized. Treatment groups included horses trimmed and left barefoot (bare, n=4) and horses trimmed and fitted with standard iron shoes (shod, n=4). Prior to the trial, horses were maintained on a routine 8 week trimming and shoeing schedule by the same farrier. Furthermore, horses in the shod group were shod during the previous 8 weeks, and horses in the bare group were barefoot during the 8 weeks prior to the study.

All horses were housed and managed at the same location as part of the university lesson horse program, with daily turnout in group paddocks with ad libitum access to hay and water and housed inside in 10' x 10' box stalls at night. At the time of the trial, all horses were sound and had no known history of long-term lameness conditions.

Thermographic Images

Prior to imaging, front limbs of each horse were examined for changes, and any observed dirt and debris were removed as any extraneous artifact found on the skin can cause irregular images (Turner, 2001). After limbs were prepared, a minimum of 30 minutes were provided for acclimation to the environment to ensure accurate thermography images following handling of the limb. Just prior to farrier work, pre-measurements (baseline) were obtained using a FLIR T420 thermography camera (Vetel Diagnostics, San Luis Obispo, CA). Images of the front hooves were taken from the following views: right and left dorsal view [right dorsal (RD) and left dorsal (LD)], as well as the lateral and medial view of both the right and left hoof [right lateral (RL), left lateral (LL) and right medial (RM), left medial (LM)]. All images (RD, LD, RL, LL, RM, LM) were taken from a distance of 60 cm. Following baseline measurements, farrier work was completed; with all horses being trimmed toward balance and those in the shod group fitted with shoes. Trimming took approximately 15 minutes per horse and shoeing took approximately 25 minutes per horse. Images were then taken at 15, 30, 60, 180, 720 min post trimming and shoeing. Between measurements, horses were housed in 10' x 10' box-stalls to minimize activity. All thermographic images were obtained in a climate-controlled facility (12.8º C); as well as by trained individuals to maintain consistency.

Images were analyzed using a thermo-analysis software (Research IR, FLIR, Wilsonville, OR), where each hoof at each view was divided in half on a transverse plane and the average (ave), minimum (min), and maximum (max) temperature of the area from the coronary band to the middle of the hoof wall was recorded. The most distal portion of the hoof was not utilized to eliminate artifact effects from the shoe/nails in the shod horses.

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Statistical Analysis

Data were analyzed in SAS (v. 9.4, SAS Institute Inc., NC) using the PROC MIXED procedure. Model included fixed effects of age, sex, time, view, and treatment. Two and three-way interactions were tested and removed if $P>0.20$, except for time*treatment which was kept regardless of p-value. Significance was set at $P\leq0.05$.

Results

Average temperature of the front, medial, and lateral views (RD, LD, RL, LL, RM, LM) of the right and left front hooves were similar (Fig A.1).
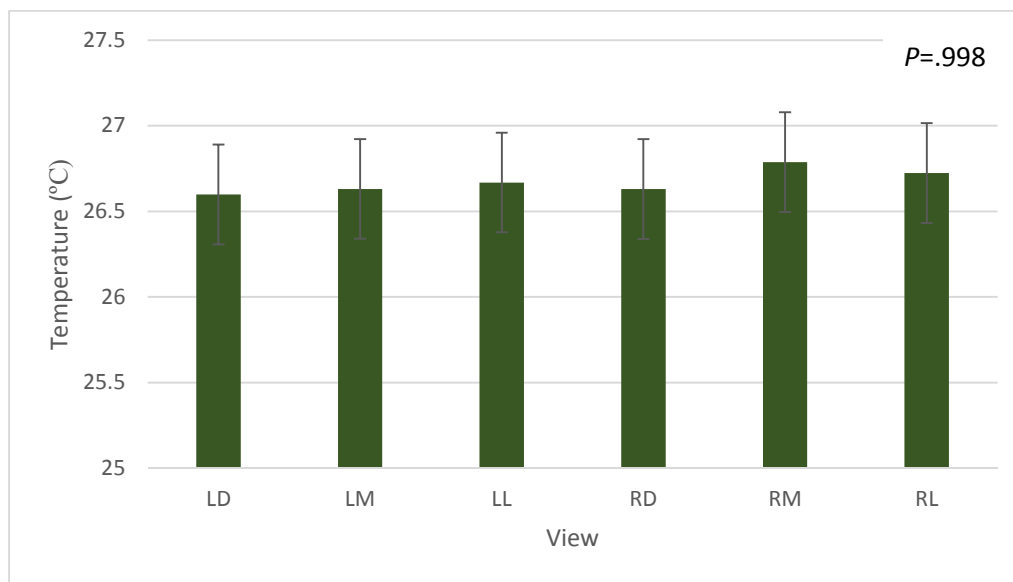

Figure A.1. Comparison of average hoof temperature between front, lateral, and medial views of the left and right front hoof.

