Efficacy of Wearable Therapies on the Ability to Improve Performance and Physical Health in Sport Horses

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Scholarly Abstract

Equines have been used for utilized for manual labor, recreation, and companionship amongst many other valuable conveniences since their domestication. As the modern horse progressed from livestock to athlete, attention was paid to the body conformation to be used as an indicator of biomechanics and can dictate equine performance. Poor conformation can put physical limitations on the body and predispose the horse to injury and chronic disease. When not managed properly, these flaws can lead to injury, lameness, and premature retirement in sport horses. The distal limb is composed of tendons and ligaments that are all susceptible to tear or rupture. Protective wraps or boots are typically applied to the distal limb prior to exercise to prevent superficial injury from the environment or interference. However, these preventatives can trap heat against the skin which can have detrimental effects on the fibroblasts which can lead to failure. It was not until the early twentieth century that the idea of equine physiotherapy was adopted, and practices changed to meet remedial needs and create a sustainable, healthy equine athlete.

Equine physiotherapy is a broad-spectrum term used to describe the therapeutic efforts made to keep the body in good health by means of prevention of injury to improve or maintain performance. Traditionally, therapeutics are administered by a veterinarian or trained professional in the event of an existing injury. In recent years therapeutics have been commercialized and are readily available for everyday preventative use. The most common readily available treatments being variations of pulsating electromagnetic fields (PEMF), vibration therapy, cryotherapy, and thermotherapy. When used prior to or after exercise, the therapeutics are designed to prepare the body for exercise and improve recovery by increasing circulation and down regulating the inflammatory response.

The studies performed evaluate the efficacy of Rambo®Ionic (Horseware, Dundalk,Ireland), Lux Ceramic Therapy® (Schneider Saddlery Co., Inc., Ohio, USA), and Ice-Vibe® (Horseware, Dundalk,Ireland) therapeutic boots when applied to the distal limb as per

manufacturer recommendation. The first study evaluated the therapeutic boots ability to alter performance performing gait analysis using the ALOGO™ MovePro (Alogo Technologies, Switzerland) stride sensor, blood analysis measuring serum concentrations of C reactive protein (CRP), basic fibroblast growth factor (bFGF) and tenascin-C (TN-C), and capturing thermal images of the distal limb using an HT-19 thermal imaging camera (HTI, La Vergne, TN). In this study, eight healthy horses were exercised for approximately ten minutes per day for five consecutive days. There was a ten-day washout period where the horse received no treatment between each period; there was a total of four periods. The second study only evaluated Rambo®Ionic (Horseware, Dundalk,Ireland) and Ice-Vibe® (Horseware, Dundalk,Ireland) therapeutic boots on seventeen healthy horses in the Virginia Tech equitation lesson program. There were three periods with five days of consecutive data collection and a ten-day washout period in between where the horses received no treatment. Gait analysis was measured using the ALOGO™ MovePro (Alogo Technologies, Switzerland) stride sensor and a blind behavioral analysis was performed to analyze behavioral changes under saddle in response to a rider.

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General Audience Abstract

Equines have been used for utilized for manual labor, recreation, and companionship amongst many other valuable conveniences since their domestication. As the modern horse progressed from livestock to athlete, attention was paid to the structure of the horse, otherwise known as conformation. Conformation is an indicator of physical movement and can dictate what uses the horse is best suited for. In undesirable cases, poor conformation can put physical limitations on the body and predispose the horse to injury and chronic disease. When not managed properly, these flaws can lead to injury, lameness, and premature retirement in sport horses. The distal limb is a particularly vulnerable structure. It is free of muscle and is comprised of tendons, ligaments, and mobile joints. A protective wrap or boot is typically applied to the distal limb prior to exercise which can have detrimental effects on the cellular components of the associated structures which can lead to failure. It was not until the early twentieth century that the idea of equine physiotherapy was adopted, and practices changed to meet remedial needs and create a sustainable, healthy equine athlete.

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List of Abbreviations

AAEP – American Association of Equine Practitioners

ACh – Acetylcholine

ATP – Adenosine Triphosphate

BEMER – Bio Electro-Magnetic Energy Regulation

bFGF – Basic Fibroblast Growth Factor

BPM – Beats per Minute

BT – Body Temperature

CD – Centrodistal

COX – Cyclooxygenase Inhibitor

CV – Canter Velocity

CYP – Cytochrome P450

DDFT – Deep Digital Flexor Tendon

DIP – Distal Interphalangeal Joint

DSLD – Degenerative Suspensory Ligament Desmitis

EPM – Equine Protozoal Myeloencephalitis

EWST – Extracorporeal Shockwave Therapy

FLU – Flunixin Meglumine

HA – Hyaluronic Acid

HJH – High Jump Height

HR – Heart Rate

HRV – Heart Rate Variability

IACUC – Institutional Animal Care and Review Committee

IL – Interleukin

IM – Intramuscular

IRAP – Interleukin-1 Receptor Antagonist Protein

JV – Jump Velocity

KTP – Ketoprotein

LatB – Lateral Balance

LonB – Longitudinal Balance

LCN – Lacunar-Canicular Network

LJH – Low Jump Height

LLLT – Low Level Laser Therapy

MCP – Metacarpophalangeal Joint

MPM – Meters per Minute

MTP – Metatarsophalangeal Joint

NSAID – Non-Steroidal Antiinflammatory Drug

OA – Osteoarthritis

PBZ – Phenylbutazone

PD – Palmar digital

PEMF – Pulsating Electromagnetic Fields

PIP – Proximal Interphalangeal Joint

PRP – Platelet Rich Plasma

PSGAG – Polysulfated Glycosaminoglycans

RR – Respiration Rate

SDFT – Superficial Digital Flexor Tendon

SL – Suspensory Ligament

TN-C – Tenascin C

TNF – Tumor Necrosis Factor

TMT – Tarsometatarsal Joint

TSP – Trot Strike Power

Chapter 1 Literature Review

Introduction

Maintaining optimal equine performance requires ensuring that a horse is healthy and free from pain and discomfort. Lameness, a structural disorder that hinders the function of the body to varying degrees, decreases the body's ability to produce symmetrical, sound movement, and thereby jeopardizes equine performance. The term 'lame' originates from the Latin term *lama,* originally meaning 'crippled' before acquiring other definitions such as 'weak', 'broken', or 'disabled by disease' (Baxter et al., 2020; Douglas). Lameness is prominent amongst sport horses and accounts for the greatest financial loss in the equine industry, appreciating hundreds of millions of dollars annually (Doug Thal, 2016). Over two-million horses in the United States are involved in recreational activities putting them at higher risk for injury and dis-ease compared to those kept as companions (Mesa, 2007). Although conformation has much to do with the performance and athletic capabilities of the horse, attention to proper use and care of the horse must be prioritized to mitigate the chances of trauma or disease resulting in lameness. The use of therapeutic technologies for such mitigation is not a foreign concept in the equine industry, but as these therapies become more accessible to equestrians, guidance on appropriate and ideal use may help optimize the use of therapeutic technologies to minimize instances of lameness within sport horses.

Anatomy and Physiology

The anatomy of the horse refers to its physical structure and represents the basis for the animal's functionality. Different anatomical systems work together and the compatibility of these systems is a determining factor of the horses' physical capabilities. The musculoskeletal, respiratory, circulatory, endocrine, and immune systems are systems necessary for the performance and dictate the horse's athletic ability as well as its health or longevity.

Musculoskeletal System

The equine musculoskeletal system is designed in such a way to sustain the horse's movement in leisure and recreation. It is comprised of bones, muscles, joints, tendons, and ligaments which all work together to create locomotion.

The skeleton is the beginning of the structural outline of the body and is made up of over two hundred bones. The equine skeleton contains long, short, flat, irregular, and sesamoid bones.

Bone marrow is located in the innermost part of the bone and is the storage unit for the body's stem cells. Differentiated stem cells make up the contents of the blood by developing into red blood cells, white blood cells, and platelets. The bone marrow cavity is enclosed by porous cancellous tissue and cortical tissue. Cancellous tissue has a spongey appearance due to the meshwork created by fibers known as trabeculae. Cortical tissue, also referred to as compact bone, is the hardened surface of the bone and acts as a calcium reservoir for the body (Stephan B. Adams, 2019; Wakim & Grewal, 2021b). Bone is a malleable structure that continuously replaces old bone with new bone which can change the shape and density in response to environmental forces, this is known as a process called remodeling (Dittmer, 2019; Stephan B. Adams, 2019). Each bone is encased in a membrane, the periosteum, which is responsible for generating new bone tissue. Mechanostat theory suggests that due to the bone's ability to adapt to strain and loading, horses need to be exposed to a small degree of strenuous exercise at a young age while the bones are still maturing. Osteoblasts and osteoclasts are cells responsible for developing new bone tissue and breaking down old bone tissue. Osteoblasts develop into osteocytes that regulate bone formation. Osteocytes have dendritic projections which form the intercellular communicative pathway for bone: the lacunar-canicular network (LCN). Strain is recognized by the LCN and is responsible for making changes to the structure of the bone according to where remodeling is needed most (Dittmer, 2019).

Joints are found between bones and allow for localized movement. Ball-and-socket and hinge joints allow for the most movement and are typically found in the proximal and distal limbs of the horse. Pivot and fixed joints offer the least amount of movement. Pivot joints can be found between vertebrae and allow for minimal rotational movement. Fixed joints provide no movement and can be found between facial bones. Joints can further be categorized as fibrous, cartilaginous, and synovial. Fibrous joints make up fixed joints and do not have a joint cavity. Cartilaginous joints attach to bones via hyaline cartilage or fibrocartilage. Synovial joints are the most functional joints found in the body. Fibrous connective tissue creates the articular capsule and attaches to each adjacent bone's epiphysis (Juneja et al., 2021). Lining the inside of the articular capsule is the synovium, which secretes synovial fluid, a clear, viscous fluid that lubricates the joint. These structures mitigate friction between bones and absorb shock.

Muscle tissue is found across various systems, generates movement of the skeletal system, and maintains posture in the body. It is host to nerve cells, blood vessels, and is a place for energy storage. Skeletal muscles are locomotor muscles located proximally to the skeleton and function under voluntary control to produce movement (Valberg, 2014). Smooth and cardiac muscles move involuntarily where one is found in the lining of organs and blood vessels and the latter is unique to the heart. Skeletal muscles have a striated appearance created by myofibrils bundled together to form sarcomeres, the contractile unit of the muscle (Dave et al., 2021). Equine skeletal muscle contains type I and type II fibers. Type I fibers have low myosin ATPase activity, making them slow-twitch fibers which are more resistant to fatigue, and are abundant in endurance horses (Debra A. Hembroff; Valberg, 2014). Type II fibers have high myosin ATPase activity, therefore classifying them as a fast-twitch fiber prone to fatigue, making them ideal for a short-distance sprinting horse. Type II fibers can be further distinguished as subtypes IIA, IIB, and IIC. Subtype IIA is an intermediate high-glycolytic, high-oxidative fiber whereas subtype IIB is a high-glycolytic but low-oxidative fiber (Debra A. Hembroff). Subtype IIC are typically found in very young horses but can be recruited by subtype IIA fibers in the mature horse if an injury occurs and fibril regeneration is needed (Debra A. Hembroff; Valberg, 2014). Each sarcomere contains a series of two myofilaments that slide and shorten to create a contraction: actin and myosin. Skeletal muscles can be extensors or flexors depending on the motion they create. An intrinsic excitation-contraction coupling process takes place to create movement in the muscle (Dave et al., 2021). Muscular innervation takes place at the neuromuscular junction. Neuromuscular junctions create a communication pathway between the brain and muscle and are comprised of sensory and motor nerve fibers. To activate this communication channel, an action potential is generated and travels to the neuromuscular junction where acetylcholine (ACh) is released from the synaptic vesicle. Muscle contraction occurs when sodium channels open and ACh along with sodium ions diffuse across the synaptic cleft to bind with muscle fiber receptors. This process depolarizes the sarcolemma and the action potential travels through the T-tubules where it can go deeper into the muscle fiber. The action potential reaches the sarcoplasmic reticulum, causing calcium channels to open, releasing calcium ions that cause the actin and myosin to contract once it has reached the sarcoplasm (Wakim & Grewal, 2021a). A working muscle relies on the phosphagen system, glycogen-lactate system, and aerobic or anaerobic metabolism to produce the energy needed for contraction. The release of phosphate is needed to produce ATP and can be done via the phosphagen system or creatine phosphate. This generally occurs while the muscle is working aerobically. Aerobic metabolism creates energy by oxidizing nutrients to produce ATP and is sustainable if the cells have continuous access to oxygen. When in need of extra energy, the muscle relies on anaerobic metabolism. The glycogen-lactate system breaks down stored sugars in the form of glycogen to ATP and pyruvic acid. Pyruvic acid metabolizes into lactic acid and can sustain the muscle for a short amount of time before it needs oxygen again (Stacey Oke, 2021).

The fascial system is body-wide and is necessary for holding tissues and organs in place as well as being a communicative system (Lusi & Davies, 2018). Fascia has two main fiber types: elastin and collagen. Elastin is made up of microfibrils that can stretch to 150% of their original size. Collagen fibers respond to strain with tension, only allowing them to stretch by approximately 10%. With collagen interwoven between elastin fibers, the fascia prevents overstretching that could result in tear or rupture. When strained there is an abundance of fibroblasts present to synthesize elastin and collagen along with other molecules. The synthesis of fibers allows for changes in the structure of the cytoskeleton and overall rearrangement of the molecular structure of the fascia. Fascia can be categorized into fascia superficialis (superficial) and fascia profunda (deep) due to their location in the body and structure. Superficial fascia can be found just under the dermal layer while deep fascia can be found between muscles, around blood vessels, and supports tendons and ligaments (Lusi & Davies, 2018).

Tendons and ligaments are supportive structures made mostly type I collagen fibers and are encased by loose connective tissue (Zschäbitz, 2005). Each respond to physical activity and prevents hyperextension. These structures are made from bundles of collagen and myofibrils called fibroblasts and contribute to the fascicle. Fascicles have a crimped texture to provide elasticity which supports excess stress and strain (*Structure and Function of Ligaments and Tendons*). Tendons attach to the muscles and create the movement of the skeleton by also attaching to bone. When a muscle contracts, it pulls the tendon with it allowing the bone to follow in that direction. Ligaments form attachments between two bones and have a slightly lower collagen volume than tendons (*Structure and Function of Ligaments and Tendons*). Ligaments can be in higher concentrations around joints for stability and in the distal limb. These collagenous structures are unique for their viscoelasticity meaning they contain both viscous and elastic properties. Tendons and ligaments will creep, or experience slow continuous strain over time, due to slow continuous stress over time or stress relaxation when subject to constant strain (Sopakayang, 2010). This gradual degradation makes them vulnerable to injury over time.

<u>The Distal Limb</u>

The distal limb is defined as the anatomical structures of the leg from the knee and hock down (*Distal Limb Bones: Lower Leg Bones*). Distal limbs are under the control of muscle located in the proximal limb but only contain tendons, ligaments, bones, blood vessels, and nerves. The bones in the knee and hock are connected by pivot joints that restrict immense amounts of movement (Stephan B. Adams, 2019). Further down the limb, there are synovial fetlock joints that absorb the strides' concussive forces.

The distal forelimb is highly specialized to support immense loading from the horse. It begins with the carpus, or knee, and includes eight individual carpals that are connected via pivot joints. Below the carpus are the second, third, and fourth metacarpals. The third metacarpal is the largest, extends down to the fetlock joint, and is commonly referred to as the cannon bone. The second and fourth metacarpals, known as splint bones, are located on the medial and lateral sides of the cannon bone where they are held in place by the interosseus ligament (*Splint Bones*). The fetlock joint is made up of the articulations between the cannon bone, both sesamoid bones, and the proximal phalanx. These articulations are held in place by the collateral metacarpophalangeal (MCP) and metacarposeasmoidean ligaments. Below the proximal phalanx is the middle and distal phalanx which make up the lower part of the pastern and hoof (Lusi & Davies, 2018). The fetlock joint is constantly in a passive state and restricts hyperextension of the passive support apparatus which includes the interosseous ligament, seasmoidian ligament, and digital flexor tendon (Lusi & Davies, 2018). Also included in preventing hyperextension of the fetlock is the suspensory and passive stay apparatus. The suspensory apparatus includes the suspensory ligament (SL), which branches under the fetlock, collateral, palmar, and distal sesamoidean ligaments. Flexor tendons are positioned on the palmar side of the limb and are responsible for the storage and release of strain as well as the flexion of the fetlock joint and hoof. The superficial digital flexor tendon (SDFT) is an extension of the superficial digital flexor muscle and fuses with the proximal check ligament. Moving distally down the limb, the deep digital flexor tendon (DDFT) is an extension of the deep digital flexor muscle and becomes prominent at the level of the fetlock. The extensor tendons work opposite the flexor tendons to allow for the extension of the distal limb. The lateral digital extensor tendon connects to the lateral digital extensor muscle and inserts into the dorsolateral aspect of the proximal phalanx (Lusi & Davies, 2018).

The anatomy and physiology of the distal hind limb is very similar to that of the forelimb. The tarsus is the joint known as the hock and is comprised of six tarsals (Head & Barr, 2012). Articulated with the tarsals are the second, third, and fourth metatarsals. Just like in the forelimb, the third metatarsal is the largest and is also referred to as the cannon bone. The second and fourth metatarsals are also fused via the interosseous ligament. The hind limbs also have sesamoid bones, proximal, medial, and distal phalanx bones. These structures receive the same ligamentous and tendonous support as the ones in the forelimb do but are under significantly less pressure.

Circulatory System

The body is reliant on the circulatory system for the transport of blood, oxygen, nutrients, and immune cells as well as eliminating toxins. The heart and spleen are the two main organs associated with the circulatory system and are assisted by a network of veins, arteries, and capillaries. Components and measurements of the circulatory system are accurate representations of health and can be used to determine illness along with other changes in the body (DACVIM, 2017). The size of the heart can account for nearly 1% of the horse's total body weight and has about 40 liters of blood in circulation at all times (DACVIM, 2017).

The equine heart and human heart are very similar. Each has four chambers, two atria, two ventricles, and four valves. Oxygen-depleted blood enters through the superior vena cava into the right atrium. A series of involuntary muscular contractions push the blood through the tricuspid valve, into the right ventricle, through the pulmonic valve, and out the pulmonary artery where oxygen is diffused into the capillaries in the alveoli of the lung. Oxygenated blood enters through the pulmonary veins and into the left atrium. It is pushed through the mitral valve into the left ventricle and exits the heart through the aorta. The oxygenated blood travels throughout the body supplying oxygen and nutrients to all the organs. Arteries carry blood away from the heart and offload nutrients at capillary beds. Simultaneously, toxins and carbon dioxide are then retrieved and are carried by the veins back to the heart. Even though veins are carrying molecules that the body is trying to get rid of, they also pick up digested nutrients from the small intestine and carry these nutrients and waste products from the body tissues through the liver and kidneys for detoxification, leaving only beneficial nutrients in circulation. Horses have a resting heart rate between 28 and 44 beats per minute (bpm) and it increases exponentially during exercise averaging 80 bpm at the walk, 130 bpm at the trot, 180 bpm at the canter, and nearly

240 bpm at the gallop (DACVIM, 2017). Heart rate also tends to increase with stress, pain, dehydration, and many other factors.

The spleen is vital for maintaining the integrity of the horse's immune system and storing red blood cells. The spleen filters the blood and removes abnormal red and white blood cells from circulation. In a relaxed state, the spleen expands and can accommodate approximately thirty liters of blood (DACVIM, 2017). When experiencing metabolic stress during physical activity, the spleen contracts to replenish the body with red blood cells which will allow for significantly more oxygen transport to the muscles for use as energy.

Blood is the mixture of many different types of cells that travel through veins and arteries to be redirected by the heart. Red blood cells make up 30 to 40% of blood and contain a protein called hemoglobin that allows oxygen to bind for transportation to or away from various tissues. White blood cells, also known as leukocytes, make up a very small percentage of blood but are necessary for creating a protective immune system. Monocytes, lymphocytes, neutrophils, basophils, and eosinophils are all types of white blood cells that provide different means of defense against disease or infection. These cells set off warnings, create antibodies, destroy, and devour any invading cells (RN et al.). A high white blood cell count is indicative of illness and increased immune response. Platelets are other specialized cells that aid in the clotting response. They are created and released from the bone marrow and begin the scabbing process when damage is inflicted on a blood vessel. Plasma is the matrix of the blood which contains red and white blood cells, platelets, and other molecules that are transported through the blood like proteins, electrolytes, hormones, and nutrients (DACVIM, 2017).

Equine Conformation and Biomechanics

Conformation is the visual assessment of a horse's physical appearance as determined by bone and muscle structure (Baxter et al., 2020). It can predispose a horse to injury and can also be used to determine what type of discipline the horse is best suited for. Conformation varies between breeds and each breed has different concepts of ideal conformation, making it a very subjective assessment. Conformation differences in horses have been brought about largely throughout selective breeding, which began shortly following the domestication of the horse. Through early selective breeding, individuals bred for physically observable attributes thought to reflect the ideal horse that best suited their needs for farm work or transportation. The Greek philosopher Xenophon (430 – 354 BC) recognized the importance of equine conformation and was the first to write about desirable and undesirable conformational traits in his treatise, *De re equestri* (Weeren & Crevier-Denoix, 2006). Today horses can be divided into five categories due to their different conformational standards: Draft, Warmblood, Light, Gaited, and Pony (*5 Major Types of Horses Defined*; Baxter et al., 2020).

Evaluating Conformation

When visually assessing the horse, the body should be divided into four groups to allow for a more thorough evaluation as seen in Figure 0.1: head and neck, forelimbs, trunk, and hind limbs (Baxter et al., 2020). A balanced horse is equally sized between the front end, trunk, and hind end with withers that are in line with or are slightly taller than the croup as well as have a body that is just as tall as it is long.

It is important to evaluate these segments individually as well. A horse with a large head and a long neck will balance more weight on its front end than hind. Naturally, horses balance around 60% of their body weight on their front end and the other 40% on their hind end. The horse that has more body mass in front will put more strain on the front limb anatomy which can lead to faster wear and degradation. To minimize undue strain, the shoulder and hip should be of equal size and have congruent sloping angles that are not too steep or too shallow (Gregory, 2014). For example, a steep shoulder angle will create much more knee locomotion with a short, choppy stride compared to a shallow shoulder angle that will have a long stride with very little movement in the knee. The same concept applies to the angle of the hip. In most cases, a short back is more ideal than a long back due to the large distances between vertebrae creating weakness (Weeren & Crevier-Denoix, 2006). The limbs can be assessed both visually and physically via palpation. Front limbs should be straight and vertically aligned with the shoulders with flat knees and no twist in the cannon bones (Committee). Long sloping pasterns are important for the absorption of concussive forces. Hind legs should be able to form a straight line from the point of the buttock down to the hock and fetlock joint (Committee). Legs that deviate from healthy conformation risk injury by interference during the stride and applying uneven pressure to the tendons, ligaments, and joints that support the distal limb.

Conformational Flaws

Conformational flaws increase the horse's risk of injury and are capable of negatively impacting performance. Conformation is heavily influenced by genetics, sex, breed, and age. Although sex, age, and even breed are rather uncontrollable variables, selective breeding plays a big role in genetics and the next generation of sport horses. Each breed has its defining traits, and over the decades those traits have been so heavily sought after that other, potentially negative, aspects of conformation were disregarded.

Conformational flaws in the forelimbs can be determined at the level of the shoulder, elbow, and carpus. When viewed from the side, the horse should have a straight leg from shoulder to carpus to ground with the dorsal half being in front of the plumb line and the palmar half being behind the plumb line. A horse with legs that slope in front of the plumb line is considered behind the knee, whereas a horse with a leg that slopes behind the plumb line is considered over at the knee and will experience suspensory ligament strain. At the level of the carpus, conformational flaws could include buck kneed and calf kneed (Gregory, 2014). A buck kneed horse is one where the knee is set too far forward compared to the rest of the leg. Conversely, a calf kneed horse has the knee is hyperextended and set too far back. This puts strain on the carpus and can hinder gait quality. When viewing a horse from the front they can be bow-legged, knock-kneed, base-wide, or base narrow (Gregory, 2014). A bow-legged horse has knees that are farther in distance than the hooves and elbows to their respective counterparts and applies more strain on the lateral aspects of the leg. Knock-kneed horses have knees that move in towards each other, putting more strain on the medial aspects of the leg. Base wide horses stand with their hooves farther apart than their elbows whereas base narrow horses stand with their hooves too close together. Base wide and base narrow horses both are at higher risk for injuries in the SL and distal seasmoidean ligaments (Boswell et al., 2011). These account for uneven weight distribution which can impact the distal limb. The pasterns are susceptible to flaws as well. Pasterns can be too upright or too sloping and can swing in, pigeon-toed, or swing out, splay footed (Gregory, 2014). These deformations predispose the horse to proximal interphalangeal (PIP) and MCP joint discomfort (Boswell et al., 2011).

Hind limb conformational flaws can be very similar to those found in the front limb. Viewing the horse from the side, the plumb line should be straight from the point of the buttocks, to the hock, and down the back of the metatarsals to the ground (Gregory, 2014). Diverging from ideal conformation, the hind legs can either be parked-out or parked under. A parked-out horse will stand with its legs out behind them. This can create strain in the back and would be most severe for horses with long backs. Parked under horses stand with their legs too far under their body creating strain on the back of the limb to maintain balance. Other abnormalities include post-legged and sickle-hocked (Gregory, 2014). Post-legged horses have a very large angle in their hock, so much so that it appears straight. This makes it harder for the horse to bend their hocks and cover ground during a stride while also putting a heavy strain on the stifle joint and hock (Sellnow, 2006). This deformity creates significant SL strain and hock pain (Boswell et al., 2011). Sickle-hocked horses have a smaller angle in their hocks and generally weaker hind limbs. More strain is applied to the plantar aspect of the tarsus, centrodistal, and tarsometatarsal joints (Boswell et al., 2011; Sellnow, 2006). Bow-hocked horses have hocks that point away from each other, placing strain on the tarsus joint (Sellnow, 2006). Cow-hocked horses have hocks turn in, or point towards each other (Gregory, 2014). This creates more strain on the medial aspect of the leg.

Consistent use and age are very common factors that contribute to alterations in conformation over the horse's life span. A young horse with existing conformational flaws will experience increased mechanical weakness or loss of energy-absorbing properties over time due to abnormal loading and the disruption of cellular activity (Gregory, 2014). A foal may not experience the complications associated with their conformational defects because of the high regenerative capacity they possess, but that slows down over time and eventually the horse will run into more complications as the it matures. The age of physical maturity of a horse varies from breed to breed and conformational defects that are seen in a young horse may become less extreme as the horse matures.

It is challenging to quantify the relationship between age, conformation, and performance because as the horse undergoes training it learns to perform in such a way that is appropriate for that discipline. Because of this, there is a weak correlation between conformation and performance (Gregory, 2014). Some conformational defects work to the rider's advantage in certain disciplines and have been included as a part of selective breeding. For example, thoroughbreds have been selectively bred to have high-speed locomotion, but the structural stability of the tissue is sacrificed (Gregory, 2014). Also, some distal limb conformation can be altered with corrective shoeing and trimming to prevent it from impacting performance.

Gait Analysis

The average horse exhibits four natural gaits: walk, trot, canter, and gallop. Each gait varies in speed, footfall, and symmetry. A symmetrical gait is one where the stride pattern is the same on each side of the horse whereas an asymmetrical gait follows no pattern. Symmetrical gaits include the walk and trot, and asymmetrical gaits include the canter and gallop. Within each gait, strides account for steps. The stride is made up of a swing and a stance phase. The swing phase is the time when the limb is making no contact with the ground and the stance phase is the time when the limb is on the ground and is weight loading. The stance phase can further be broken down into impact when the hoof first makes contact with the ground and break over when the hoof leaves the ground. The limbs should be able to move equally, meaning they can cover the same amount of ground for each step.

The walk is a slow four-beat gait. Only one limb is in the swing phase at a time and the limb diagonal is bearing the most weight. The horse creates the walk using the swaying motion of the head and neck which occurs in rhythm with the motion of the body and limbs.

The trot is an up and down two-beat gait that lacks head and neck movement characteristic to what is seen at the walk. The limbs move in diagonal pairs; when a limb is in the swing phase, the front limb diagonal to it is also in the swing phase and weight is evenly distributed amongst the limbs in the stance phase. The trot is the most recognizable gait for lameness due to its symmetry and even weight distribution.

The canter is a rocking three-beat gait. Unlike the symmetrical walk and trot, the canter has a moment of suspension where no hoof is in contact with the ground. At times there is a diagonal pair on the ground that is supporting the bodyweight of the horse whereas in other phases of the stride all weight is balanced on one of the forelimbs. Footfall is dependent on the lead that the horse is on. Leads can either be left or right and it is indicative of which front leg is the last to leave the ground and is stretching the farthest.

The gallop is a one-beat gait that also has a moment of suspension like the canter. Instead of there being a diagonal pair on the ground, only one limb is in the stance phase at a time. The footfall of the gallop is also indicative of what lead the horse is on.

Lameness in the Equine Industry

Equine lameness can be described as gate abnormalities presented in any environment in response to pain or mechanical restriction (Doug Thal, 2016). Abnormalities in the horse's gate can be due to a variety of reasons such as trauma, disease, poor conformation, or pathological disturbances and disorders (Baxter et al., 2020). Although there may appear to be a gate abnormality, it does not always mean the horse is experiencing pain or discomfort. These lameness's are referred to as mechanical lameness because of neurological dysfunction. Lameness is classified as a clinical sign rather than a disease indicating that it presents itself due to an underlying problem (Baxter et al., 2020).

Types and Causes of Lameness

Soundness is the absence of lameness and can be recognized in a horse that moves symmetrically and with an even magnitude of movement from the limbs and body. To have a horse that is truly lame, they must have irregular asymmetry in both limb movement and weight loading. A horse that presents with an asymmetrical limb movement, but regular weight loading could have a conformational defect that is the cause of the irregularity. Horses can be predisposed to lameness due to a multitude of reasons including premature training, orthopedic disease, poor conformation, trauma, and improper conditioning to name a few (Stephan B. Adams, 2015).

Degenerative diseases cause chronic lameness issues in the horse. They can begin at any age and will continue to progress throughout the horse's life. Osteoarthritis (OA) is one of the most common degenerative joint diseases and occurs when the articular cartilage begins to degenerate due to inflammation in the joint. This can be due to consistent excessive loading to the joint or infection (Boswell et al., 2011). OA restricts the natural locomotion of the joint making movement uncomfortable. A horse might not always present as lame unless progressive changes have occurred or more strain was recently experienced than normal, but the gait does tend to be stiff due to decreased motion in the joints. Degenerative suspensory ligament desmitis (DSLD) is a detrimental, progressive disorder found in older horses and is characterized by low and swollen fetlocks (DVM). Other than genetic predisposition, the exact cause is still up for debate but research allows many veterinarians to believe it is the result of improper healing of "microtraumas" that occurred over time and went unnoticed (DVM). Disorders like DSLD may present with mild lameness during extension of the fetlock and can be diagnosed via ultrasound. The branches of the suspensory ligament may appear enlarged, have torn collagen fibers, irregular fiber patterns, and occasionally calcification is present within the ligament (DVM).

Lameness resulting from injury typically influences the musculoskeletal system and can be due to improper strain from poor conformation, overloading, or trauma to the body (Staff, 2017). When an injury occurs such as a torn tendon, ligament, or bone fracture inflammatory modulators are released from a multitude of cells to protect and heal the area. This is the cause for swelling resulting in tenderness and reluctance to put weight on that limb. The most common structures in the distal limb to be affected by trauma or conformational defect include the SDFT, DDFT, and SL (Staff, 2017). Extreme concussive forces cause hairline and stress fractures and can be observed in the cannon bones as well as carpals or tarsals. Leg protection is used in most disciplines during exercise and occasionally competition to prevent injury from knocking rails, being scratched by brush, interfering, and providing extra support to the tendons and ligaments in the distal limb. However, research has shown that boots and wraps do not provide substantial support and are merely protection from external trauma (FRCVS & Schramme, 2020). Improperly fitted boots or tight wraps can be detrimental to the horse's physical health by causing an injury rather than preventing one. Bowed tendons occur when a leg wrap is too tight and the underlying tendon swells and appears bowed. The use of boots can disrupt the natural cooling of the limb. Tendons function by releasing energy as heat when loading and offloading (Smith, 2011). With a boot or wrap on, heat is trapped against the leg, and it cannot cool down. As a result, tenocyte metabolism is obstructed and cell death occurs making the structure weaker and at higher risk for a rupture over time (Smith, 2011).

Neurological dysfunction results in a deviation from normal gait pattern that can be observed as lameness but is not always painful for the horse. Neurologic conditions may influence musculoskeletal function from disruptions in the signaling pathway caused by lesions in the spinal cord, segmental spinal nerves, and neuromuscular junctions (DACVS, 2019). Radial and suprascapular nerve trauma can be very painful and have to potential to create a paralysis-like syndrome in the affected limb (DACVS, 2019). Electromyography can be performed to diagnose the severity of the nerve damage and assess treatment options. Equine protozoal myeloencephalitis (EPM) is a protozoan disease caused by *Sarcocystis neurona*. The opossum is the definitive host of *S neurona* and the horse ingests sporocysts of contaminated opossum feces. In the horse's body, the protozoa travel to the central nervous system. The most common symptom associated with EPM is gait abnormality and lack of coordination in the form of stumbling and interference. As the disease progresses muscle will begin to atrophy (DACVS, 2019). With early detection and aggressive treatment, most horses experience a successful recovery.

Lameness can occur in any limb at any time and can co-exist in multiple limbs at once. When lameness occurs in two or more limbs at once it can be referred to as ipsilateral or bilateral lameness. Ipsilateral lameness occurs on the same side of the body whereas bilateral lameness is expressed as lameness presented on both sides of the body. Due to the nature of this lameness, it is much more complicated to observe any asymmetry in the trajectory of the head and pelvis. To properly evaluate a bilateral lameness and its severity, efforts must be made to make the lameness lateral. This can be done by evaluating the horse on a circle where the horse's weight is distributed more to one side than it is when tracking straight. Horses will compensate for limb discomfort by transferring some bodyweight onto the diagonal limb as a means of relief. The abnormal load that is being placed on the limb is a contributing factor to the bilateral lameness but because one limb is more affected than the other it is typical to observe a more severe lameness in one leg than the other.

Evaluation and Diagnosis of Lameness

Lameness can be evaluated using several different methods. The most common and convenient way is by performing a subjective evaluation. Subjective evaluations give insight into the general location of lameness and with a more careful eye, the source of the pain within that location. Objective assessments give much more detail on the source of the lameness and can be used to confirm observations from the subjective assessment and diagnose the lameness.

The subjective assessment is used when lameness is initially presented. It is made up of a series of observations to determine the severity and location of discomfort. Visual evaluations can be performed under saddle or in hand and on a circle. Under saddle, evaluations occur with a rider which can be a contributing factor to the lameness with added load and manipulation. Because of these factors, under saddle evaluations are not always appropriate and do not need to be used every time a lameness is assessed. When watching a horse trot in hand it is much easier to see how the horse carries itself. Evaluations, when lameness is not noticeable at the walk, should be performed at the trot in both a straight line and on a circle. The straight-line allows evaluators to see how the limb responds when the pressure has the opportunity to be evenly distributed. When on the circle, the center of balance and therefore weight is shifted which can also help assign a degree of lameness. Evaluating a horse on the circle also addresses the possibility of bilateral lameness.

The American Association of Equine Practitioners (AAEP) created a grading scale to assign a subjective score to the degree of the horse's lameness and can be seen in Table 0.1.

Because each horse is different in how it moves the lameness grading scale is beneficial for categorizing lameness as well as communicating the degree of lameness between individuals like veterinarians, farriers, and trainers.

Lameness at the walk can be difficult to evaluate because weight is so evenly distributed the pain might not be high enough for the horse to show clinical signs. However, in a severely front limb lame horse stride irregularities can be detected by the trajectory of the head movement. When a horse is in the stance phase on the lame limb, the head will heighten before lowering itself again during the stance phases of the other limbs. Lameness in the hind limb can be detected by the movement of the pelvis. It is even more complicated to detect a hind limb lameness at the walk because the pelvis does not have as much movement as the head (Baxter et al., 2020).

The trot is most used for identifying lameness. Like the walk, when lameness is presented at the trot the horse will lift its head in response to the lame forelimb hitting the ground. Figure 0.2 and Figure 0.3 show the difference in vertical head trajectory in a sound horse compared to a horse presenting with front limb lameness. The horse in Figure 0.2 is experiencing the most pain during the stance phase of the stride in the right forelimb. A is labeled as the beginning of the stance on the right forelimb whereas C is the beginning of the stance on the left forelimb. B and D are labeled as the peak stance of the right and left forelimbs. Specific head movement can also be indicative of the location of lameness. For example, when the most pain is experienced near the middle of the stance the head's trajectory will move down more rather than move up. The phrase "down on sound" is a common way to evaluate front limb lameness and can be characterized as the horse's head remaining low when the sound limbs meet the ground. This finding combats the common phrase because depending on when or how pain is felt, the horse may lower their head in response without having any change in maximal head height.