As seen in Fig A.2, horses in the bare group had a significantly higher hoof temperature overall (27.53°C $\pm$ 0.19) than those horses in the shod group (25.82°C $\pm$ 0.19) ($P<.0001$). It has been previously identified that a difference of more than 1°C is physiologically significant in the hoof (Turner, 2001). In the current study, the overall difference between bare and shod horses was 1.71°C.
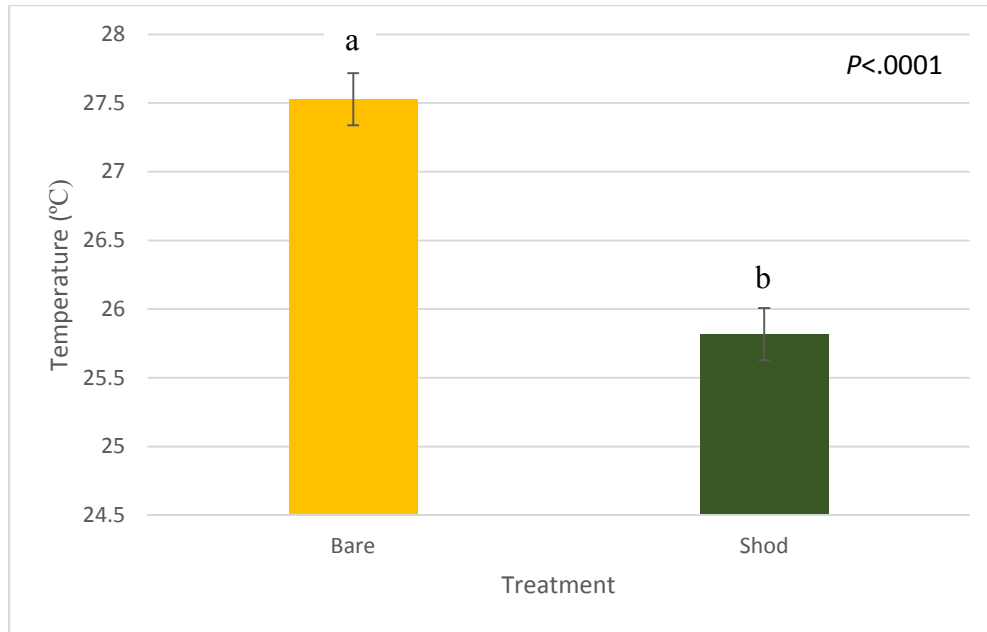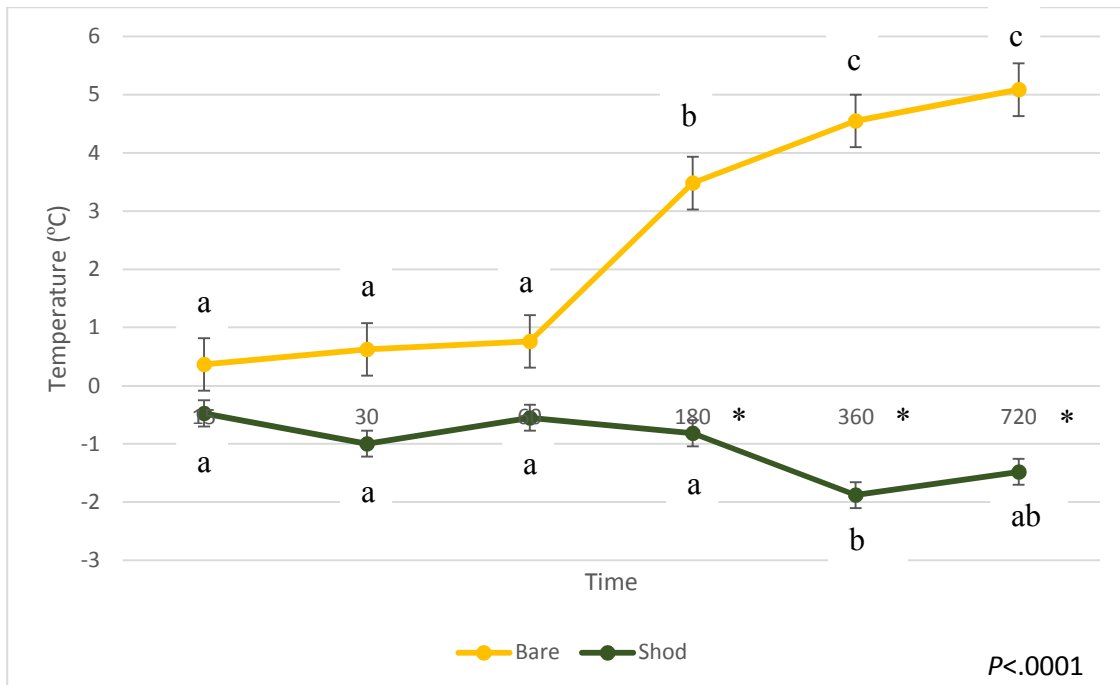
Figure A.2. Comparison of average hoof temperature over a 12 h period following trimming and shoeing in bare and shod horses. Columns within treatment with differing superscripts differ by *P*<0.05.

When comparing the min, ave, and max temperature of the hoof, all measurements follow a similar trend within the bare group as well as within the shod group (Fig A.3). However, there was a time by treatment interaction (*P*<0.0001) with horses in the bare group increasing in hoof temperatures over time and those in the shod group decreasing in hoof temperatures over time (Figure A.3). It is interesting to note however that the shod group had a higher hoof temperature in the min (*P*=0.0004) and ave (*P*=0.05) categories than the bare group at baseline; but the max temperature was not significantly different (*P*=0.60).
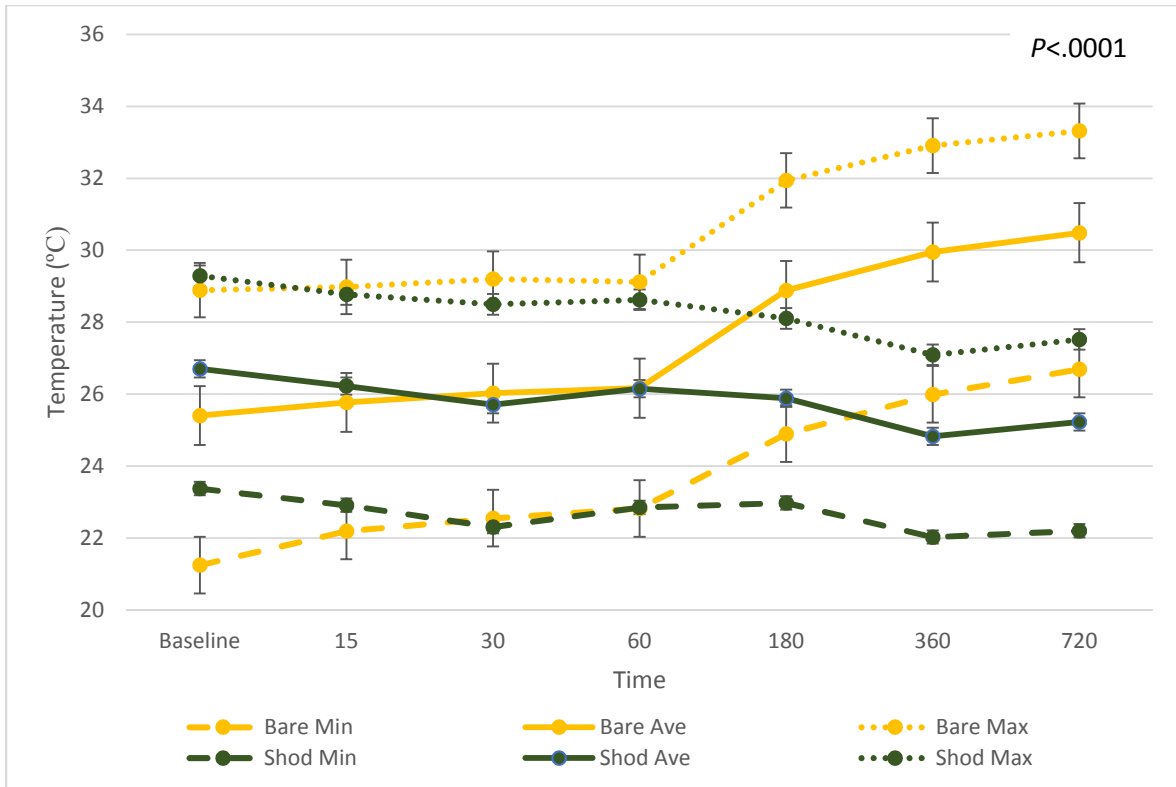
Figure A.3. Minimum (dashed line), average (solid line), and maximum (dotted line) temperature of hooves from bare (yellow) and shod (green) horses at baseline and 12 h following trimming and shoeing.