Hind limb lameness can be recognized via the vertical trajectory of the pelvis. It is arguably harder to recognize because there is not as much motion in the pelvis compared to the head and neck. Another sign of hind limb lameness is the presence of toe dragging when the horse is unable to retract its leg for the swing phase. This trajectory can be referred to as a "hip hike" or "hip dip" which indicates the extreme upward or downward movement of the hip. Contrary to the name, it is not the hip that is being observed but the tuber coxae (Baxter et al., 2020). The tuber coxae move in a rotational pattern meaning it reaches its minimum halfway through the stance phase and maximum halfway through the swing phase. When a horse presents with lameness the tuber coxae reach more extreme minimum and maximum heights. The hip hike is the pain response to impact type lameness whereas the hip dip is the response to a push-off lameness.

Lameness can also be evaluated using other parameters such as joint angles during the stance phase of the stride and abnormalities in stride demographics. As previously mentioned, a horse will compensate by transferring weight from its lame leg to the leg diagonal. Because of this during the peak stance phase, the horse will not extend its joints as much as it is in the other limbs. An obvious case of this can be seen in the fetlock joint that absorbs the weight of the body by lowering itself. If there is an uneven weight being distributed, the fetlock will not drop down as far. One study found that fetlock extension during the lame limb stance was decreased by 8° (Baxter et al., 2020). In the event of severe lameness, stride timing and length will be shortened to minimize concussive forces on the affected limb. Although changes in stride demographics are indicative of lameness, it is not an efficient way of assessing the severity of lameness because the horse may be more or less lame at different speeds and stride lengths.

Once the initial subjective evaluation is complete, more diagnostic measured can be taken to confirm the degree and potential cause of lameness. An objective approach requires technology that can slow down the kinematics of the horse and evaluate what humans cannot process with the naked eye. Many of these technologies involve 2-D or 3-D imaging, the use of accelerometers, and the measurement of ground reaction forces. Using these technologies is more challenging because the horse must be kept in a consistent environment and have very precise movements. Because of these requirements results have a higher confidence interval and less variability.

Measuring ground reaction forces is the most common way of quantifying lameness and can be performed using a stationary force plate, the most utilized technology for this assessment. When the horse walks across the force plate it is preferential that just one hoof steps on the surface of the plate at a time. The stationary force plate is unique because it measures ground reaction forces vertically, horizontally, and transversely. Lameness can be indicated by decreased vertical forces and abnormalities in horizontal forces while the severity of lameness can be indicated by peak forces and impulse (Kevin G. Keegan DVM). A study performed by Back W et al. determined an AAEP grade 4 lameness will strike the force plate with forces as low as 50%

of the horse's body weight compared to an AAEP grade 0 lameness with strike with 100% body weight (Back W, 2007). Other ground reaction force techniques include pressure mats that are applied in-shoe, force measuring horseshoes, and a force-measuring treadmill. These three systems have a similar ideology as the stationary force plate, but only record vertical forces and are harder to obtain. The treadmill, however, provides measurements on continuous strides and compensatory limb patterns.

"Line-of-sight" kinematics is another method of quantifying lameness. This technique utilizes a camera that can capture multiple, individual movements and analyze them independently using sensors located on the horse's body. Instead of using ground reaction forces to measure lameness the camera tracks kinematics, the measurement of movement (Kevin G. Keegan DVM). Abnormal movements that stray from baseline are considered a stride irregularity indicating the presence of lameness. EquuSense Equine by Equusys, Inc. and Lameness Locator® by Equinosis® use sensors that transmit data to a nearby device. EquuSense is commercially available and provides information on body position, velocity, acceleration, orientation, and rotation. The data can be visualized on a screen using a stick figure model of the horse to animate movement. The use of the Lameness Locator® is performed by a veterinarian and assesses the stride based on ratios of vertical movement between a sound and lame leg as well as means and standard deviations of maximum and minimum head heights while trotting. Kinematics and ground reaction forces are compatible data points which when used together can accurately detect gate abnormalities and lameness.

Once the lame limb is recognized, steps can be taken to diagnose, or discover, the cause of the lameness. This process uses highly specialized tools and analgesics therefore veterinary intervention is required. Palpating the legs allows the evaluator to feel for any abnormalities in the leg like heat, swelling, and effusion. This method works the best when the lameness occurs from trauma. Other abnormalities like changes in OA may be harder to feel due to the location and severity. However, nerve blocking can be used to numb localized regions of the leg to assess changes in lameness and determine where the pain is being experienced. Analgesics like lidocaine or carbocaine are injected into the leg near the nerves (Grant Miller, 2014). If the area of pain is not suspected, most veterinarians will begin at the most distal location and work their way up the leg. Nerve block locations in the distal limb include palmar digital (PD), abaxial, low 4-point, and high 4- or 2-point (Grant Miller, 2014). When a horse "blocks sound" this means that the source of the pain was successfully located (*Nerve Blocking Horses as Part of a Lameness Exam*). A diagram detailing the locations of analgesic administration can be seen in Figure 0.4. Diagnostic imaging can be used to examine the lame leg once the location is confirmed. Radiography and ultrasonography can be used to examine the internal integrity of the affected anatomy. Radiography can detect changes in the bone such as a fracture or arthritic changes. Ultrasonography is used to investigate soft tissue structures like tendons and ligaments to investigate fibrotic changes from strains or lesions.

Lameness in the Sport Horse

Many factors contribute to lameness in the sport horse. Age, conformation, athletic ability, and trauma to the musculoskeletal system are all potential causes of discomfort. Riding surfaces also have a substantial role in altering the horse's performance and can have detrimental effects. When using a horse for recreational purposes it is important to make sure they can perform what you are asking them to do to prevent the risk of injury and discomfort.

Almost any breed is used for dressage and hunter/jumper riding with the most popular ones being thoroughbreds, warmbloods, quarter horses, and crosses. Typically, horses begin moderate work and competition at the age of four where they will reach peak performance between the ages of nine to twelve and can continue into their twenties. English riding, dressage especially, focuses on the engagement of the horse's hind end to propel them forward across the ground. This is counterintuitive for the horse because they naturally prefer to balance their weight on the forelimbs. The transfer of weight results in increased loading causing lameness associated with the thoracolumbar and pelvic regions along with the ligaments and joints of the hindlimbs (Boswell et al., 2011). Not only can jumping horses experience the repercussions of engaging the hind end, but they also experience increased strain on the forelimb during the take-off and landing phases of the jump. Most affected structures are the hoof, joints, and soft tissue of the distal forelimb (Boswell et al., 2011).

Injury to the SL is the most common and most serious soft tissue injury in the equine athlete. The SL may have lesions in it that go unnoticed and only become apparent when they become so severe that the horse appears lame. Damage to the SL in the forelimb can be diagnosed when the affected limb is on the outside of a circle at the trot where lameness is the most pronounced (Boswell et al., 2011). SL damage to the midbody and branches can be easily diagnosed by palpating the area, but the proximal segment is more difficult and may require nerve blocking and ultrasonography. Hindlimb SL injury does not create significant differences in lameness depending on where the affected limb is located on the circle. SL injuries take extensive amounts of time to heal (6-12 months) and require a gradual reintroduction to work. Premature work can harden the SL where it will lose elasticity and be prone to reinjury (Boswell et al., 2011).

Osteoarthritis can occur in sport horses of any age and is common in the aging population. It is primarily seen in the synovial joints of the limb but can occur in cartilaginous joints and is caused by persistent inflammation in the joint capsule that breaks down the articular cartilage (Rebecca Bishop, 2018). Osteoarthritis is often coupled with joint synovitis, specifically in the DIP, MCP, MTP, femoropatellar, tarsometatarsal (TMT), centrodistal (CD), and PIP joints to name a few (Boswell et al., 2011; Rebecca Bishop, 2018). Trauma, overloading, and infection of the joint capsule result in inflammation of the joint(Rebecca Bishop, 2018). Interleukin-1 (IL-1), tumor necrosis factor-alpha (TNF-alpha), and interleukin-6 (IL-6) are inflammatory cytokines released by the synovium, cartilage, and subchondral bone into the extracellular matrix of the joint that progressively degrade the joint structure (Omoigui, 2007; Rebecca Bishop, 2018). Osteoarthritis can result in bilateral lameness, reduced stride length, joint stiffness, and reluctance to jump.

Back pain is a common ailment across horses of any discipline, can be due to several factors, and can be noticed when interacting with the horse and riding. Signs of back pain include sensitivity when grooming, putting the saddle on, applying more weight in the saddle, and shifting weight in the saddle. The horse can develop a stiff stride, present with lateral lameness, and show a decline in performance. Back pain can be caused by muscle strain, impingement, kospondylosis, sacroiliac desmitis, supraspinous desmitis, and OA (Boswell et al., 2011).

Soft tissue injuries are also very common in sport horses and may not always be painful or show lameness (Boswell et al., 2011). Aside from the SL, oblique seasmoidian ligaments are one of the most affected soft tissue structures in the distal limb. Injury to the oblique seasmoidian ligament predisposes the horse to issues with the DDFT. The DDFT can easily be displaced either medially or laterally and risk a higher rate of injury in the metacarpal region (Boswell et al., 2011). Injury to the SDFT is not relatively common or severe in hunter/jumper horses but is common in young racing thoroughbreds. Strain to the SDFT is normally the result of a misstep in deep footing or training at high speeds (Boswell et al., 2011). Superficial digital flexor tendon injuries typically occur in middle age and older horses and can be recurring. Older jumpers will experience spontaneous rupture of the SDFT and have no history or indication of tendonitis. This occurrence mainly takes place in geldings compared to intact mares and stallions leading researchers to believe there is an association between trauma and hormonal imbalance (Boswell et al., 2011).

Treatments

A treatment plan is designed specifically for the type and severity of the injury. Recovery from and treatment of an injury used to be a very long process that required plenty of rest and time off for the horse. Today, with the use of growing technology, the healing process has been made faster and more efficient (Boswell et al., 2011). Horses can be maintained with the use of non-steroidal anti-inflammatory drugs (NSAID), intra-articular injections, shock wave therapy, intralesional injections, and physical therapy.

The use of NSAIDs is commonly for the maintenance of inflammation in horses with disorders like OA or other mild lameness. Phenylbutazone (PBZ) is the most prescribed NSAID and is a cyclooxygenase inhibitor-1 (COX-1) (Knych, 2017). COX-1 is an integral membrane protein in nearly all cell types that help maintain homeostasis and converts arachidonic acid into PGG2, an inflammatory mediator (Hinz & Pahl, 2007; Knych, 2017). Other examples of COX-1 inhibitor NSAIDs are flunixin meglumine (FLU), and ketoprofen (KTP)(Knych, 2017). COX-2 enzymes are upregulated because of the inflammatory response. Exposure to cytokines like IL-1, IL-2, TNF-alpha stimulates the proliferation of COX-2 and are the cytokines produced by the articular surface. Meloxicam is a COX-2 targeted NSAID but is only approved for use in dogs in the United States (Knych, 2017). By inhibiting COX-2, the gradual progression of OA can be mitigated and deterioration of the joints would be prevented due to the inhibition of the proinflammatory response (Knych, 2017).

Intra-articular injections are also used as a treatment and preventative measure for joint diseases like OA. Intra-articular injections are injected directly into the joint and can be hyaluronic acid (HA), polysulfated glycosaminoglycans (PSGAG), and corticosteroids. Hyaluronic acid adds lubrication back into the joint and is synthesized by the synovial membrane (Benjamin Espy & Justin Harper, 2016). Hyaluronic acid is most beneficial when acute joint inflammation is present but PSGAGs are administered when cartilaginous damage is present in the joint. Injections of PSGAGs are given intramuscularly (IM) or intra-articularly. These injections help repair cartilage and delay further breakdown in the joint (Benjamin Espy & Justin Harper, 2016). The use of corticosteroids has a great deal of controversy behind it with a frequent history of post-injection injury when administered improperly. Corticosteroids induce HA production within the joint (Benjamin Espy & Justin Harper, 2016). However, an inflamed joint cannot properly produce viscous HA that is needed to lubricate the joint. When administering intra-articular injections, the area surrounding the injection site must be sterile. Bacteria and infection in the joint will only lead to more progressive and debilitating joint disease.

Extracorporeal shockwave therapy (ESWT) can be used in the treatment of musculoskeletal and soft tissue injuries. This non-invasive procedure uses acoustic sound to produce high-pressure waves that stimulate regenerative processes (*Shockwave Therapy*, 2019). ESWT increases blood flow, reduces inflammation, and can act as an analgesic. This treatment is performed by a veterinarian or specialist as a series of sessions that are performed for approximately ten minutes. One study shows that nearly 80% of arthritic horses had improved lameness scores and horses with chronic SL disease were successfully treated after three sessions (*Shockwave Therapy*, 2019).

Intralesional injections of stem cells, interleukin-1 receptor antagonist protein (IRAP), platelet-rich plasma (PRP), or A-Cell (collagen dense substrate from pig bladder) aid in the repair of lesions found in tendons and ligaments. This approach flushes fluid in and out of the lesion, with a purpose similar to that of a lavage (Boswell et al., 2011). Fluid is injected into the lesion forcing blood, serum, and inflammatory modulators out of the injured area. Intralesional injections should also be used with ultrasound therapy to reduce inflammation and promote healing (Boswell et al., 2011).

Physical therapy can vary on a case-to-case basis but is used to reacclimate the body and the recent healed site to loading or work. It is an extensive process that takes time that usually starts with hand walking to reintroduce the injury to mobility. As the horse builds fitness, they can graduate to walking for a short time under saddle and can go on restricted turnout. After about a month of walking, the horse should be fit enough to endure a small amount of trot that will increase in time from week to week. By three months the horse should be capable of performing basic flatwork. It is important not to push this process too quickly because it can result in the reinjury of the structure or increase scar tissue which can make the injury site hard and brittle. When not being physically rehabilitated, the horse can receive support from standing wraps which will prevent swelling in the leg, and the use of topical anti-inflammatory treatments like a poultice or ice therapy.

Prevention

The prevention of lameness is the prevention of injury and disease. It is an ongoing discussion between researchers as to how exposing a physically immature horse to light work will impact the horse's soundness and long-term health. Some believe that light work is important for the developing horse because of the body's ability to quickly remodel and adapt to environmental pressure (Dittmer, 2019; Stephan B. Adams, 2019). Whereas it is common practice in some European countries like Germany to not begin work with a horse until after it has had time to almost fully mature. Other potential prevention measures can take place before, during, and after a horse is exercised.

Correct physical conditioning, stretching, and allotting sufficient time for a warm-up can help reduce the risk of lameness in sport horses (FabíolaFarinelli et al., 2021). Stretching is done before the horse is ridden and can help increase mechanic coordination and amplitude. Warm-up is used to prepare the body for exercise. It gives ample time for muscle temperature to rise, metabolic activity to increase, as well as improve tissue elasticity, and increase cardiac output (FabíolaFarinelli et al., 2021). The cool-down is a decrease in exercise that allows the body to reach homeostasis by reducing oxidative stress in the muscles and lowering the body temperature to within normal range.

Preventative measures can be taken into consideration when exercising a horse. Riding on adequate surfaces and not overtraining the horse are good management practices. Riding on surfaces that are too hard increases concussive forces which can be detrimental for bones and joints. Surfaces that are too soft require extra effort from the horse which fatigues them quickly and puts a lot of strain on the tendons and ligaments (Boswell et al., 2011). Training and conditioning the horse is a gradual process aimed to increase performance capacity and fitness. As the horse progresses the body will be able to adapt to higher intensity and training volume as well (Bruin et al., 1994). The involuntary objective of the body is to always maintain homeostasis, a concept that the body strays from when under metabolic stress from exercise. Post-exercise recovery is vital for the horse because it provides the body time to return to pre-exercise conditions. Short-term overtraining, also known as overreaching, is the condition when the body is given enough time to rest before the next bout of exercise and can be solved with a couple of days off (Bruin et al., 1994). Overtraining syndrome, or staleness, is a more extreme form of overreaching. It occurs when there is a consistent imbalance between training and recovery that lasts for long periods of time (Bruin et al., 1994). Constant fatigue, behavioral changes, endocrine, and metabolic changes are all symptoms associated with staleness (Bruin et al., 1994). A study performed in standardbred trotters found that during bouts of loading and fatigue the horse struggles to maintain stride frequency and joint movement is compromised (Johnston et al., 2010). This can be caused by the muscles' inability to support locomotion. The alteration in joint movement due to muscle fatigue creates a gait abnormality that can weaken the structures and make them more susceptible to injury. A training regimen should be created and maintained based on the horse's level of fitness to prevent lameness. This would involve providing time off to allow the horse to rest and not engaging in intense exercise more than a couple of days per week.

Therapeutic Technologies

The effectiveness and use of therapeutic technologies have always been a topic of debate between equestrians, trainers, and veterinarians. Therapeutics has typically been used with an already existing lameness to treat the horse's injury or disease with the assistance of a veterinarian or specialist. As technology advances, therapies have become more commercialized, convenient, and are used as maintenance to help the body prepare or recover from exercise to prevent lameness. Although some of the therapeutics mentioned below are capable of healing injuries, the purpose is to evaluate them based on their ability to support the body in the preparation for and recovery from exercise.

Types of Therapeutic Technologies

There are a variety of therapeutic technologies that are used to support athletic horses as they undergo training and conditioning to maintain fitness. Therapies can also be applied to older horses to provide relief from physical discomfort due to an old injury or degenerative disease. Most therapeutics share similar goals but use different methods and applications.

Low energy pulsating electromagnetic fields (PEMF) is not a novel idea and has been a controversial topic of discussion between physiotherapists for decades. Therapies using PEMF are non-invasive and work by using variable low-frequency pulses to create a biophysical stimulation that promotes cell proliferation within the tissue (Gyulai et al., 2015; Zucchini et al., 2002). The controversy behind this therapy may lie in the broad frequency range that is used for PEMF treatment: 1to 30 Hz (Biermann et al., 2014; Gyulai et al., 2015). The electromagnetic field is capable of penetrating 16 to 18 inches at a high frequency (*How Does PEMF Work on Horses?*). In the event of strain or injury, the body naturally creates an inflammatory response that involves the release and proliferation of metabolites and growth factors. Inflammatory modulators naturally control the process of healing but do not always return the structure to its former integrity and function. PEMF therapy mediates the enzymatic activity and gene expression early in the recovery process to return the affected area back to its original state (Zucchini et al., 2002). Studies suggest that not only does PEMF treatment aid in healing, but it also offers long-term relief from pain, degenerative changes, and reduces muscular fatigue when used regularly (Gyulai et al., 2015).

Low-level laser therapy (LLLT), or red-light therapy, is the use of photobiomodulation therapy to stimulate healing and can be used to prepare for and recover from exercise (Rosenkrans et al., 2020). This therapy uses quantum mechanics to stimulate electrons and increase the speed and quality of tissue repair as well as reduce inflammation, provide pain relief, and increase localized motion (Freeman, 2019). It also adopts the photochemical theory which states that absorbed light interacts with organic molecules (chromophores) in the body to modulate cellular activity (Ryan & Smith, 2007). One study tested its ability to alter serum concentrations of cortisol, lactate, and cytochrome P450 (CYP) inhibition (Rosenkrans et al., 2020). The use of LLLT at 635 nm prior to exercise resulted in a decrease of cortisol concentration and CYP but an increase in lactate concentration. A similar 2019 study suggests that there is no significant evidence to suggest that LLLT has an effect on the body due to the inverse relationship between lactate and cortisol (Freeman, 2019). Discrepancies in effectiveness arise due to the varying quality and strength of the lasers being used in each study. However, it is widely accepted that the longer the wavelength is, the deeper it will penetrate, leading researchers to believe that red light is only effective at the superficial level where non-visible infrared light is needed to affect the musculoskeletal system (Ryan & Smith, 2007).

Cryotherapy is used after exercise to help lower body temperature and prevent an inflammatory response to strain. The cold also creates an analgesic effect which will provide relief from post-exercise discomfort. In the event of strain or injury, cryotherapy causes vasoconstriction which restricts the body’s ability to release inflammatory modulators into the affected area and reduce swelling while lowering cell metabolism, muscle contractility, and nerve conduction (Thomas, 2019). When using cryotherapy after exercise, muscle soreness is reduced, and the horse can maintain athletic performance.

Ceramic therapy involves the use of fabrics infused with ceramic powder that mimics infrared radiation to naturally radiate energy back towards the body to improve circulation and relax muscles (Kemp; *Product Innovation*). The ability to keep the muscles relaxed allows the body to begin preparing for exercise before it even begins. Improved circulation is beneficial for horses that develop swelling in the distal limb from standing too long in a confined space or accumulation of fluid post-exercise. Studies performed on the use of ceramic therapy for two weeks show a reduction of inflammation in a painful back muscle using thermal imaging and the stride length of those receiving treatment also increased (*Product Innovation*).

Ionic therapy utilizes negative ions in the air to improve circulation throughout the body. Negative ions are referred to as anions and are molecules that possess more electrons than they do protons (*What is Ionic Therapy?*). The anions charge the air and cells in the body making it more energized to improve cellular function. Tourmaline is a pyroelectric stone that generates an electric charge when it experiences friction or pressure (*What is Ionic Therapy?*). When wearing tourmaline, negative ions are absorbed into blood stream where they circulate the body to improve oxygen delivery to the muscles and support lymphatics (*Rambo Ionic*).

Modes of Action

Therapeutics can be applied and utilized in many ways and can influence the whole body or target specific areas of the horse that need the most support. These therapies can be used daily and for extended periods of time if necessary.

Treatment technology using PEMF is available to equestrians in many different forms that can be kept in the barn or require the use of a specialist to administer treatment. Bio-electro-magnetic-energy-regulation (BEMER) technology is a version of PEMF treatment that produces a very weak magnetic field to enhance tissue microcirculation (Gyulai et al., 2015). The BEMER technology uses signal patterns to increase vasomotion, make a difference in pO2, open capillaries, increase arterial and venular flow volume, and flow rate of red blood cells (Gyulai et al., 2015). This device generates a magnetic induction of 100 to 150 μT and can be used daily for twenty minutes (Gyulai et al., 2015). Several manufacturers produce wearable PEMF treatments, specifically in the form of a blanket and boots. This allows the consumer to be able to choose where they target their treatment, whether that be in the distal limb or across the whole body. Other forms of PEMF treatment, like the Magnawave, can be used by individuals but also have certified specialists available to apply the therapy. Magnawave utilizes a copper coil that can be draped over the horse's body or be held in a specific location to administer treatment (*How Does PEMF Work on Horses?*).

Low level laser therapy can be used at varying wavelengths to penetrate deep enough to provide the appropriate relief. Most cold laser therapy systems can produce a wavelength as low as 500 nm and up to 860 nm to accommodate different uses. When applying LLLT to an injured or recovering area like tendon or ligament, the ideal wavelength is between 600 to 680 nm (*A guide to Equine Lasers*). Some LLLT systems can be portable with the use of a wand or stand as a permanent structure in a barn, depending on if use is intended for specific locations or whole-body treatment. One challenge associated with the use of laser therapy in horses is the pigmentation of skin and density of hair. This is because different skin pigmentations absorb light differently which suggests the potential of the wavelength being too low to be effective. Most manufacturers recommend that the horse is clipped prior to treatment to prevent interference (Ryan & Smith, 2007).

Cytotherapeutic methods vary greatly and are one of the most accessible methods for all equestrians. Cryotherapy, also known as cold therapy, involves using some form of cold on the body for approximately twenty to thirty minutes. Coldwater, a bucket of ice, or ice boots are all acceptable ways of using cryotherapy. When cooling down muscles, the use of a hose is more convenient however it is very important to keep the distal limb cool, especially after exercise. In recent years, manufacturers have created boots that can accommodate ice packs for easy and clean application. Horseware® Ireland produces an Ice-Vibe boot that utilizes cooling and massage therapy in conjunction with one another to help the body recover (*Ice-Vibe*). Current ice boots on the market have options of leg wraps, knee wraps, and hock wraps to help horses experiencing OA or joint pain.

Ceramic therapy can be worn for extended periods and can be used under a variety of circumstances. Although others are available on the market, Back on Track® is one of the leading manufactures of ceramic products for horses. The wearable therapy is made from polyester with infused ceramic particles (*Product Innovation*). Boots and wraps can be applied to the legs to reduce swelling while blankets target the muscles in the neck and back to induce relaxation. Some manufacturers infuse this technology into saddle pads and leg wraps as well so the horse can achieve relaxation easier while exercising.

Ionic therapy uses similar formulation techniques as wearable ceramic therapies do. Ground tourmaline produces the negative ions and is interwoven into the fabric and sold as a full-body therapy in the form of blankets or localized distal limb therapy as boots and wraps. Rambo® is the largest manufacture of negative ion therapy products for horses. Their fabrics release over 1000 negative ions per cubic centimeter (*Rambo Ionic*). Not only does this product improve cellular function, but it also improves mood which can create more positive, relaxed experiences for the horse and can limit strain or injury.

Next Steps

Therapeutic technologies can transform the lives of equine athletes. Consistent and appropriate use provides benefit to the horse at a cellular level to prepare the body for change whether that be preparing the body for exercise or allowing it to recover. The utilization of musculoskeletal therapy can mitigate concerns over lameness or injury due to fatigue and strain.

Equine therapeutics have made progress in recent decades in becoming more user-friendly and no longer require the use of large machines or veterinary intervention, although that option is still offered today. Modern devices are smaller in size, making them portable, and can easily be integrated into the daily routine. However, these devices can be monetarily unavailable meaning that they are only affordable by a limited portion of equestrians. These purchases can be made by businesses and would be especially useful in competition barns, but even so, it can be an unrealistic purchase. Cryotherapy, ionic therapy, and ceramic therapy are more affordable for individuals and can even be more convenient methods because of their low maintenance applications. Technologies like LLLT are not regulated by the FDA, therefore manufacturers can set their prices on the product with little to no regulation(*A guide to Equine Lasers*). To make these therapies available to most, prices need to be standardized to prevent overinflation in the market.

Aside from creating variations of products that are affordable for most equestrians, more consistent research needs to be performed on these technologies. As previously stated, there is a great deal of controversy behind the effectiveness of PEMF and LLLT. This could be due to the various environments and strengths that these therapies are tested under. Both technologies specifically vary in wavelength and frequency making them effective for certain purposes over others. Replicating studies in these therapies could provide a more definitive answer as to if these are beneficial or not. Not only does there need to be consistent research, but more research needs to be performed on the use of ionic and ceramic therapies. Very few publications can provide data on research conducted using these technologies for influence on the musculoskeletal system.

Conclusion

Measuring equine performance is a complicated task that is determined by the anatomical design and conformation that influence biomechanics, gait quality, and athleticism. Human intervention and selective breeding have created the modern horse which is further categorized by breed. Regardless of breed, conformational flaws continue to present themselves, predisposing the horse to strain and injury during exercise which hinders the horse's performance and athletic capabilities. When the body detects physical distress, it initiates the inflammatory response which is responsible for treating and fortifying the injured area. Some argue that this is a beneficial process, especially in young horses to help the body adapt to what it may experience later in life however it can limit the strength, elasticity, and function of the injured site after it is healed. These structural changes can lead to secondary problems like discomfort during exercise or reinjury in the future which can restrict or end the horse's athletic career. Lameness is a common issue and can be a result of physical trauma, disease, and neurological disorders. These factors make treatment complicated because a diagnosis must be made on the source of the lameness. Time off from exercise is the most common, and most lengthy, treatment and can sometimes be the only answer for lameness that cannot be diagnosed. Otherwise, pharmaceutical intervention and therapeutic treatment can be used to treat the underlying cause and prevent its progression. Although these methods allow the horse to return to a physically sound state, it does not solve the problem of preventing the lameness in the first place. Since most lameness occurs due to strain or forces inflicted on the horse during exercise, pre- and post-exercise management practices can be put in place to ensure that the horse is prepared to work and that it is able to achieve homeostasis after. Beneficial wearable and applied therapies are available to equestrians, but current studies fail to reach an agreement on their effectiveness. With more research, conclusions can be formed on their ability to benefit the equine athlete which could create an industry with less lameness due to strain or injury.

Tables and Figures

Table 0.1 AAEP Lameness Grading Scale (Lameness Exams: Evaluating the Lame Horse

Grade	Description
0	Lameness not perceptible under any circumstances.
1	Lameness is difficult to observe and is not consistently apparent, regardless of circumstances (e.g. under saddle, circling, inclines, hard surface, etc.)
2	Lameness is difficult to observe at a walk or when trotting in a straight line but consistently apparent under certain circumstances (e.g. weight-carrying, circline, inclines, hard surface, etc.)
3	Lameness is constantly observable at a trot under all circumstances.
4	Lameness is obvious at the walk.
5	Lameness produces minimal weight bearing in motion and/or at rest or a complete inability to move.

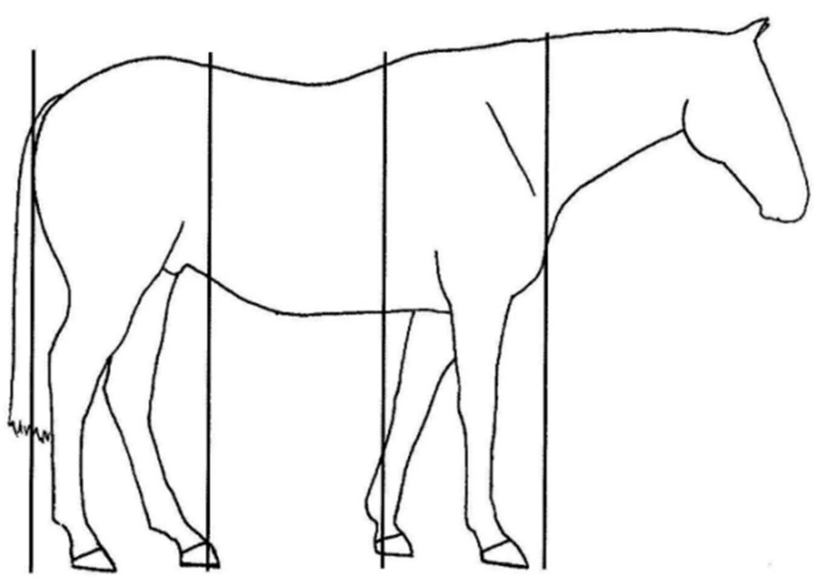

Figure 0.1 Conformational Proportions (Committee)

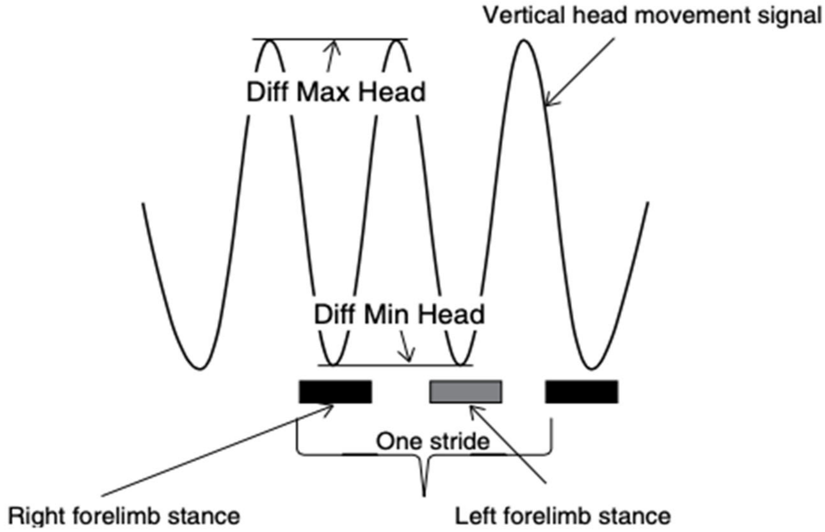

Figure 0.2 Head Movement Trajectory in a Sound Horse (Baxter et al., 2020)

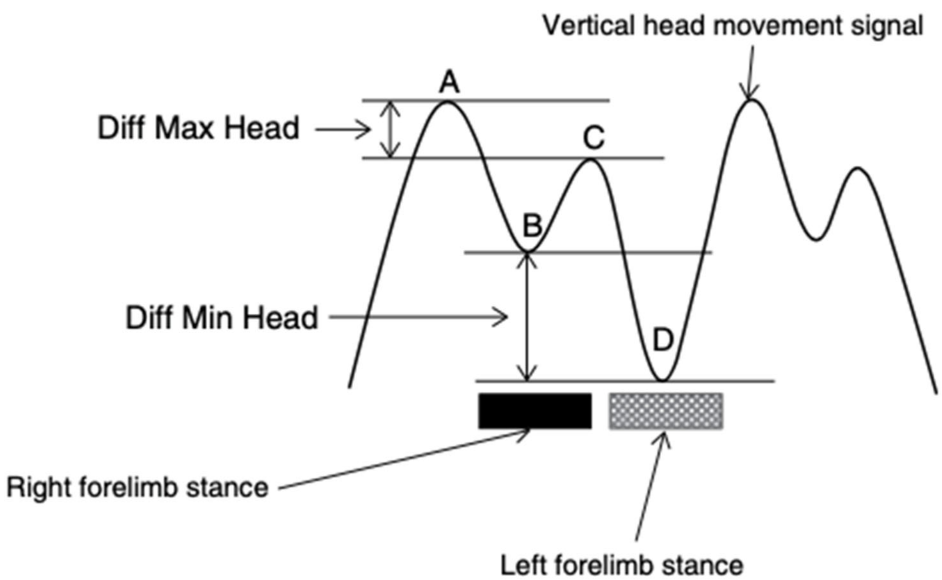

Figure 0.3 Head Movement Trajectory in a Lame Horse (Baxter et al., 2020)

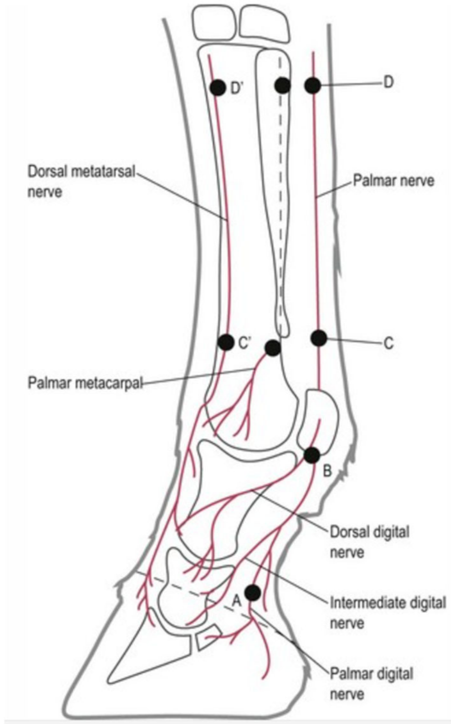

Figure 0.4 Nerve Block Locations of the Distal Limb(Nerve Blocking Horses as Part of a Lameness Exam) **(A)** Palmar digital. **(B)**Abaxial. **(C)**Low 4-Point. **(D)**High 4-/2-Point. Prime marks (‘) represent dorsal locations.

Literature Referenced

5 Major Types of Horses Defined. Copper Mare Media, Ltd. . https://www.equinespot.com/types-of-horses.html

Back W, M. C., van Heel MCV, et al. . (2007). Vertical Frontlimb Ground Reaction Forces of Sound and Lame Warmbloods from those in Quarter Horses. *Journal of Equine Veterinary Science*, 123-129.

Baxter, G. M., Stashak, T. S., & Keegan, K. G. (2020). Examination for Lameness. In *Adams and Stashak's Lameness in Horses* (pp. 67-188). John Wiley & Sons, Ltd. http://onlinelibrary.wiley.com/doi/abs/10.1002/9781119276715.ch2

files/25/9781119276715.html

Benjamin Espy, D., DACT, & Justin Harper, D., MS, DACVS, LA. (2016). *Lameness and Joint Medications*. American Association of Equine Practitioners.

Biermann, N. M., Rindler, N., Buchner, H. H. F. E. S. D. f. C. A., & Horses, U. o. V. M. V. A. (2014). The Effect of Pulsed Electromagnetic Fields on Back Pain in Polo Ponies Evaluated by Pressure Algometry and Flexion Testing—A Randomized, Double-blind, Placebo-controlled Trial. *Journal of Equine Veterinary Science*, *34*(4), 500-507. https://doi.org/10.1016/j.jevs.2013.10.177

Boswell, R. P., Mitchell, R. D., Ober, T. R., Benoit, P. H., Miller, C. B., & Dyson, S. J. (2011). Chapter 115 - Lameness in the Show Hunter and Show Jumper. In M. W. Ross & S. J. Dyson (Eds.), *Diagnosis and Management of Lameness in the Horse (Second Edition)* (pp. 1096-1112). W.B. Saunders. https://www.sciencedirect.com/science/article/pii/B9781416060697001152

files/17/B9781416060697001152.html

Bruin, G., Kuipers, H., Keizer, H. A., & Vander Vusse, G. J. (1994). Adaptation and overtraining in horses subjected to increasing training loads. *JOURNAL OF APPLIED PHYSIOLOGY*, *76*(5), 1908.

Committee, U. H. Q. C. P. Horsemanship Quiz Challenge Study Guide. In. USHJA: United States Hunter Jumper Association, Inc.

DACVIM, J. N. V. (2017). The Equine Circulatory System. https://equimed.com/health-centers/general-care/articles/the-equine-circulatory-system

DACVS, J. C. J. D. M. (2019). Neurologic Lameness.

Dave, H. D., Shook, M., & Varacallo, M. (2021). Anatomy, Skeletal Muscle. *National Center for Biotechnology Information*. https://www.ncbi.nlm.nih.gov/books/NBK537236/

Debra A. Hembroff, R. Equine Exercise Physiology.

Distal Limb Bones: Lower Leg Bones. http://www.anatomy-of-the-equine.com/distal-limb-bones.html

Dittmer, C. W. R. a. K. E. (2019). Does Juvenile Play Programme the Equine Musculoskeletal System? *Animals*. https://doi.org/10.3390/ani9090646

Doug Thal, D. (2016). Understanding Lameness. *American Association of Equine Practitioners*. https://aaep.org/horsehealth/understanding-lameness

Douglas, H. *Etymology of lame*. https://www.etymonline.com/word/lame

DVM, B. C. Degenerative Suspensory Ligament Desmitis (DSLD).