The change in average temperature from baseline measurements was also calculated (Fig A.4). Horses in the bare group had a positive change in temperature, where those horses had an increase in hoof temperature from baseline. In contrast, the shod group had a negative change, where hoof temperature became cooler over time when compared to baseline (Fig A.4).

Figure A.4. Average change in hoof temperature from baseline in bare and shod horses over a 12 h period following trimming and shoeing. Lines within treatment with differing superscripts differ by $P<0.05$ across time. Time points with asterisks (*) bare and shod differ by $P<0.05$.

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APPENDIX B. ACCLIMATION OF THE EQUINE DISTAL LIMB TEMPERATURE FOLLOWING EXPOSURE TO EXTREME COLD

Abstract

Thermography is a useful tool in veterinary medicine for evaluation of relative blood flow. To ensure accurate imaging, it has been recommended that horses have 10-20 minutes to acclimate to the environment where imaging takes place. However, it is unknown how the limb acclimates after extreme cold exposure. Therefore, the objective of this study was to investigate temperature changes in the distal limb following exposure to extreme cold. To meet this objective eight mature, stock-type horses, all acclimated to cold climate, were assigned to the study. Horses were randomly assigned to one of four days, with two horses examined each day. Horses were housed in a climate controlled facility (12.8º C) the night prior to data collection. The morning of data collection, baseline measurements were obtained using a thermography camera (FLIR T420, Vetel Diagnostics, San Luis Obispo, CA). Dorsal images of the front feet were taken, including both right and left hoof and pastern, as well as lateral and medial views. Horses were then turned out in cold weather conditions in group paddocks for a six hour period. Following turnout, horses were brought back inside the climate controlled facility and the same images were obtained immediately (0 min) and again at 15, 30, 60, 90, and 120 min post-cold exposure. Between post-cold exposure measurements, horses remained in box stalls to minimize activity. Environmental temperature and conditions were recorded. Images were analyzed using a thermo-analysis software (Research IR, FLIR, Wilsonville, OR), where average, minimum, and maximum temperature from all views were recorded. Data were analyzed in SAS (v. 9.4, SAS Institute Inc., NC) using the PROC MIXED procedure. Model included fixed effects of age, sex, time, and anatomical location (hoof vs. pastern). Significance was set at $P \leq 0.05$. All data

collection days were considered extreme cold, where temperature with wind-chill ranged from -22.78°C to -34.44°C and snowfall amounts ranged from 0 to 5.6 cm. Time by anatomical location interaction was significant ($P<.0005$); where average hoof and pastern temperature decreased from baseline after six hours of exposure to cold and gradually returned to baseline over time. However, neither hoof nor pastern temperature returned to baseline within the 120 min post-cold exposure measurement period. Thus, interpretation of thermographic images performed during extreme cold will require longer acclimation periods than those previously recommended in literature.

Materials and Methods

All animal procedures were approved by the North Dakota State University (NDSU) Institutional Animal Care and Use Committee.

Horses

Eight mature, stock-type horses were utilized in this trial to investigate temperature changes in the distal limb following exposure to extreme cold. All horses were housed and managed at the same location as part of a university lesson horse program with daily turnout in group paddocks with ad libitum access to hay and water and housed inside in 10' x 10' box stalls at night. Horses were all acclimated to the cold climate. At the time of the trial, horses were sound and had no known history of long-term lameness conditions.

Experimental Procedure

Horses were randomly assigned to one of four days, with two horses examined each day. Horses were housed in a climate controlled facility (12.8º C) in individual 10' x 10' box stalls the night prior to data collection. The morning of data collection, front limbs of each horse were examined for changes, and any observed dirt and debris were removed as any extraneous artifact

found on the skin can cause irregular images (Turner, 2001). After limbs were prepared, a minimum of 30 minutes were provided for acclimation to the environment to ensure accurate thermography images following handling of the limb. Baseline measurements were then obtained using a thermography camera (FLIR T420, Vetel Diagnostics, San Luis Obispo, CA) and included images of the dorsal view of the right and left hoof and pastern [right dorsal (RD) and left dorsal (LD)], as well as lateral and medial view of the hoof and pastern [right lateral (RL), left lateral (LL) and right medial (RM), left medial (LM)]. All images (RD, LD, RL, LL, RM, LM) were taken from a distance of 60 cm. After imaging, horses were turned out in group paddocks for a six hour period. Following the turnout period, horses were brought inside the climate-controlled barn and thermography images obtained. Images were obtained at the same views as baseline (RD, LD, RL, LL, RM, LM) immediately after horses were brought inside (0 min) and again at 15, 30, 60, 90, and 120 minutes post-cold exposure. Between post-cold exposure measurements, horses were housed in 10' x 10' box stalls in the barn to minimize activity. Environmental temperature with wind chill, as well as amount of snowfall, was recorded for each day of data collection.

Image Analysis

Images were analyzed using a thermo-analysis software (Research IR, FLIR, Wilsonville, OR), where the average (ave), minimum (min), and maximum (max) temperature from the dorsal, lateral, and medial views of the hoof and pastern area were recorded.

Statistical Analysis

Data were analyzed in SAS (v. 9.4, SAS Institute Inc., NC) using the PROC MIXED procedure. Model included fixed effects of age, sex, time, and anatomical part (hoof vs. pastern).

Two and three-way interactions were tested and removed if *P*>0.20. Significance was set at

P≤0.05.

## Results

All data collection days were considered extreme cold weather conditions, where

temperature ranged from -9.44 °C to -14.44 °C (-22.78 °C to -34.44 °C with wind-chill) and

snowfall amounts ranged from none to 5.6 cm (Table B.1).

Table B.1. Record of average temperature, wind-chill, and snowfall for each day of data
collection.

Day	Average Temperature (°C)	Wind-chill range (°C)	Snowfall (cm)
1	-9.44	-22.78 to -27.78	5.6
2	-14.44	-27.78	None
3	-12.22	-34.44 to -25.56	Trace amounts
4	-14.44	-32.78 to -23.33	None

Overall, the hoof had a significantly lower temperature (15.13°C) than the pastern

(18.72°C) (Fig B.1).
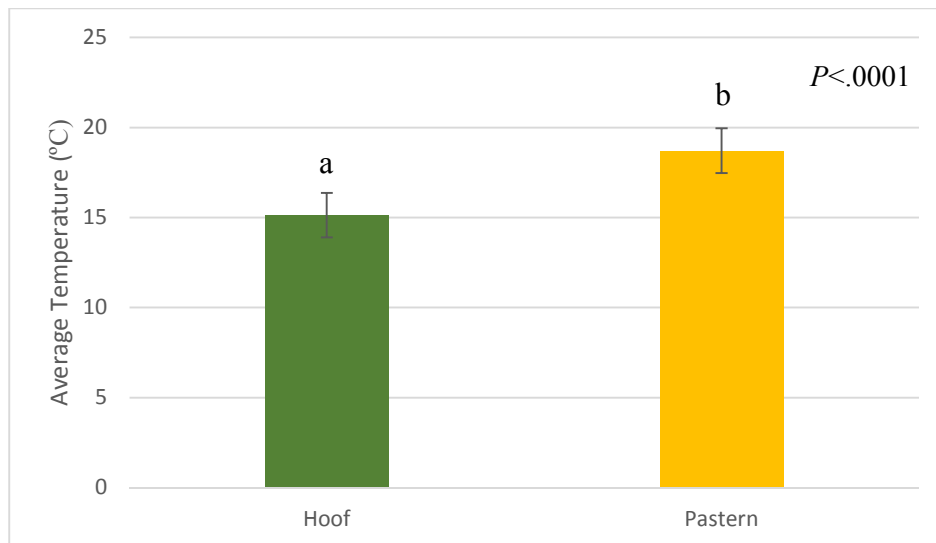
Figure B.1. Comparison of average temperature between the hoof and pastern following
exposure to extreme cold.

There were no significant differences identified between dorsal, medial, and lateral views (RD, LD, RL, LL, RM, LM) for min ($P<0.87$) and ave ($P<0.39$) temperatures (Fig B.2). However, there was a significant difference found in the max ($P<0.03$) temperature, where the front view on both the left and right were cooler than the lateral and medial views (Figure B.2).
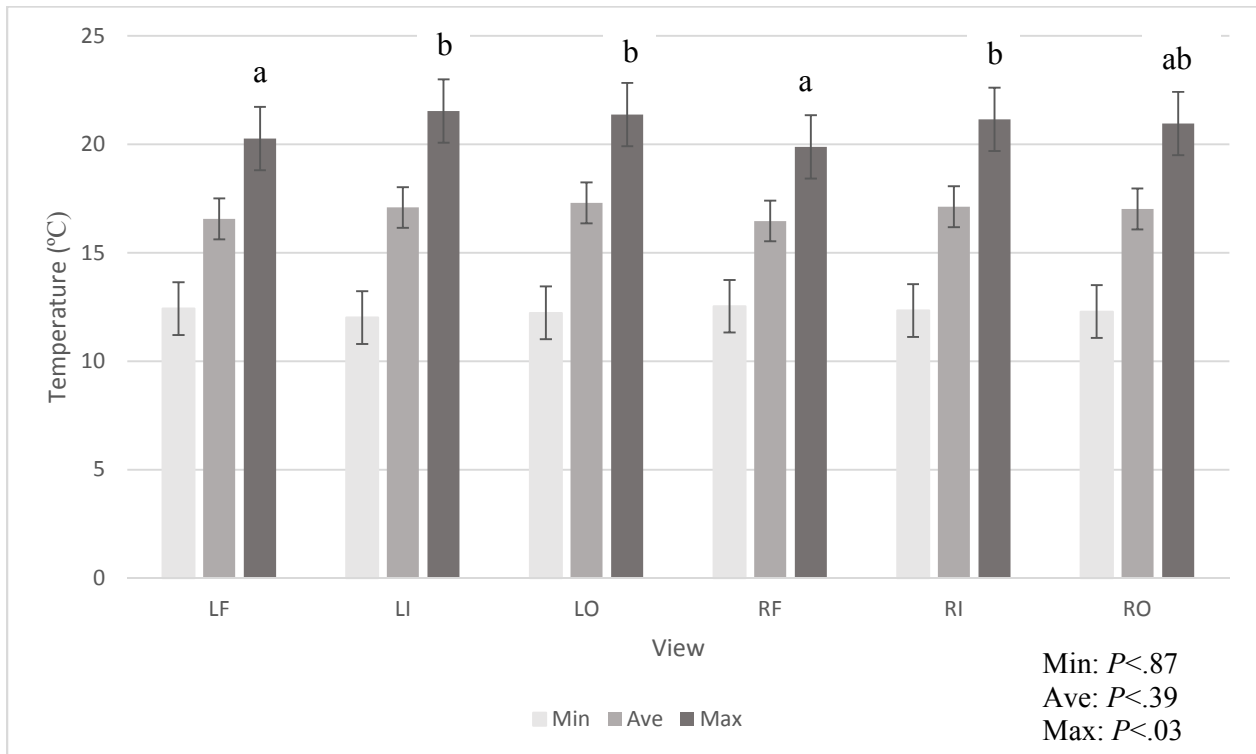
Figure B.2. Temperature comparison (min, ave, and max) between front, lateral, and medial views of the left and right front hoof and pastern. Columns with differing superscripts differ by $P<0.05$.