FabíolaFarinelli, AdalgizaSouzaCarneirodeRezende, MayaraGonçalvesFonseca, ÂngelaMariaQuintãoLana, FabíoladeOliveiraPaesLeme, BárbaradeOliveiraNacifKlein, RafaelHenriquePradoSilva, AndersonPereiradeAbreu, ManoelladeJesusDamazio, & MaríliaMartinsMelo. (2021). Influence of Stretching Exercises, Warm-Up, or Cool-Down on the Physical Performance of Mangalarga Marchador Horses. *Journal of Equine Veterinary Science*. https://doi.org/https://doi.org/10.1016/j.jevs.2021.103714

FRCVS, R. S., & Schramme, M. (2020). The risks and benefits of using boots or bandages on horses' legs.

Freeman, C. (2019). *The Effects of Pre and Post Exercise Low-Level Laser Therapy on Biochemical Markers of Skeletal Muscle Fatigue in Equines* [Undergraduate Honors, University of Arkansas]. Scholarwork@UARK.

Grant Miller, D. (2014). The Basics of Nerve Blocks. *Equisearch*.

Gregory, B. (2014). Conformation. In (pp. 253-265). Elsevier. https://doi.org/10.1016/b978-0-7216-0075-8.00024-1

A guide to Equine Lasers. ColdLasers.Org.

Gyulai, F., Rába, K., Baranyai, I., Berkes, E., & Bender, T. (2015). BEMER Therapy Combined with Physiotherapy in Patients with Musculoskeletal Diseases: A Randomised, Controlled Double Blind Follow-Up Pilot Study. *Evidence-Based Complementary and Alternative Medicine*, *2015*, 1-8. https://doi.org/10.1155/2015/245742

Head, M. J., & Barr, A. (2012). Orthopaedics 3. The proximal limbs. In (pp. 369-388). Elsevier. https://doi.org/10.1016/b978-0-7020-2801-4.00017-1

Hinz, B., & Pahl, A. (2007). Cyclooxygenase-1. *xPharm: The Comprehesive Pharmacalogical Reference*, 1-5.

How Does PEMF Work on Horses? Magnawave PEMF.

Ice-Vibe. Horseware Ireland.

Johnston, C., Gottlieb-Vedi, M., Drevemo, S., & Roepstorff, L. (2010). The kinematics of loading and fatigue in the Standardbred trotter. *Equine Veterinary Journal*, *31*(S30), 249-253. https://doi.org/10.1111/j.2042-3306.1999.tb05228.x

Juneja, P., Munjal, A., & Hubbard, J. B. (2021). Anatomy, Joints. *National Center for Biotechnology Information*. https://www.ncbi.nlm.nih.gov/books/NBK507893/

Kemp, L. *Tools You Can Use: Guidelines and Cautions for Equine Therapy Equiptment*. Holistic Horse.

Kevin G. Keegan DVM, M., DACVS. Objective Measures of Lameness Evaluation. *ACVS*, 127-130. https://www.acvs.org/files/proceedings/2012/data/papers/037.pdf

Knych, H. K. (2017). Nonsteroidal Anti-inflammatory Drug Use in Horses. *Veterinary Clinics of North America: Equine Practice*, *33*(1), 1-15. https://doi.org/10.1016/j.cveq.2016.11.001

Lameness Exams: Evaluating the Lame Horse. American Association of Equine Practitioners. https://aaep.org/issue/lameness-exams-evaluating-lame-horse

Lusi, C. M., & Davies, H. M. S. (2018). *Fascial anatomy of the equine forelimb*. CRC Press. https://doi.org/10.1201/9781351172929.

Mesa, S. (2007). *American Horse Council Study Finds Equestrian Recreation Industry has Significant Economic Impact*. https://www.usef.org/media/press-releases/1992_american-horse-council-study-finds-equestrian-recreation-industry-has-significant-economic-impact

Nerve Blocking Horses as Part of a Lameness Exam. Momentum Equine.

Omoigui, S. (2007). The biochemical origin of pain: The origin of all pain is inflammation and the inflammatory response. Part 2 of 3 – Inflammatory profile of pain syndromes. *Medical Hypotheses*, *69*(6), 1169-1178. https://doi.org/10.1016/j.mehy.2007.06.033

Product Innovation. Back On Track.

Rambo Ionic. Horseware Ireland.

Rebecca Bishop, D. (2018). Osteoarthritis and the Equine Athlete.
RN, L. R. W. M., PA-C, R. T. J., & MD, T. G. *What are White Blood Cells?* University of Rochester Medical Center. https://www.urmc.rochester.edu/encyclopedia/content.aspx?ContentID=35&ContentTypeID=160
Rosenkrans, A., Freeman, C., Oberhaus, E. L., Dias Morse, P., & Rosenkrans, C. (2020). 122 Physiological effects of low level laser therapy on exercised horses. *Journal of Animal Science*, *98*(Supplement_2 ASAS Southern Section 2020 Meeting Abstracts), 80-81. https://doi.org/10.1093/jas/skz397.189
Ryan, T., & Smith, R. (2007). An investigation into the depth of penetration of low level laser therapy through the equine tendon in vivo. *Irish Veterinary Journal*, *60*(5), 295. https://doi.org/10.1186/2046-0481-60-5-295
Sellnow, L. (2006). The Perfect Engine. *The Horse*, 83-88.
Shockwave Therapy. (2019).
Smith, R. K. W. (2011). Chapter 68 - Pathophysiology of Tendon Injury. In M. W. Ross & S. J. Dyson (Eds.), *Diagnosis and Management of Lameness in the Horse (Second Edition)* (pp. 694-706). W.B. Saunders. https://www.sciencedirect.com/science/article/pii/B9781416060697000687
files/11/B9781416060697000687.html
Sopakayang, R. (2010). *Viscoelastic Models for Ligaments and Tendons* Virginia Polytechnic Institute and State University]. https://vtechworks.lib.vt.edu/handle/10919/77298
Splint Bones. https://www.atlantaequine.com/pages/client_lib_splint.html
Stacey Oke, D., MSc. (2021). Understanding the Equine Muscular System. https://thehorse.com/193585/understanding-the-equine-muscular-system/
Staff, E. (2017). *Causes of Equine Lameness*. Equimed, LLC.
Stephan B. Adams, D., MS, DACVS. (2015, June 2016). *Overview of Lameness in Horses*. Merck & Co., Inc.
Stephan B. Adams, D., MS, DACVS. (2019). *Components of the Musculoskeletal System of Horses*. Merck Sharp & Dohme Corp. https://www.merckvetmanual.com/horse-owners/bone,-joint,-and-muscle-disorders-in-horses/components-of-the-musculoskeletal-system-of-horses
Structure and Function of Ligaments and Tendons. http://sites.bsyse.wsu.edu/pitts/be120/Handouts/animal%20tssue%20descriptions%20and%20mechanical%20proprties.htm
Thomas, H. S. (2019). The Power of Cold Therapy. *Equus Magazine*, (457).
Valberg, S. J. (2014). Muscle anatomy, physiology, and adaptations to exercise and training. In (pp. 174-201). Elsevier. https://doi.org/10.1016/b978-0-7216-0075-8.00021-6
Wakim, S., & Grewal, M. (2021a). *Muscle Contraction*. https://bio.libretexts.org/Bookshelves/Human_Biology/Book%3A_Human_Biology_(Wakim_and_Grewal)/15%3A_Muscular_System/15.4%3A_Muscle_Contraction
Wakim, S., & Grewal, M. (2021b). *Structure of Bone*. https://bio.libretexts.org/Bookshelves/Human_Biology/Book%3A_Human_Biology_(Wakim_and_Grewal)/14%3A_Skeletal_System/14.4%3A_Structure_of_Bone
Weeren, P. R., & Crevier-Denoix, N. (2006). Equine conformation: clues to performance and soundness? *Equine Veterinary Journal*, *38*(7), 591-596. https://doi.org/10.2746/042516406x159007

What is Ionic Therapy?
Zschäbitz, A. (2005). Anatomie und Verhalten von Sehnen und Bändern. *Der Orthopäde*, *34*(6), 516-525. https://doi.org/10.1007/s00132-005-0799-4
Zucchini, P., Zaffe, D., Botti, P., Grande, A., Cavani, F., Cadossi, M., Ferrari, S., Cadossi, R., Fini, M., & Canè, V. (2002). IN VIVO EFFECTS OF LOW FREQUENCY LOW ENERGY PULSING ELECTROMAGNETIC FIELDS ON GENE EXPRESSION DURING THE INFLAMMATION PHASE OF BONE REPAIR. *Electromagnetic Biology and Medicine*, *21*(3), 197-208. https://doi.org/10.1081/jbc-120015991

Chapter 2 Effects of wearable therapies on performance, inflammation, and localized body temperature

Abstract

Failure to properly prepare the horse for and recover from exercise is a contributing factor to physical breakdown and lameness in the equine athlete amongst many other causes. Equine physiotherapy was not introduced until the early twentieth century, making it a relatively new practice. It has since evolved to allow for wearable therapies to be accessible to a broad spectrum of equestrians. The purpose of this study was to evaluate the effects of Rambo®Ionic (Horseware, Dundalk,Ireland), Lux Ceramic Therapy® (Schneider Saddlery Co., Inc., Ohio, USA), and Ice-Vibe® (Horseware, Dundalk,Ireland) therapeutic boots on the performance of sport horses during flatwork and jumping as well as determine biological changes as a response to treatment. This study utilized eight healthy horses that performed approximately ten minutes of exercise on the lunge line and through a jump chute for five consecutive days. Stride analysis was recorded during each exercise session, as well as thermal images and blood samples, were collected on days 1, 3, and 5 of each period. Therapeutics were applied in the morning prior to exercise as per the manufacturer's recommendation and were removed only for exercise. Serum was collected from the blood samples and was analyzed for concentrations of C reactive protein (CRP), basic fibroblast growth factor (bFGF), and tenascin C (TN-C). Results found minor correlations between improvement in performance and therapeutic treatment. It can be stated that treatment also aided in the moderation of the inflammatory response as well as improved circulation. It can be concluded that although there are no major changes in performance, treatment from therapeutic boots leads to biological alterations that may lead to a longer, healthier career.

Introduction

Equine lameness is the most common reason for performance failures in sport horses and can lead to serious financial and athletic losses (Doug Thal, 2016). Conformation, age, and physical exertion are a few of the many factors that influence a horse’s ability to remain in good physical health (Baxter et al., 2020). Compromised physical health often presents as lameness, most frequently related to ailments in the distal limb. Disease and injury to the distal limb result in pain, decreased performance, and increased risk of reinjury. After clinical symptoms of these injuries present, veterinarians can treat these injuries with advanced or invasive therapies and prescribe rest to allow for the structure to heal under limited stress. Historically, therapeutic technologies were used for recovery following the occurrence of an injury. However, recent advancements in technology have simplified therapeutic devices which allows them to be commercially made, making them readily available to consumers to be used for maintenance of the equine athlete.

Wearable therapeutics are popular amongst athletes, both human and equine, to prevent and protect from injury during exercise as well as to accelerate post-exercise recovery. Many of these products contain materials like tourmaline or ceramics and are infused into the fabric. Additional commercial products rely on mechanical stimulation to enhance therapeutic effects on tissues. Examples of each of these modes of action are available in commercial boots marketed for equines to be applied to the distal limb. Previous research shows how the dymanics of these different technologies may have a positive influence on equine physical health. For example, tourmaline is a naturally occurring crystal that has been shown to enhance cellular metabolism by producing negative ions and converting electromagnetic waves into infrared radiation (Zou et al., 2017). Alternatively, ceramic materials thermally manipulate the body to increase bloodflow (Li et al., 2018). Mechanical stimulation under the presence of ice improves circulation increase the flow of cooled blood to efficiently cool down the horse post-exercise and mitigates apoptosis in the soft tissue of the distal limb due to prolonged heat. Although research has demonstrated the potential capacity for how each of these technologies may benefit physical health and recovery, there is limited evaluation of how these technologies influence the horse's comfort in normal exercise conditions, free of clinical injury or recovery efforts. As such, there is a need to improve the characterization of how commercially available technologies influence horse comfort when applied in a non-clinical setting to support regular exercise activities.

The purpose of this study was to evaluate the effects of Rambo®Ionic (Horseware, Dundalk,Ireland), Lux Ceramic Therapy® (Schneider Saddlery Co., Inc., Ohio, USA), and Ice-Vibe® (Horseware, Dundalk,Ireland) therapeutic boots on the performance of sport horses during flatwork and jumping as well as determine biological changes as a response to treatment. Thermal images, blood sampling, and stride analysis were used to measure biological and performance changes in response to treatment. We hypothesize that with a consistent and proper application of the therapeutic boots, there will be increased consistency and improvement in the performance of sport horses as well as improved metabolic response to exercise.

Materials and Methods

Animals, Treatments, and Experimental Design

All animal use and procedures described within this study were approved by the Institutional Animal Care and Review Committee (IACUC) of Virginia Tech. Eight healthy horses (3 thoroughbreds, 3 warmbloods, 2 quarter horses; 3 mares, 6 geldings) in a light to moderate exercise program were used for data collection. Horses were stalled on weekdays and turned out into paddocks (n=5) on weeknights and weekends. Prior to the start of the study, horse height and girth were measured for calibration of the ALOGO™ MovePro (Alogo Technologies, Switzerland) stride sensor calculations. Horses were also trained to lunge in each direction at the walk, trot, and canter as well as canter through a jump chute off the left lead.

The study consisted of four periods lasting five days each with a ten-day washout period in between. On days one, three, and five of each period the horses were subject to thermal images and blood sampling. Temperature, pulse, and respiration were taken each morning prior to treatment. Two horses were assigned to each jump height (0.70m, 0.80m, 0.90m, 1.0m) according to athletic ability and treatment groups were arranged by jump height capability. A Latin square was used to arrange treatments for each animal in each period. The Latin Square was used to designate a treatment for each animal for each period without repeating the treatment for the animal in another period. Treatments consisted of control, Rambo®Ionic, Lux Ceramic Therapy®, and Ice-Vibe® boots.

Rambo Ionic® boots (Horseware Ireland, Dundalk, Ireland) were applied at 0800hr to the distal front limb while the horse was stalled during the day as per the manufacturer's recommendation; with the exception that no adjustment period was granted in each period. Two modes of application were used: a Velcro boot and a traditional standing wrap. The boots were only removed for exercise, lessons, and turn out at 1730hr.

Lux Ceramic Therapy® boots (Schneider Saddlery Co., Inc., Ohio, USA) were applied at 0800hr to the distal front limb while the horse was stalled during the day as per the manufacturer's recommendation. Again, given the experimental conditions, no adjustment period was granted in each period. The boots were secured using Velcro attachments and were removed for exercise, lessons, and turn out at 1730hr.

Horseware®Ireland's Ice-Vibe boots (Horseware Ireland, Dundalk, Ireland) were applied immediately before and after exercise. The boots have three vibration settings, but only the first two settings were used in this study as per the manufacturer's recommendation for use with exercise. Setting one was used prior to exercise for ten minutes at a low frequency. After exercise, cold packs were placed underneath the Ice-Vibe® boot and were worn for twenty minutes at a slightly higher frequency.

<u>Experimental Protocol</u>

For the 5 days of data collection during each period, each horse was brought in from the field by Virginia Tech farm stall and volunteers at approximately 0730 h and placed into a 12 by 12 box stall. On the 1^{st}, 3^{rd}, and 5^{th} days at approximately 0800 h, horses were restrained for blood sample collection via jugular venipuncture. Blood collection alternated between the right and left jugular with each collection. On these same days, and immediately following blood sampling, horses' legs were thermally imaged using an HT-19 thermal imaging camera (HTI, La Vergne, TN). This camera has a temperature range from -20 to 300°C and a resolution of 320 by 240 dots per inch (DPI). Images were collected from the dorsal, palmar, medial, and lateral aspects of the distal front limb. Animals receiving ceramic or ionic treatment during any given period, boots were applied as described previously immediately following wither arrival to the stall (days 2 and 4) or after blood sampling (days 1, 3, and 5).

Beginning at 1200 h and running through roughly 1500 h, the horses were individually exercised for approximately ten minutes a day. Preparation for exercise consisted of removing horses from the stalls, restraining them in cross ties, and removing boots (if applicable). Horses' legs were thermally imaged (days 1, 3, and 5) and horses were outfitted with a lunging surcingle, equipped with the ALOGO™ MovePro (Alogo Technologies, Switzerland) sensor on the girth strap. To achieve balance, the girth was tightened evenly on each side. Stride length, strike power, jump height, and balance parameters were recorded during exercise. Horses were walked to the exercise arena where the sensor recording was started via Bluetooth connection using the ALOGO™ app. Horses were warmed up on a lunge line in both directions at the walk, trot, and canter (approximately 3 minutes per gait). Once acclimated, the horse was asked to canter through a jump chute with three obstacles set twenty-four feet apart three times. The final time through the jump chute, the third jump in the sequence was raised 0.05 meters to the horse's designated height.

After exercise, sensor recording was stopped before leaving the exercise arena. Once removed from the arena, horses were restrained on the cross ties, and lunging equipment was removed. Thermal images were taken (days 1, 3, and 5) as previously mentioned. Horses were lightly hosed over with cold water to remove sweat accumulation. Boots were then reapplied as previously described and horses were returned to their stall. Designated boots were removed, and horses were turned out to their respective fields at 1750 h.

Serum Analysis

Immediately following collection, blood samples were centrifuged, and serum was collected and frozen for future analysis. Samples were individually thawed at the time of analysis. ELISA kits (MyBioSource, Inc. , San Diego, CA) were used to measure serum concentrations of C-reactive protein (CRP), basic fibroblast growth factor (bFGF), and tenascin-C (TN-C) to quantify inflammatory response and cell regeneration in response to treatment. Reagents for all ELISA kits were stored between 2-8°C until use. All plates consisted of 96 wells and standard solutions and samples were repeated twice each plate. A baseline concentration of 0 was measured on each plate by leaving 2 wells blank. All plates were incubated for a designated amount of time (CRP: 80 min, 50 min, 50 min, 20 min; bFGF: 60 min, 15 min; TN-C: 60 min, 15 min) at 37°C and were manually aspirated and washed between incubation periods before a new reagent was added. Optical density was measured at 450 nm using an ELISA plate reader within 15 minutes of adding stop solution to each well.

Horse CRP ELISA kit (MyBioSource, Inc. , San Diego, CA) has a sensitivity of 2.43 ng/mL and detection range of 6.25 ng/mL-400 ng/mL. Standard solutions were prepared using a double dilution method (400 ng/mL, 200 ng/mL, 100 ng/mL, 50 ng/mL, 25 ng/mL, 12.5 ng/mL, 6.25 ng/mL). Biotinylated antibody and streptavidin-HRP were diluted to the working concentration using the respective dilutants supplied by the manufacturer. The 25x wash buffer was diluted to 1x working concentration with distilled water.