As seen in Fig B.3, temperature significantly decreased from baseline after a six hour period of exposure to extreme cold in both the hoof (26.14°C to 3.48°C) and pastern (22.68°C to 9.27°C) ($P<.0001$); with a gradual increase in temperature toward baseline over time. However, neither hoof nor pastern temperature returned to baseline within the 120 min post-cold exposure measurement period. Furthermore, although overall average hoof temperature was cooler than the pastern (Fig B.1), when observing across each time point, it can been seen that hoof temperature is not significantly different than pastern at baseline ($P=0.14$) and at 120 min

(*P*=0.30; Fig B.3). Immediately following the exposure to extreme cold (0 min) through 90

minutes, hoof was significantly cooler than pastern in all measurements (*P*=0.0005; Fig B.3).
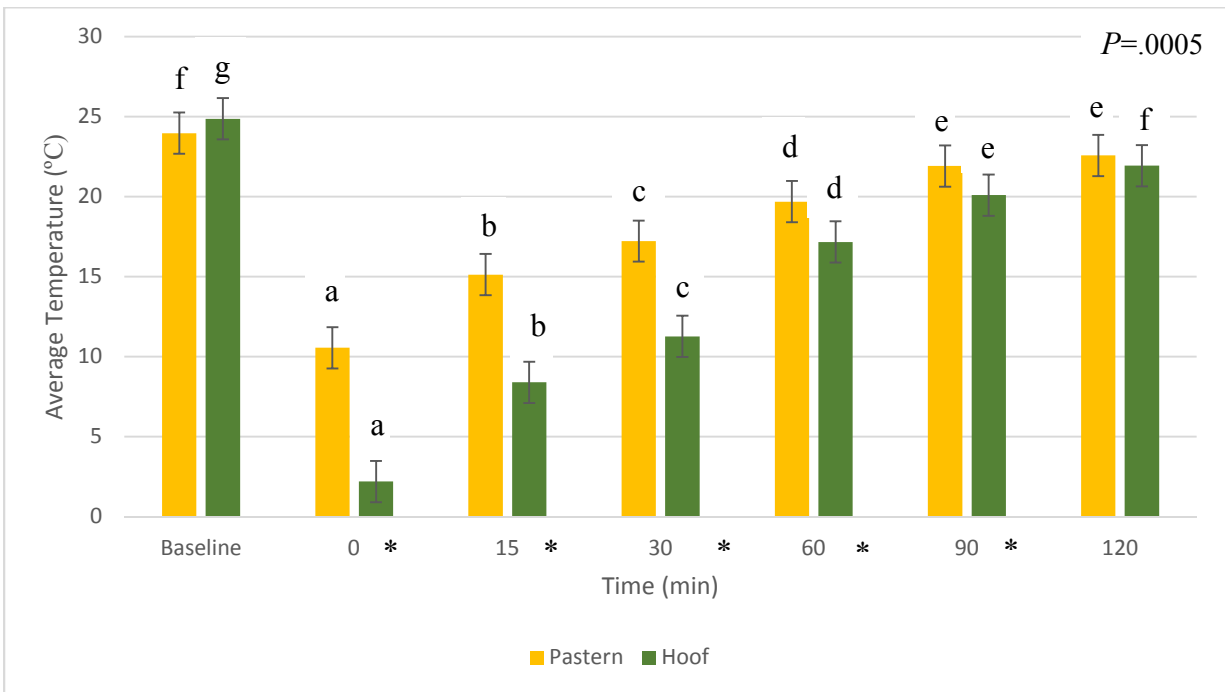
Figure B.3. Average temperature of the pastern and hoof over time following exposure to extreme cold. Columns within part (pastern vs hoof) with differing superscripts differ by *P*<0.05 across time. Time points with asterisks (*) pastern vs hoof differ by *P*<0.05.

When comparing the min, ave, and max temperature of the hoof and pastern areas, all

follow the same trend where both hoof and pastern temperatures significantly decreased from

baseline (*P*<.0001), gradually warming over the two hour sampling period (Fig B.4). However,

overall, time by treatment interaction was not significant in the min temperature (*P*=0.31; Fig

B.4). However, temperature in all categories in both hoof and pastern never reached baseline

(min: hoof *P*<.0001, pastern *P*=0.03; ave: hoof *P*<.0001, pastern *P*=0.01; max: hoof *P*<.0001,

pastern *P*=0.01).
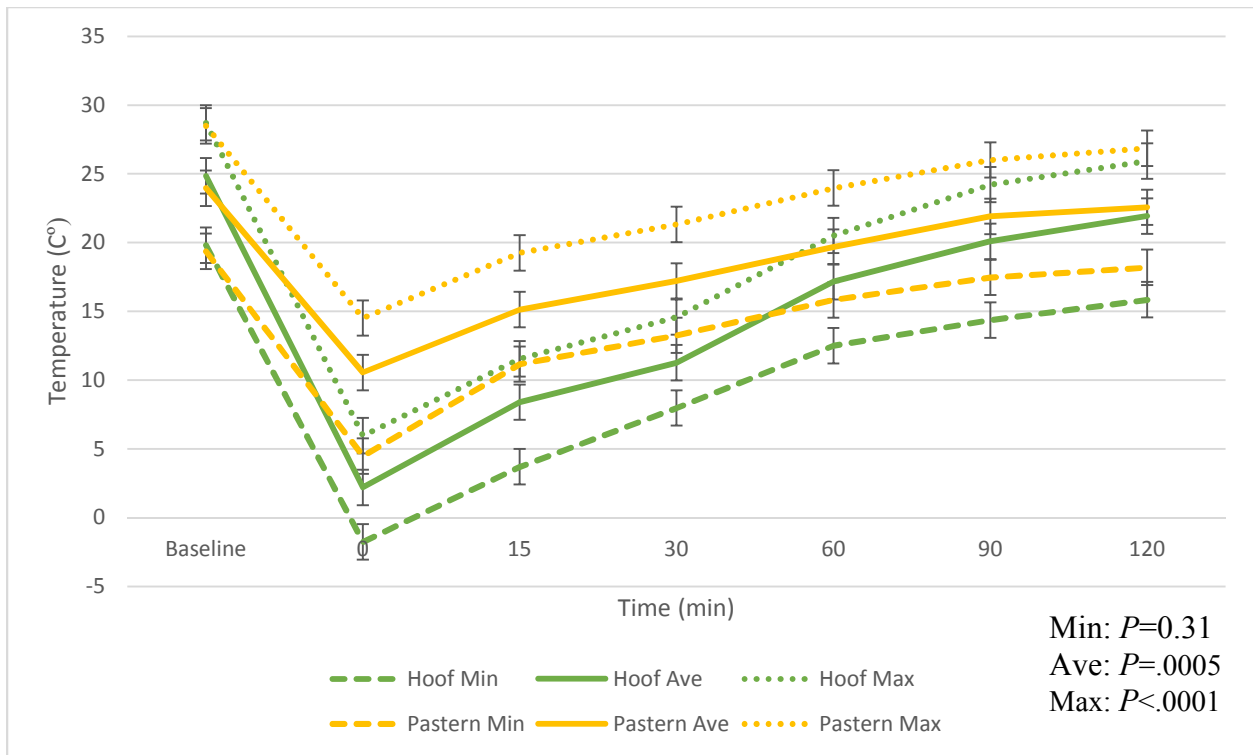
Figure B.4. Min (dashed line), ave (solid line), and max (dotted line) temperature of hoof (green) and pastern (yellow) area at baseline and during the sampling period following exposure to extreme cold.

Literature Cited

Turner TA. Diagnostic Thermography. Vet Clin North Am Equine Pract 2001;17:95-113.

APPENDIX C. RESEARCH IN ANIMAL SCIENCE SYLLABUS

Animal Science 393
Research in Animal Science
1 to 5 credits
Spring 2018

Instructor:

Section	Title	Instructor	Hultz Hall room	Email (@ndsu.edu)
1	Research in Nutrition	Dr. Marc Bauer	155	Marc.Bauer
2	Research in Meat Science	Dr. Eric Berg	100e	Eric.P.Berg
3	Research in Equine Therapy	Dr. Erika Berg	174	Erika.Berg
4	Research in Nutrition	Dr. Joel Caton	185	Joel.Caton
5	Research in Beef Cattle	Dr. Carl Dahlen	160	Carl.Dahlen
6	Research in Disease	Dr. Neil Dyer	195	Neil.Dyer
7	Research in Assisted Reproduction	Dr. Anna Grazul-Bilska	189	Anna.Grazul-Bilska
8	Research in Equine	Dr. Carrie Hammer	100f	Carrie.Hammer
9	Research in Breeding and Genetics	Dr. Lauren Hanna	162	Lauren.Hanna
10	Research in Meat Science	Dr. Rob Maddock	175	Robert.Maddock
11	Research in Muscle Biology	Dr. Kasey Maddock Carlin	187	Kasey.MaddockCarlin
12	Research in Sheep	Dr. Travis Hoffman	193	Travis.W.Hoffman
13	Research in Environmental Stewardship	Dr. Miranda Meehan	191	Miranda.Meehan
14	Research in Epigenetics	Dr. Alison Ward	183	Alison.Ward
15	Research in Reproduction	Dr. Larry Reynolds	209b†	Larry.Reynolds
16	Research in Health and Stewardship	Dr. Gerald Stokka	207c†	Gerald.Stokka
17	Research in Nutrition	Dr. Kendall Swanson	166	Kendall.Swanson
19	Research in Dairy Cattle	Dr. Sarah Wagner	165	Sarah.Wagner
20	Research in Meat Science	Dr. Xin (Rex) Sun	209c†	Xin.Sun

† Morrill Hall

Office hours are by appointment. Please contact the individual instructor.

Course Credits

Credits are earned based on time devoted to the research project. As a guideline, 1 credit hour involves a minimum of 30 hours (e.g., 2 hours weekly for 15 weeks).

Course Description

Supervised research experience outside the college classroom that includes a preplanned assessment of the experience. Students must meet with and attain approval from faculty member before enrolling. Course may be repeated.

Course Objectives

1. Students will learn the application of the scientific method including hypothesis development, experimental design, research methods, data collection and analysis, and interpretation of results.

2. Aid students in making decisions about post-baccalaureate career (e.g., graduate or professional school).

Student Expectations
Students will conduct research under the auspices of an advisor.
Students will read *How to Develop a Research Protocol* (http://interactive.snm.org/docs/how%20to%20develop%20a%20research%20protocol.pdf).
Students will read *What is Ethics in Research & Why is it Important?* (http://www.niehs.nih.gov/research/resources/bioethics/whatis/) – A summary is attached to the syllabus.
Students will watch *Guide to Keeping a Lab Notebook* (http://youtu.be/MgVbXMD-e-w).
Students may be required to take project-specific training (e.g., IACUC, safety, etc.).**Course Outline**
Week 1: Meet with instructor and make a time schedule for the semester. Complete appropriate training as necessary.
Week 2 to 14: Develop and execute the research project. Meet with instructor weekly or as necessary to conduct research, read journal articles, listen to lectures, etc.
Week 15: Complete final activities (e.g., final draft of abstract or paper, presentation).

Final activity: The final activity will be at least one of the following: preparation of a research abstract or paper; a presentation to a club, animal science class like ANSC 150, scientific meeting or forum, or a research group meeting.

Written final activity grading

Metric	Criteria	Value
Journal style	Follow a specified journal's style of formatting, organization, and stylistic choices (e.g., http://www.journalofanimalscience.org/; http://www.journalofdairyscience.org/, http://www.journals.elsevier.com/meat-science/, etc.)	10%
Content	Report, summarize, and interpret information or an idea to an audience with a purpose.	30%
Data presentation	Use data to extend ideas in a way that enhances reader's understanding.	20%
Sources	Use literature to extend, argue with, develop, define, or shape ideas.	20%
Grammar, usage, and mechanics	Errors in constructing sentences, use of inappropriate words, and errors of punctuation.	20%

Oral final activity grading

Metric	Criteria	Value
Abstract	Clearness, conciseness, correctness	10%

Metric	Criteria	Value
Knowledge of Subject	Background, design, statistics, interpretation of results, answering questions	25%
Subject Matter	Pertinence, relation of results to purpose, innovation and quality of science	20%
Organization	Introduction, logical sequence of material, summary, time allocation	15%
Presentation and Personal	Voice, eye contact, grammar, terminology, enthusiasm, motivation of audience, neatness, pleasantness, mannerisms	15%
Visuals	Appropriate number, clarity, use, variety	15%

Laboratory notebook: Your laboratory notebook should contain all observations made during your research experience. Watch what to put in a laboratory notebook: http://youtu.be/MgVbXMD-e-w. The laboratory notebook will be graded based on the following.