Horse bFGF ELISA kit (MyBioSource, Inc. , San Diego, CA) has a sensitivity of 1.0 pg/mL and detection range of 6.25 pg/mL-200 pg/mL. Standard concentrations (200 pg/mL, 100 pg/mL, 50 pg/mL, 25 pg/mL, 12.5 pg/mL, 6.25 pg/mL) were supplied in each kit. Reagent preparation consisted of creating a working concentration of 1x wash solution by diluting 20x wash buffer with distilled water.

Horse TN-C ELISA kit (MyBioSource, Inc. , San Diego, CA) has a sensitivity of 0.1 ng/mL and detection range of 0.625 ng/mL-20 ng/mL. Standard concentrations (20 ng/mL, 10 ng/mL, 5 ng/mL, 2.5 ng/mL, 1.25 ng/mL, 0.625 ng/mL) were supplied in each kit. Reagent preparation consisted of creating a 1x wash solution by diluting 20x wash buffer with distilled water.

Statistical Analysis

Data collected during the study were compiled into a spreadsheet and organized by vitals, serum concentrations of CRP, bFGF, and TN-C, flatwork, jumping, and thermal imaging. Statistical analysis was conducted using RStudio (Version 1. 4. 1717, Boston, MA). This study utilized a linear mixed effects model where the fixed effects accounted for boot type, image orientation, and day of exposure; and the random effects accounted for period and animal. An analysis of variance using Satterthwaite's method was performed to assess behavior, jump strike power, jump height, jump longitudinal balance, jump lateral balance, and jump straightness. Stride cadence, stride height, stride strike power, stride longitudinal balance, stride lateral balance, and stride straightness were also analyzed using Satterthwaite's method. Data means separation were calculated using least square means and Tukey method. Serum concentrations for CRP, bFGF, and TN-C were calculated using a standard curve determined by the standard solutions to develop a regression model. Thermal images were analyzed using ImageJ (National Institute of Health, Bethesda, MD). Red, blue, and green pixels indicating temperature were measured from all four perspectives at the level of the knee, cannon bone, fetlock, pastern, and hoof.

Results & Discussion

The design of this study allowed the horse to simulate an exercise ride without rider intervention. With the influence of the rider, the horse may balance differently and compromise gait quality. With the application of therapeutic boots, there is the potential for changes in performance and circulation as well as biochemical changes. Effects of treatment were evaluated based on day, boot type, and jump height (low jump height (LJH; 0.61m) and high jump height (HJH; 0,84m)).

Heart rate (HR), body temperature (BT), and respiration rate (RR) were not only monitored as an indicator of health, but also to determine response to treatment relative to baseline measurements. **Error! Reference source not found.** demonstrates the change in resting HR in beats per minute (bpm) relative to baseline where day 1 acts as the baseline measurement and day 5 is used to calculate change. Data shows a significant interaction between boot type and jump height (P=0.013). Horses in the HJH group had very different responses for each treatment. Ceramic treatment expressed a decrease in HR (-4.59±1.5) and Ice-Vibe had the opposite effect with an increase in HR (3.76±1.5). Studies show that whole-body vibration therapy increases HR and heart rate variability (HRV) in the elderly (Licurci MD, 2018; Wang L, 2014). This finding implies that HR benefits while at rest and during exercise from whole-body vibration which occurred in the distal limb with Ice-Vibe. No notable changes in resting HR occurred when receiving treatment from Ionic boots (-0.05±1.46). Figure 2.2 explores the change in RR in breaths per minute (bpm) relative to baseline where day 1 serves as the baseline measurement and day 5 is used to calculate change. There was a significant interaction between boot type and jump height on the change in RR (P=0.019). Horses in the HJH receiving Ice-Vibe treatment (-1.13±2.38) had very similar change compared to control (-0.57 ±2.34), both expressing a minor decrease in RR. Ceramic treatment in HJH horses had a larger decrease in RR (-5.24±2.38) whereas Ionic treatment in the HJH showed an increase in RR (2.93±2.34). Figure 2.3 shows the change in resting BT relative to baseline where day 1 served as baseline measurements and day 5 measurements were used to calculate change. There was a significant interaction between boot type and jump height on the change in resting BT (P=0.003). Horses receiving ceramic treatment (-0.083±0.154) in the HJH group have a similar change in BT with the control (-0.192±0.151). Ice-Vibe treatment in the HJH group also expressed a greater decrease in BT (-0.289±0.154) and Ionic treatment experienced an increase in BT (0.255±0.151).

Flat work analysis resulted in a significant interaction between boot type and jump height on canter velocity (P=0.065) and canter cadence (P=0.046) as represented in Figure 2.4 and Figure 2.5. Canter velocity (CV) refers to the rate at which the horse travels across the ground in meters per minute (mpm). When analyzing HJH horses, all treatment groups demonstrate an increase in CV. Ice-Vibe treatment experienced the most increased mean CV (293±50) compared to control (108±63). Ceramic treatment was most similar to control (134±52) and Ionic treatment had increased CV as well (166±75).

Jump velocity (JV) refers to the rate of propulsion over a jump in meters per minute (mpm). Results show an interaction between boot type, day, and jump height on JV (P=0.022).

Figure 2.6 represents mean JV on day 1 of each period where Figure 2.7 displays mean JV on day 5. Regardless of treatment, HJH horses had varying JV on day 1. Both treatment from Ice-Vibe (224±83) and Ionic (72±118) resulted in lower JV compared to control (323±88). Ceramic treatment expressed an increase in mean JV (499±81). By day 5, ceramic treatment resulted in a decrease in mean JV (367±83) whereas Ionic (152±144) and Ice-Vibe (319±76) experienced an increase. Mean JV for all treatment groups surpassed the control (151±97) on day 5. Slower jumps are typically associated with improved jump quality. However, response repeatability is limited due to high bouts of repeatability after several days, but lower instances of repeatability during early runs through the jump chute (de Godoi FN, 2014).

Changes in lateral balance (LatB) were recognized according to boot type, day, and jump height (P=0.021). Mean LatB is represented in Figure 2.8 on day 1 and Figure 2.9 on day 5. There were no significant differences in LatB among treatments early in exposure. However, by day 5, HJH horses had a tendency to lean left in the ceramic (-7.45±2), control (-6.92±2.02), and Ionic (-5.09±1.93) groups. Ice-Vibe treatment in HJH horses had an opposite result and tended to lean right (7.2±1.85). A horse that balances most of its weight on one side over the other during exercise is applying the most stress to the limbs on the side the horse is leaning. If lateral unbalance remains consistent, over time can lead to tears in the soft tissue and allows for the onset of joint disease. Irregular LatB can be an indicator of lameness and presents itself when the horse is consistently leaning to one side, showing favoritism to the painful limb. The lateral unbalance is most prominent when the horse is tracking on a circle or around a turn. This is significant at the trot and is due to the changes in point force application that are needed to keep the horse balanced during the lateral gait (Merritt et al., 2014). Changes in LatB aid in supporting the horse. A strong left lead from most treatment groups can be a result of lunging and cantering through the jump chute on the left lead. Horses generally lean into the turn and can be seen in the data. Because Ice-Vibe experienced an opposite effect where the horse leaned against the turn suggests not only improved balance, but straightness as well.

Longitudinal balance (LonB) determines the horse's distribution of weight between fore and hind limbs. Considering horses naturally balance 60% of their body weight on the forelimbs, we expect LonB to favor the front end of the horse. There was a relationship between boot type, day, and jump height that had a significant influence on mean LonB (P <0.001). Figure 2.10 represents mean jump LonB on day 1 whereas Figure 2.11 represent mean jump LonB on day 5.

There is no significance in mean jump LonB as a result of treatment early in exposure. However, on day 5, horses treated with Ice-Vibe boots (29.6±2.08) showed elevated LonB compared to other treatments and control (17.4±2.26). A horse that bears excess weight on the forelimb's experiences increased concussive forces and strain. Both factors can lead to the deterioration and damage of soft tissue structures in the distal limb. This is supported by evidence that maximum strain occurs during the stance phase of the stride when the horse bears all of its weight on the limb (Lochner FK, 1980). Although the distal limb is designed to accommodate increased loads, the tendons and ligaments do not always perform as they should as seen in horses with healed tears or ruptures as well as aging horses. Elevated LonB can suggest an improvement in jumping technique based on the horses ability to adequately clear the fence (P.N.R Powers, 2000).

C reactive protein (CRP) is produced as a response to inflammatory cytokines initiated by trauma, inflammation, or infection (Du Clos, 2000). CRP was analyzed compared to baseline (Day 1 concentrations) and is displayed in Figure 2.12. There was no significance in the influence of boot type, day, or jump height on relative change in CRP concentration. However, horses receiving treatment from Ceramic (-0.044±0.0554), Ionic (-0.0502±0.0511), and Ice-Vibe (-0.0613±0.0533) all experienced a decrease in CRP concentrations relative to baseline which is opposite of the control (0.0376±0.0511) which had an increase in CRP concentration. The findings in the current study did not match what was observed in the literature. When a thermotherapeutic setting, like Ceramic and Ionic, studies report a decrease in CRP concentrations (Kunutsor et al., 2018). It has also been reported that cryotherapy also resulted in decreased CRP concentrations in healthy adult humans (Pournot et al., 2011). The mentioned studies focused on a whole-body effect in humans whereas treatment here was restricted to the distal limb in horses making treatment unable to create an adequate response. This could also be due to high levels of variability observed within the data.

Basic fibroblast growth factor (bFGF) is responsible for cellular proliferation and has a natural therapeutic due to its promotion of self-renewal (XiaokunLi, 2018). In Figure 2.13, proportional changes in bFGF concentration relative to baseline are represented. There was significant influence of jump height ($P=0.02$) as well as the interaction between day and jump height ($P=0.051$) on change in bFGF concentrations. Horses jumping HJH had increased concentrations of bFGF on day 3 (0.0586±0.153) as well as day 5 (0.405±0.153). Whereas horses jumping LJH experienced a decrease in bFGF concentrations on day 3 (-0.259±0.168) and day 5 (-0.074±0.168). Basic fibroblast growth factor supports increased blood flow to the limb and is enhanced with exercise (H. T. Yang, 1998). With the occurance of the increase in bFGF concentration in HJH horses on days 3 and 5 implies that these horses were performing enough exercise to produce this metabolic response. This is further supported because there was no significant response to bFGF concentration in LJH horses.

Tenascin C (TN-C) is primarily expressed in the tendons and responds quickly to tissue in need of repair (Midwood & Orend, 2009). It is particularly important during capillary remodeling during exercise as well as muscle repair (Flück M, 2007; Valdivieso et al., 2017). The proportional relative change in TNC concentration is displayed in Figure 2.14. The interaction between boot type, jump height, and day has shown to have significant influence on TN-C concentrations (P=0.02). When looking at HJH horses, there are similar responses between Ceramic and control as well as Ice-Vibe and Ionic. Compared to baseline Ceramic (-0.305±0.124) and the control (-0.208±0.121) experience a decrease in TN-C. However, Ionic (0.112±0.121) and Ice-Vibe (0.096±0.124) responded with an increase in TN-C concentrations. Literature suggests that when exposed to low-frequency vibration, TN-C concentrations were elevated in rats (Chen et al., 2018). These results coincide with what was observed in horses receiving Ice-Vibe treatment. However, exposure to localized thermotherapy had no significant result in the production of TN-C in humans (Hyldahl et al., 2021). This suggests that the elevation in TN-C concentrations from the Ionic group is due to another effect from treatment. Based on the regenerative properties of TN-C, elevated concentrations suggest the Ice-Vibe and Ionic therapies may be more beneficial as a means of preparation for exercise.

Thermal images were evaluated for changes in localized temperature as well as concentration of red, blue, and green pixels. There was a significant influence of the interaction between boot type and time of measurement on temperature of the knee (P<0.001) and is displayed in Figure 2.15. The most notable increase in temperature occurred between the morning measurement and pre-exercise measurement. This is distinctly recognized in with Ceramic treatment (AM: 24.1±0.49, Before: 27±0.5) and Ice-Vibe treatment (AM: 25.8±0.49, Before: 27.7±0.49). There was no significant change in temperature between pre-exercise and post-exercise measurements. Figure 2.16 displays the significance of the interaction between boot type and time of measurement (P<0.001). The most notable increase in temperature occurred between AM and pre-exercise measurements for Ice-Vibe (AM: 25.4±0.51, Before:

27.7±0.51) and Ceramic (AM:24.4±0.52, Before:25.5±0.51) treatments. There was a contradictory decrease in localized temperature occurred in the control (AM: 27±0.36, Before:26.8±0.51) and Ionic (AM:26.7±0.57, Before:26.5±0.58) treatment group. No significant change in localized temperature between pre-exercise and post-exercise measurements were found. Hoof temperature was significantly influenced by boot type (P=0.013) and is displayed in Figure 2.17. Compared to control (27.6±0.41), horses receiving Ceramic treatment experienced a lower hoof temperature (27±0.48). Higher hoof temperatures were represented in Ice-Vibe (28±0.48) and Ionic (27.9±0.51) treatment groups. Thermotherapy, such as Ionic, has the ability to increase tissue metabolism, blood flow, inflammation, and connective tissue extensibility (Nadler SF, 2004) . Seeing increased temperatures in structures such as the hoof in response to treatment is expected considering the vasculature of that area.

Conclusions

This paper analyzed the efficacy of Rambo®Ionic, Lux Ceramic®, and Ice-Vibe® therapeutic boots on their abilities to influence performance, inflammation, and localized temperature. Based on the data collected, it can be concluded that each treatment effected the horse differently. Results were most significant in HJH horses compared to LJH horses. When receiving ceramic treatment, HJH horses experienced increased HR and RR as well as increased jump velocity. Regardless of jump height, localized limb temperatures were lower during morning measurements. During Ice-Vibe treatment, HJH horses had elevated HR and TN-C concentrations. When reviewing day 5 measurements, HJH horses receiving Ice-Vibe treatment also had increased jump velocity, height, and longitudinal balance. Ionic treatment resulted in increased RR, BT, and TN-C concentrations in the HJH group. Comparatively, Ionic treatment also resulted in reduced limb temperature post-exercise. The use of wearable therapeutics in a non-clinical setting can influence factors associated with performance and physical health. These findings can allow for future research to be performed in an environment that is representative of typical exercise between horse and rider.

Figures

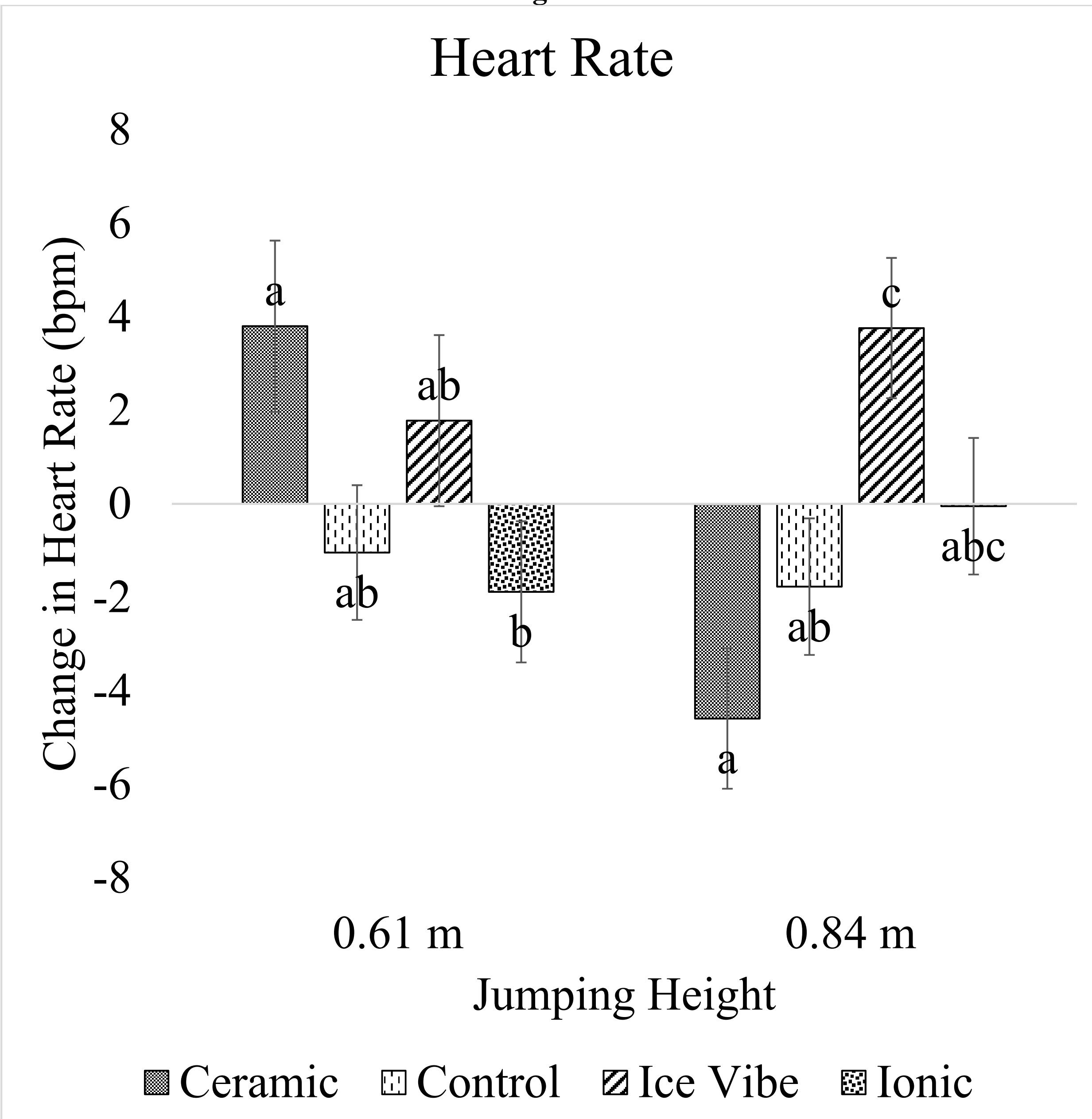

Figure 2.1Change in Resting Heart Rate Relative to Baseline Heart rate was collected each morning prior to exposure to treatment. Baseline heart rate corresponds to day 1 of each period and change was measured based on the difference in beats per minute (bpm) from day 5 measurements. There was an effect of jump height (0.61 meters and 0.84 meters) as well as treatment on the change in heart rate (P=0.013). In the higher jump group, treatment from ceramic boots shows a decrease in heart rate, Ice-Vibe boots have an increase in heart rate, and ionic treatment remains near baseline. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