Metric	Criteria	Value
Date	Date every page at the top	10%
Pen	Write in pen, not pencil	10%
Legible	Obvious care taken to make it readable, even if you have bad handwriting	10%
Mistakes	Mistakes crossed out with one line and explained	10%
Organized	Table of contents; title of activity on 1st page; clear objectives of activity in notebook; what you were doing when	30%
Informative	All required data and information; descriptive comments of your observations	30%

Evaluation Procedure

Students will be evaluated on the following criteria:

Lab book maintenance   50%
Final activity   50%

Grading Criteria: Students will be assigned letter grades of A, B, C, D, and F based on ≥90, ≥80, ≥70, ≥60 and <60 percent of points earned, respectively.

Attendance: Because research depends on timely and prompt observations, attending to detailed activities of the research protocol is paramount and will significantly affect your lab book maintenance and final activity.

Academic Honesty: All students taking any course in the College of Agriculture, Food Systems, and Natural Resources are under the Honor System (http://www.ag.ndsu.edu/academics/honor-system-1). The Honor System is a system that is governed by the students and operates on the premise that most students are honest and work best when their honesty, and the honesty of others, is not in question. It functions to prevent cheating as well as penalize those who are dishonest. It is the responsibility of the

students to report any violations of the honor pledge to the instructor, honor commission or the Dean of the College of Agriculture, Food Systems, and Natural Resources.

All work in this course must be completed in a manner consistent with NDSU University Senate Policy, Section 335: Code of Academic Responsibility and Conduct (http://www.ndsu.edu/fileadmin/policy/335.pdf).

Students with special requirements: Any students with disabilities or other special needs, who need special accommodations in this course are invited to share these concerns or requests with the instructor as soon as possible. The instructor may ask for verification and that, plus other assistance, can be requested from Disability Services in Wallman Wellness Center (701-231-8463; http://www.ndsu.edu/disabilityservices/).

Veterans and military personnel: Veterans or military personnel with special circumstances or who are activated are encouraged to notify the instructor as early as possible.

Research Ethics
Excerpt from *What is Ethics in Research & Why is it Important?* by David B. Resnik, J.D., Ph.D.
(http://www.niehs.nih.gov/research/resources/bioethics/whatis/)

The following is a … summary of some ethical principles:

Honesty. Strive for honesty in all scientific communications. Honestly report data, results, methods and procedures, and publication status. Do not fabricate, falsify, or misrepresent data. Do not deceive colleagues, granting agencies, or the public.

Objectivity. Strive to avoid bias in experimental design, data analysis, data interpretation, peer review, personnel decisions, grant writing, expert testimony, and other aspects of research where objectivity is expected or required. Avoid or minimize bias or self-deception. Disclose personal or financial interests that may affect research.

Integrity. Keep your promises and agreements; act with sincerity; strive for consistency of thought and action.

Carefulness. Avoid careless errors and negligence; carefully and critically examine your own work and the work of your peers. Keep good records of research activities, such as data collection, research design, and correspondence with agencies or journals.

Openness. Share data, results, ideas, tools, resources. Be open to criticism and new ideas.

Respect for Intellectual Property. Honor patents, copyrights, and other forms of intellectual property. Do not use unpublished data, methods, or results without permission. Give credit where credit is due. Give proper acknowledgement or credit for all contributions to research. Never plagiarize.

Confidentiality. Protect confidential communications, such as papers or grants submitted for publication, personnel records, trade or military secrets, and patient records.

Responsible Publication. Publish in order to advance research and scholarship, not to advance just your own career. Avoid wasteful and duplicative publication.

Responsible Mentoring. Help to educate, mentor, and advise students. Promote their welfare and allow them to make their own decisions.

Respect for colleagues. Respect your colleagues and treat them fairly.

Social Responsibility. Strive to promote social good and prevent or mitigate social harms through research, public education, and advocacy.

Non-Discrimination. Avoid discrimination against colleagues or students on the basis of sex, race, ethnicity, or other factors that are not related to their scientific competence and integrity.

Competence. Maintain and improve your own professional competence and expertise through lifelong education and learning; take steps to promote competence in science as a whole.

Legality. Know and obey relevant laws and institutional and governmental policies.

Animal Care. Show proper respect and care for animals when using them in research. Do not conduct unnecessary or poorly designed animal experiments.

Human Subjects Protection. When conducting research on human subjects, minimize harms and risks and maximize benefits; respect human dignity, privacy, and autonomy; take special precautions with vulnerable populations; and strive to distribute the benefits and burdens of research fairly.
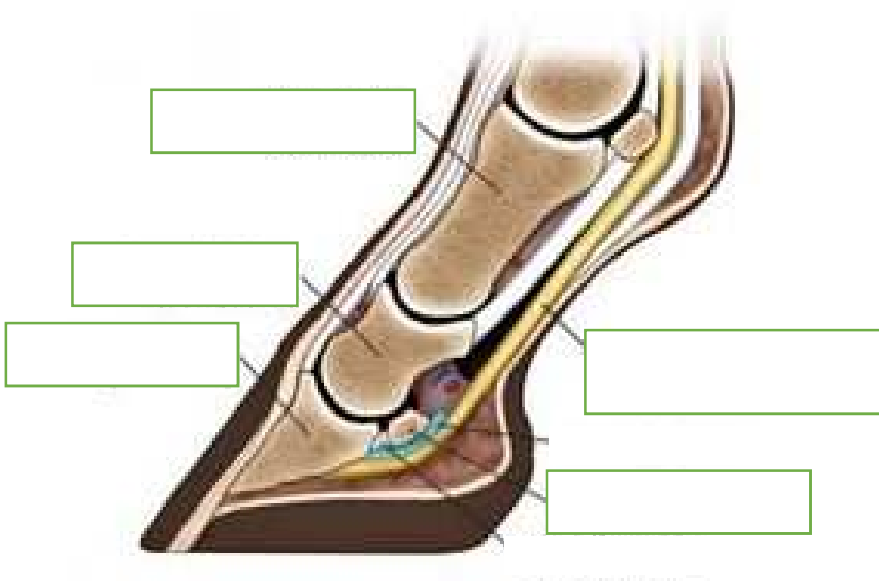
APPENDIX D. PRE-TEST/POST-TEST