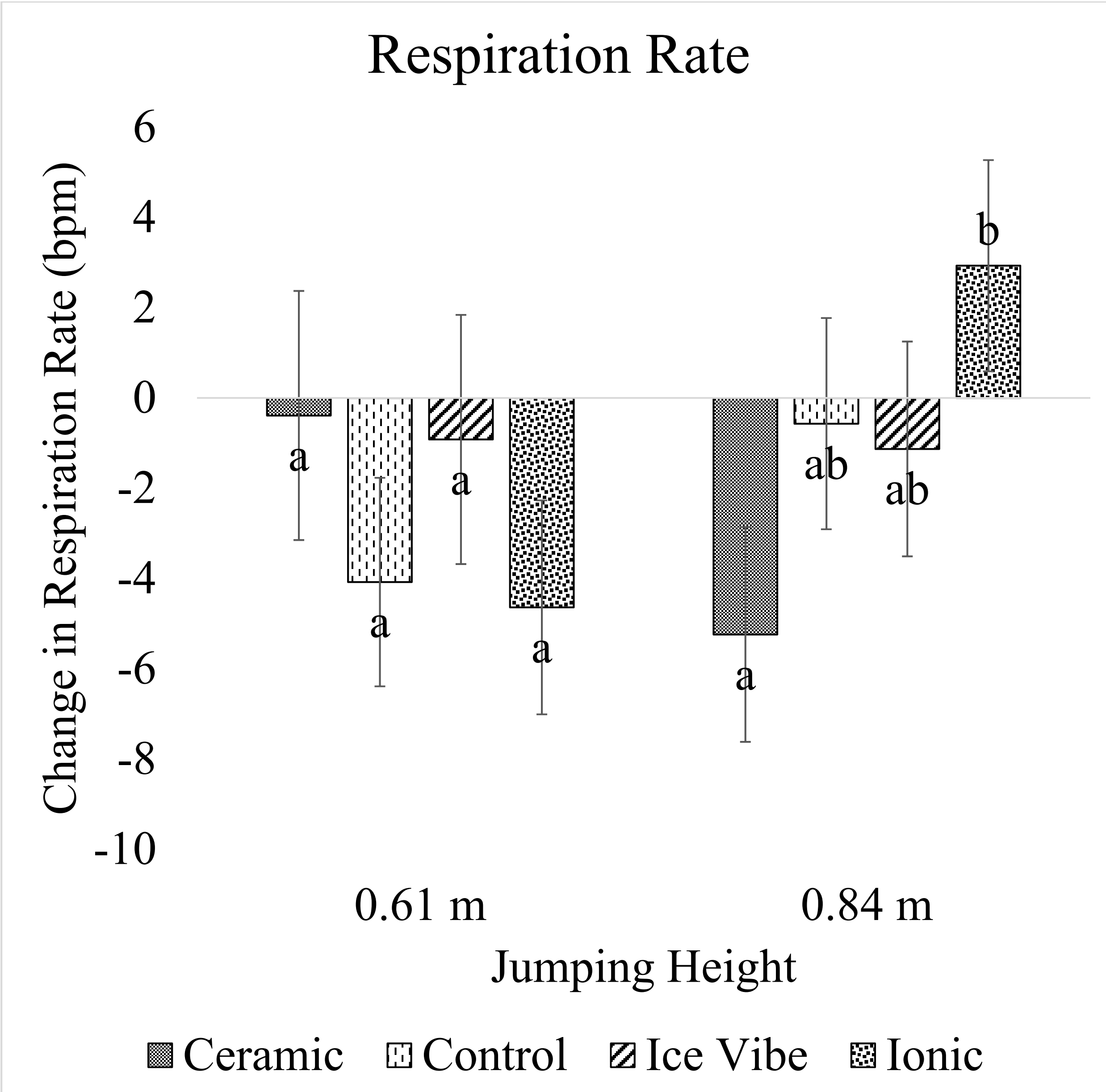

Figure 2.2 Change in Resting Respiration Rate Relative to Baseline Respiration rate was measured prior to exposure to treatment while the horse was undisturbed in its stall. Baseline respiration rate refers to breaths per minute (bpm) recorded on day 1 and the difference was calculated using day 5 respiration rates. There is an interaction between treatment and jump height (0.61 meters and 0.84 meters) on the change in resting respiration rate relative to baseline (P=0.019). In the higher jumping group, horses experience a decrease in respiration rate when receiving ceramic treatment and an increase in respiration rate when receiving ionic treatment. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

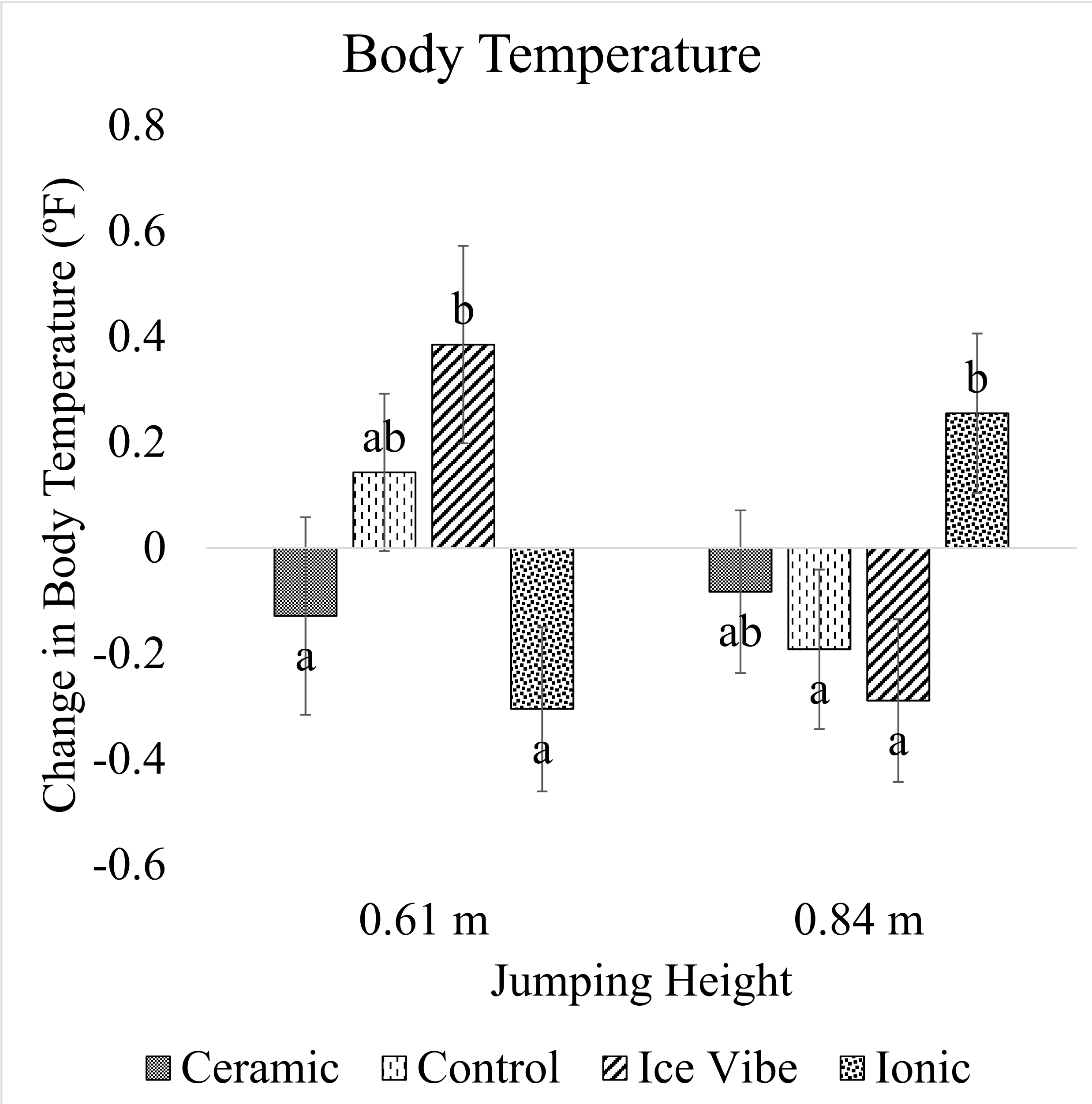

Figure 2.3 Change in Body Temperature Relative to Baseline Body temperature was recorded using a rectal digital thermometer prior to exposure to treatment. Day 1 body temperature (ºC) refers to baseline levels. The change in body temperature was calculated using mean day 5 temperatures. There was significant influence of treatment and jump height (0.61 meters and 0.84 meters) on the change in body temperature (P=0.03). In the higher jumping group, horses experience a decrease in body temperature when receiving ice-vibe treatment and an increase in body temperature when receiving ionic treatment. Horses receiving treatment from ceramic boots express similarly to the control group. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

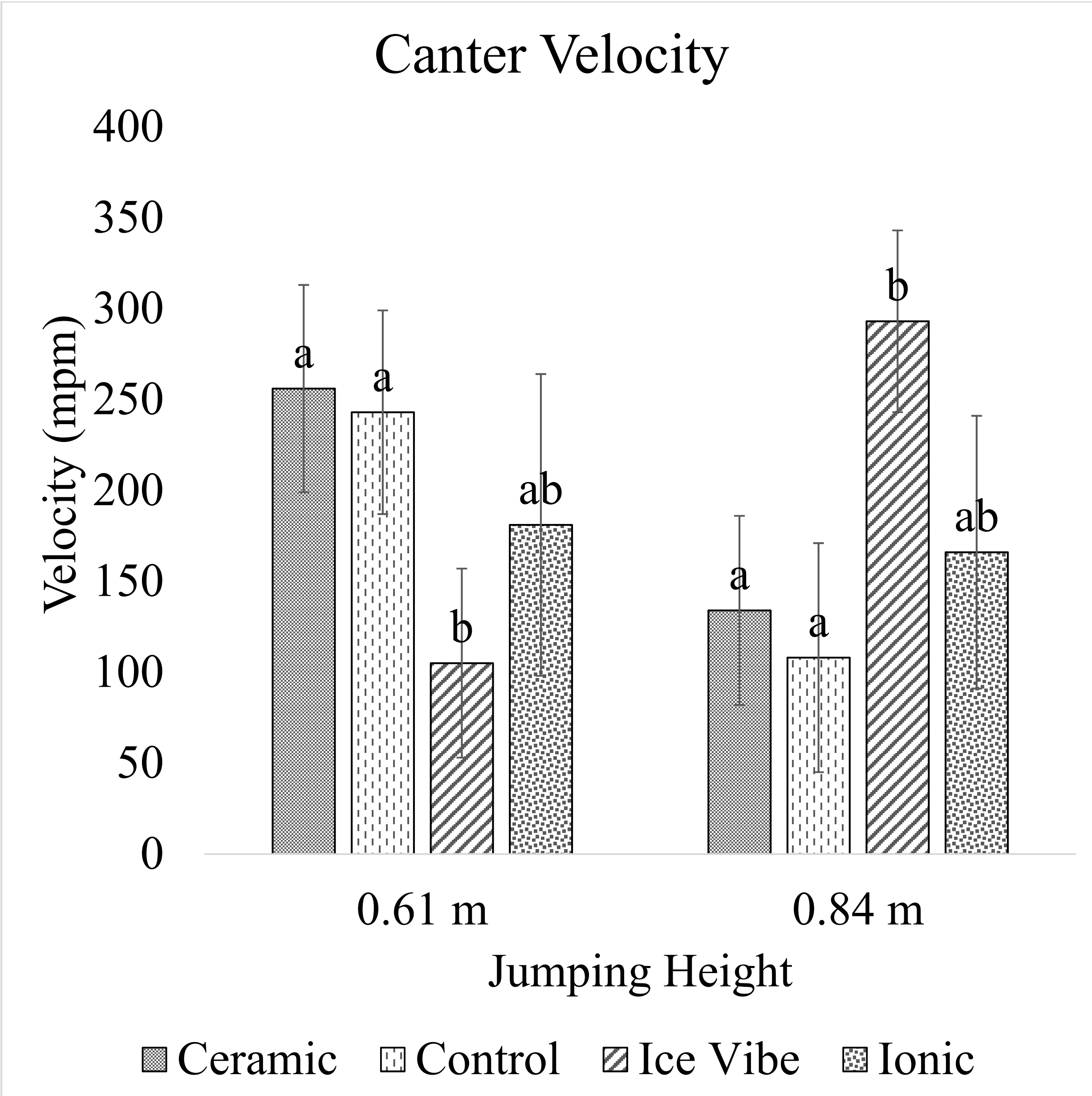

Figure 2.4 Canter Velocity Canter velocity was measured in meters per minute (mpm). There was an influence on jump height (0.61 meters and 0.84 meters) and treatment on canter velocity (P=0.065). When receiving treatment from ice-vibe boots, horses jumping higher express an increase in canter velocity. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

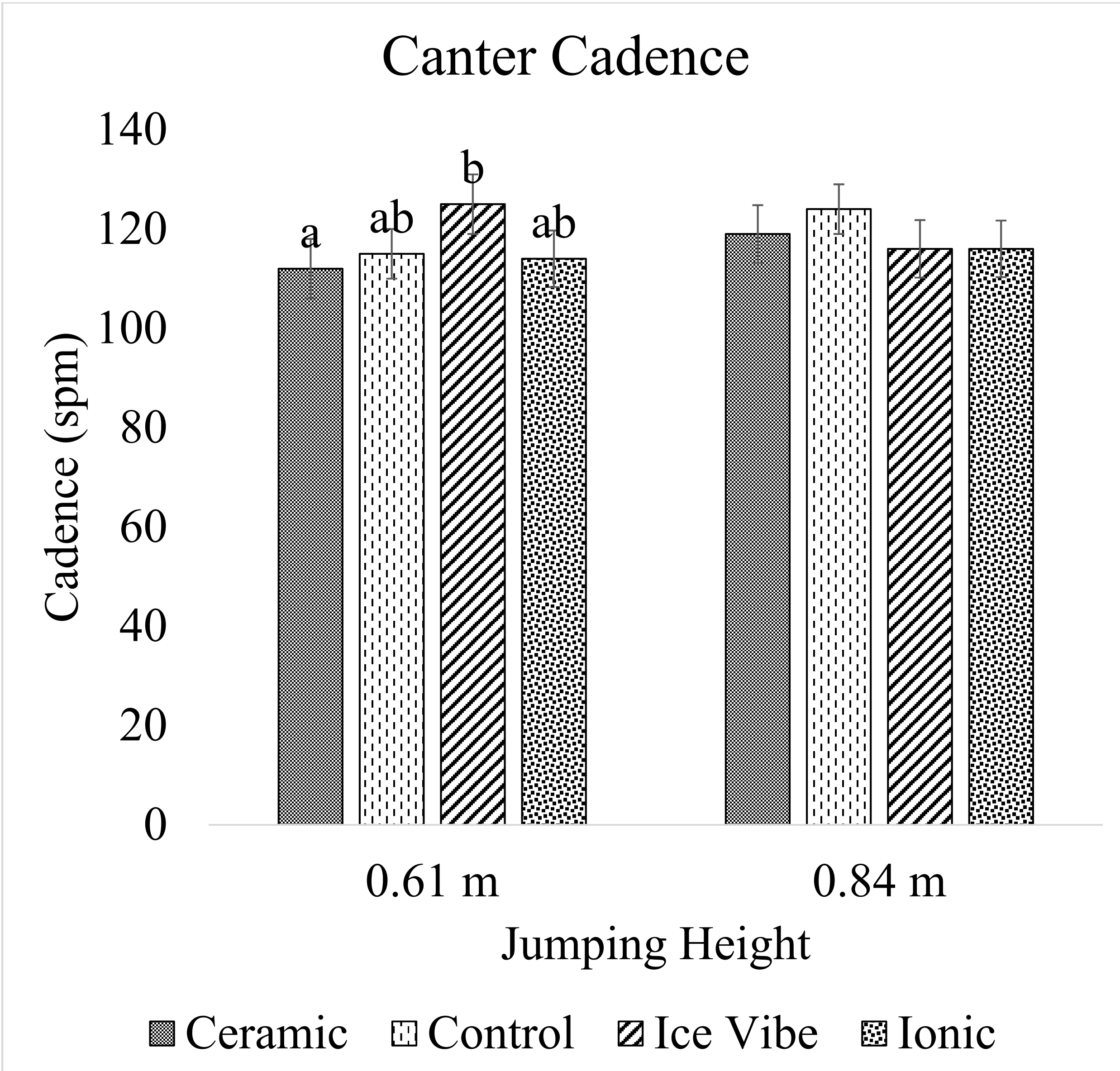

Figure 2.5 Canter Cadence Canter cadence was measured in strides per minute (spm). Mean canter cadence was calculated according to jump height and treatment. There was an effect of treatment on canter cadence (P=0.046). When jumping higher, horses experienced a slower canter cadence. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

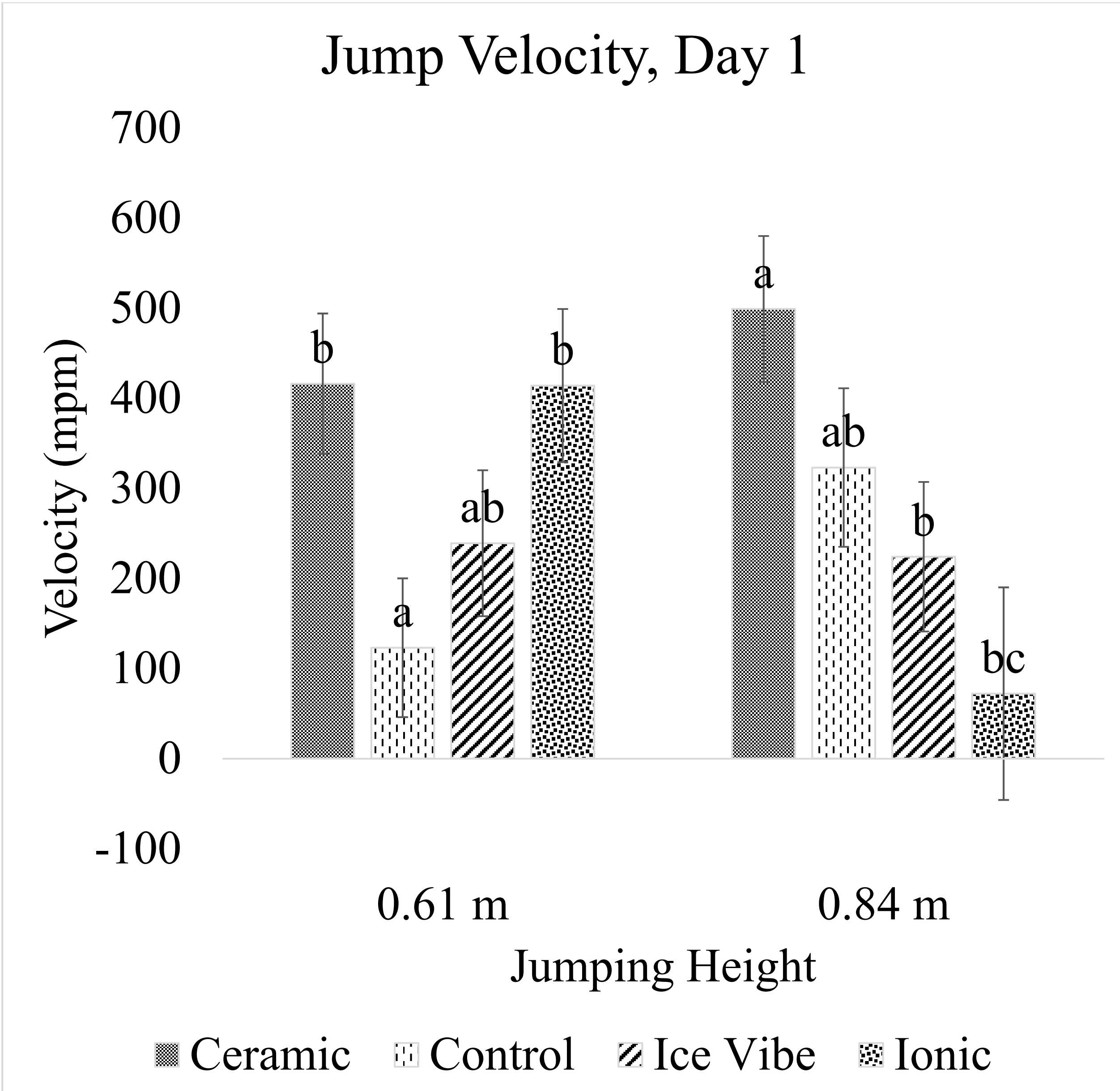

Figure 2.6 Jump Velocity on Day 1 Velocity was measured in meters per minute (mpm) over the course of a jump. Mean jump velocity was calculated for jump height and treatment. There was an interaction between treatment and jump height on the velocity of the jump (P=0.022). When jumping higher, horses receiving ceramic treatment express an increase in velocity where ice-vibe and ionic express a decrease compared to controls. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