Equine Undergraduate Research

Name: _____

1. <u>List</u> 3 distal limb lameness conditions/diseases and briefly <u>describe</u> them?
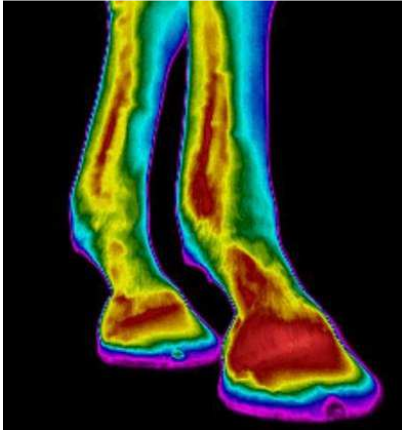
2. Label the internal distal limb anatomy:

3. Why is it necessary that we trim horse's hooves?

4. Where does the hoof grow from?

5. Below is a thermography image of the equine distal limb. What does thermography detect and briefly <u>explain</u> the image?

6. While doing research and taking this course, what is one thing you want to learn this semester?

APPENDIX E. REFLECTION RESPONSES

Structured reflection questions:

5. What is your expectation of research in general? This semester?

   - What past experiences made you draw upon these expectations?

6. What hypothesis do you derive for your project? The other projects?

7. Describe your experience while doing your research project?

   - How do these experiences align with your expectations? Explain.

8. How will your experiences this semester affect your future research experiences?

   - What application could this have? For you? For horse owners? Equine industry professionals?

Example response 1: "I did not have any specific expectations from this semester other than that it would be a lot of work and a lot of hours spent at the barn! I thought this because of the blanket research that was done last year where undergraduates basically lived at the barn. My project did align with these expectations in terms of spending time taking data, but I did not realize how much help we would receive in writing our papers, and that extra help was very beneficial. The biggest takeaway from my research project is the conduction of the project itself. It was incredibly beneficial to do a project start to finish to learn about the proper methods of research. I can now use these skills to apply for more undergraduate research jobs to gain more knowledge. I am excited to take the skills I have learned here and to apply them to more undergraduate research projects in the future!"

Example response 2: "My expectation of research went from expecting answers to expecting more questions. In this project, I had hypothesized that hoof would be warmer initially post-trimming, but would return to base line about an hour after post-trimming. However, instead of

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what I had expected, the hooves continuously got warmer and never did return to base line. I have yet to understand the "why" behind this. Also, I never realized how many research projects are necessary to get a "true" answer. Even then, more often than not only speculations can be drawn due to the many factors that can influence results. This project has shown me how difficult it can be to think about all the factors that could influence your research; it seems there's always something you didn't account for."

Example response 3: "My undergraduate research experiences have altered my future career goals. I went from only wanting to be a large animal veterinarian to wanting to specialize in large animal theriogenology. Now, I realize this project had nothing to do with reproductive medicine, but the overall research experience is what has brought me to alter my career goals. I enjoy the thought process behind research, and I look forward to implementing my own research based on my own ideas. I used to question my ability to even come up with ideas to research, but I have learned that by picking an area of interest and reading research papers in that area can result in some great ideas. I have enjoyed reading the research papers you have provided this semester because it has allowed me to better understand why we did things a certain way in this project. I look forward to applying the knowledge I have gained this semester to my future career goals."

Open ended reflection questions:

5. My experience this semester taught me _____.

   Example response 1: "This project has allowed me to see a project through from nearly start to finish. It has allowed me to practice scientific thinking such as hypothesizing and asking questions. Also, it has allowed me to practice my scientific writing, statistical

analysis, and the work that goes behind not only data collection days, but organizing the data collected."

Example response 2: "My experience in equine research this semester taught me a while new way of conducting research. Having previously only conducted very controlled settings, there was a lot adapting my thinking to fit an equine research project. This experience taught me how to conduct research in a setting that is variable that I don't have much control over. In the lab, everything is performed at the same time under the same conditions whereas equine research is almost impossible to conduct that way. The temperature and weather varied amount the days and individual horses differed in their body composition and activity level. While this seems very different from what I previously did, it makes the most sense when trying to apply the concepts to the general public because almost every horse and facility is different form the other so our research served as a type of average that could be applied."

Example response 3: "My experience this semester taught me a lot about research and the scientific method. Through other classes, they have students memorize the method, but it is must more useful and interesting to walk through those steps physically. I also appreciated the opportunity to write a paper on my own to get a sense of what writing in the sciences should compose of. It is not the most perfect paper, but I feel that now I at least have a general idea of how to write for research."

6. My previous knowledge was transformed because _____.

Example response 1: "My previous knowledge wasn't necessarily transformed but enhanced by having my own project from start to finish vs. jumping in on an already started project. I better understand the time commitment that research entails, as well as,

the amount of critical thinking that is necessary for a successful project. I learned that you must be continuously thinking about factors that could skew the data in order to perform the most accurate project."

Example response 2: "My previous knowledge was transformed because I had learned a completely new way to conduct and analyze research. Everything needs to be figured out in advance and there is not always a chance that it can be repeated in the case that an error occurs. If an error would occur in the microbiology lab, it can be repeated in another way at a separate time under similar conditions."

7. The biggest take away message from my research experience is _____.

Example response 1: "Overall, my biggest take away is that research doesn't necessarily provide you with answers. Often times it requires further research for answers and tends to leave you with more questions than answers. You may not get answers, but the questions provide for more ideas that could be further researched. It seems that research is an unending circle of "why's" and "how's"."

Example response 2: "The biggest takeaway from my research project is the conduction of the project itself. It was incredibly beneficial to do a project start to finish to learn about the proper methods of research. I can now use these skills to apply for more undergraduate research jobs to gain more knowledge."

8. I can use what I learned throughout the semester to _____.

Example response 1: "Prior to participating in undergraduate research, I had thought this would be great to put on a vet school application. However, after becoming more involved with undergraduate research, I have come to realize how much I enjoy it. This project along with others that I have assisted with have expanded my career goals from

just wanting to become a veterinarian to wanting to become a veterinarian specialized in

theriogenology and have research focused on reproductive medicine."

Example response 2: "My experience this semester will help me with future research

experiences in that I will be able to adapt my thinking to work in multiple ways. This has

helped me plan ahead and try to take everything into consideration prior to starting the

research project."