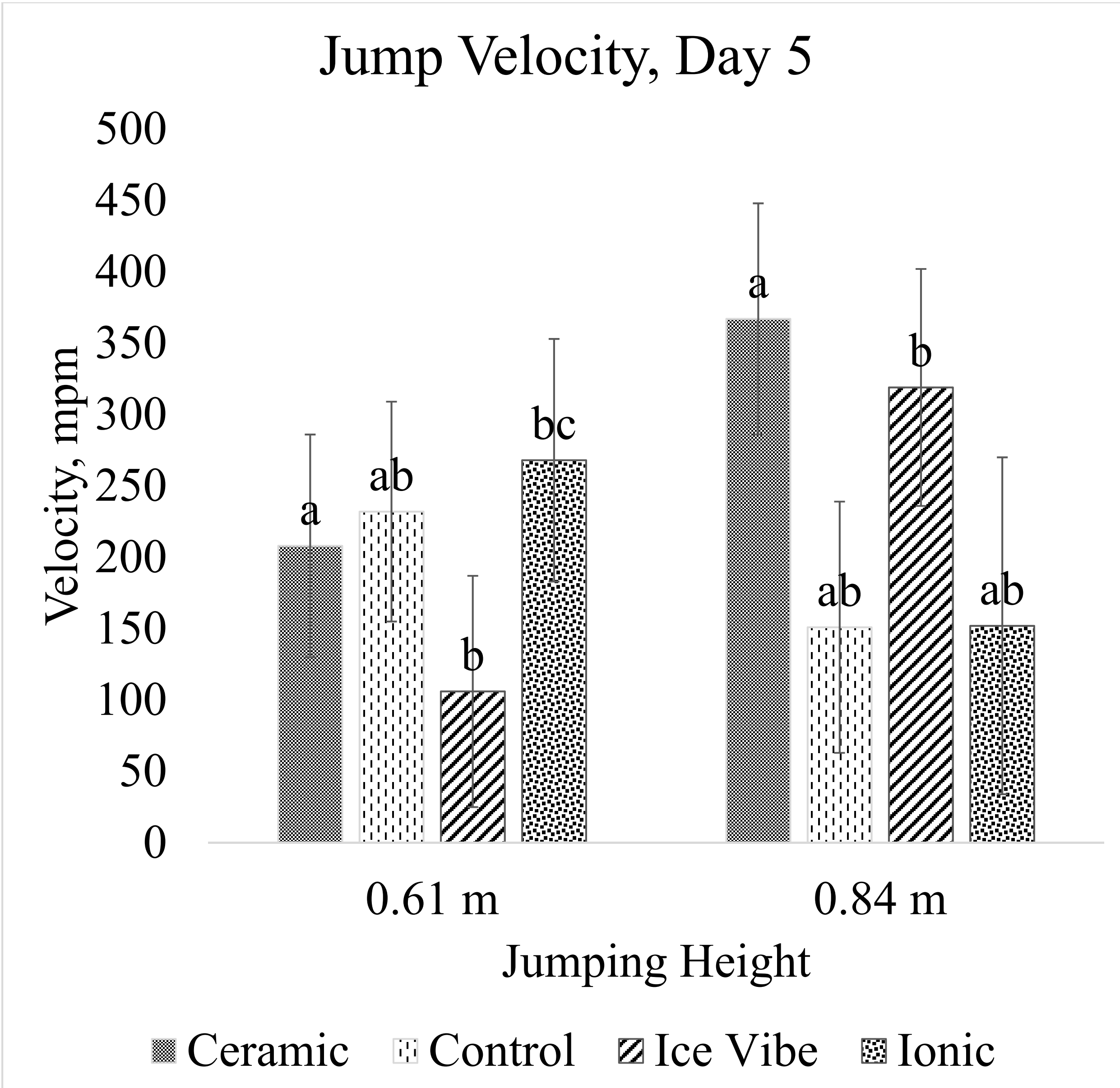

Figure 2.7 Jump Velocity on Day 5 Jump velocity on day 5 was measured in meters per minute (mpm). Mean jump velocity was calculated by jump height and treatment. There was an interaction between treatment and jump height on jump velocity (P=0.022). Ceramic and ice-vibe treatment shows a higher jump velocity compared to ionic treatment which resulted similarly to the control group when horses were jumping higher. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

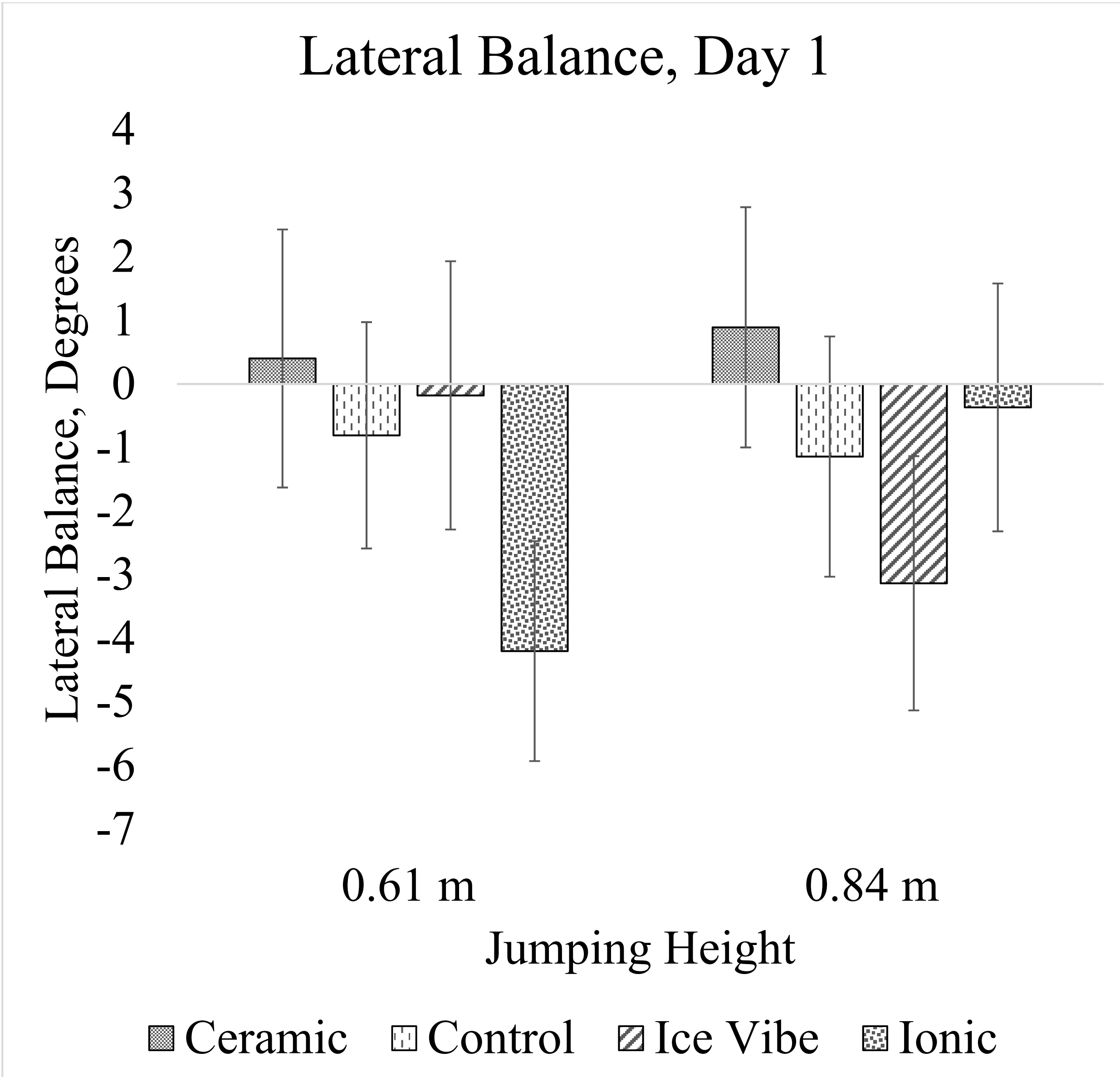

Figure 2.8 Lateral Balance on Day 1 Lateral balance was measured in degrees. A negative value for lateral balance indicates that the horse leaned more to the left whereas a positive value indicates a stronger right lean. Mean lateral balance was calculated by jump height and treatment. Lateral balance over the jump was influenced by an interaction between treatment and jump height (P=0.021). When horses were jumping higher (0.84 meters), those receiving ceramic treatment had a right lateral balance. Ice-vibe treatment resulted in a strong left lateral balance, and ionic treatment, although having a minor left lean, remained balanced compared to the control. Standard error bars show variation in the data.

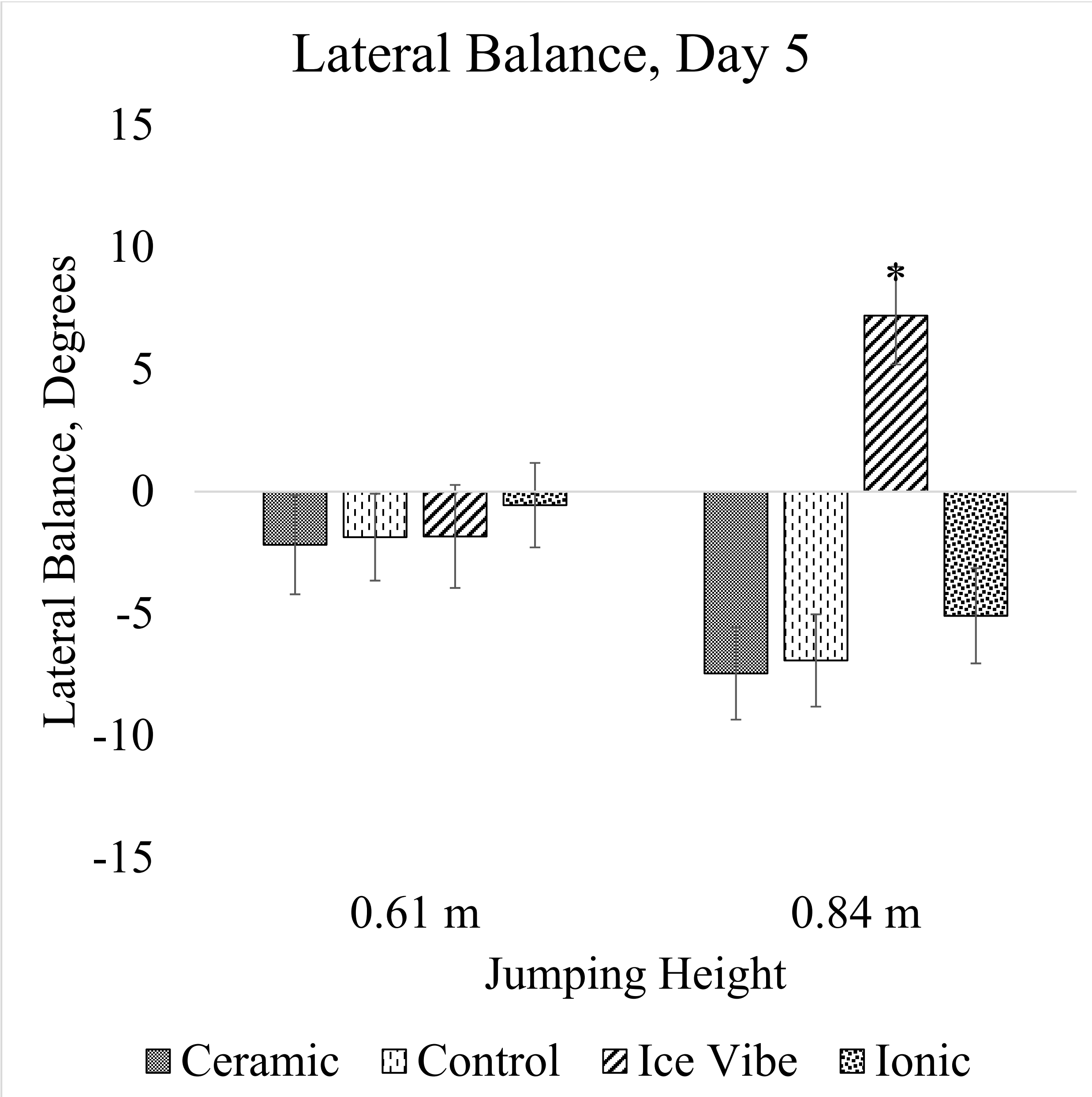

Figure 2.9 Lateral Balance on Day 5 Lateral balance was measured in degrees. A negative value for lateral balance indicates that the horse leaned more to the left whereas a positive value indicates a stronger right lean. Mean lateral balance was calculated by jump height and treatment. Lateral balance over the jump was influenced by an interaction between treatment and jump height (P=0.021). When horses were jumping higher (0.84 meters), those receiving ceramic and ionic treatment had a left lateral balance similar to the control group. Ice-vibe treatment resulted in a strong right lateral balance. Standard error bars show variation in the data.

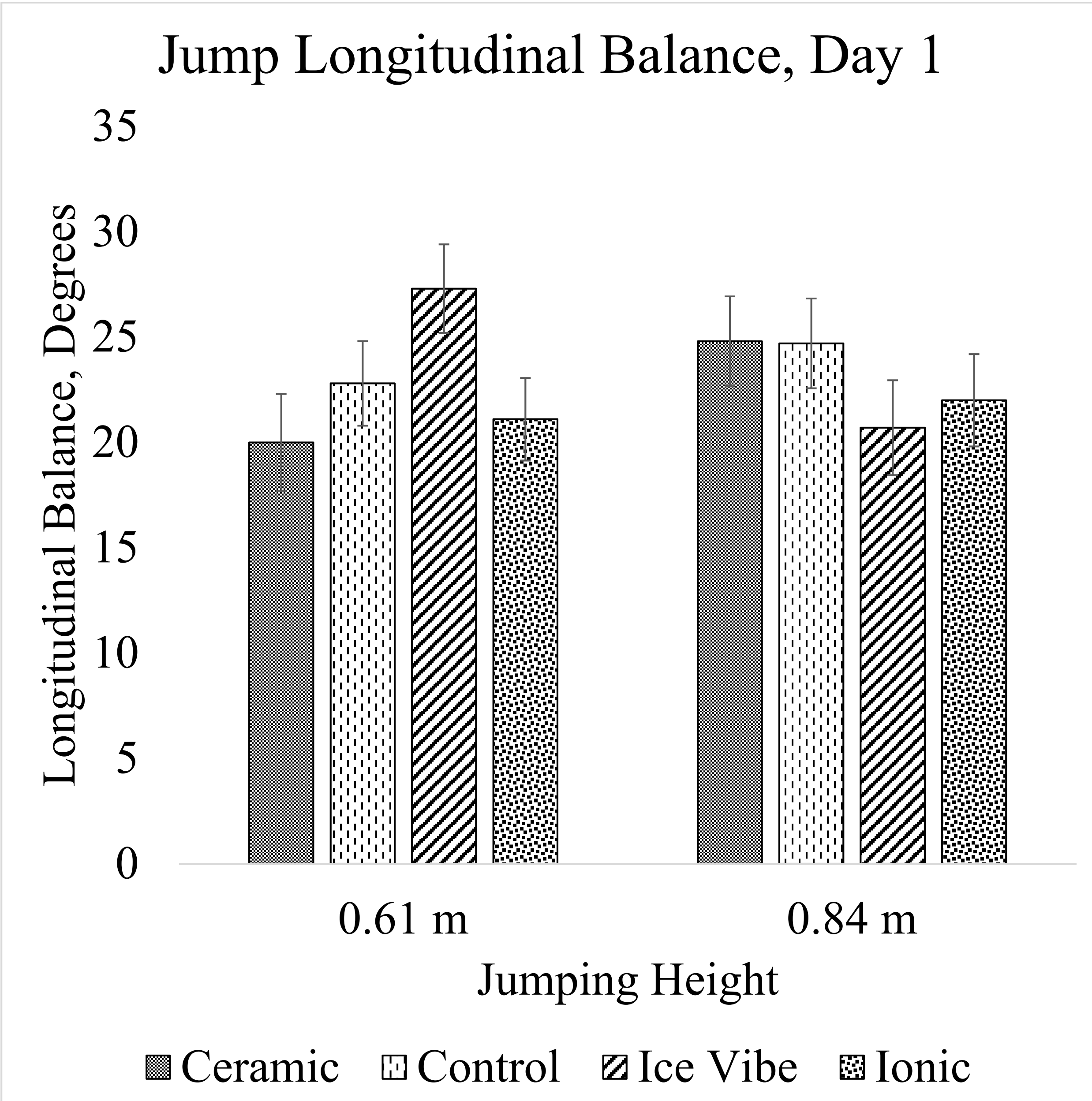

Figure 2.10 Jump Longitudinal Balance on Day 1 Longitudinal balance was measured in degrees and indicates the trajectory of the jump. Mean longitudinal balance was calculated by jump height and treatment. There was influence of treatment and jump height on longitudinal balance (P<0.001). When jumoing higher, horses experienced similar trajectory to that of control, and treatment from ice-vibe and ionic boots resulted in a lower longitudinal balance. Standard error bars show variation in the data.

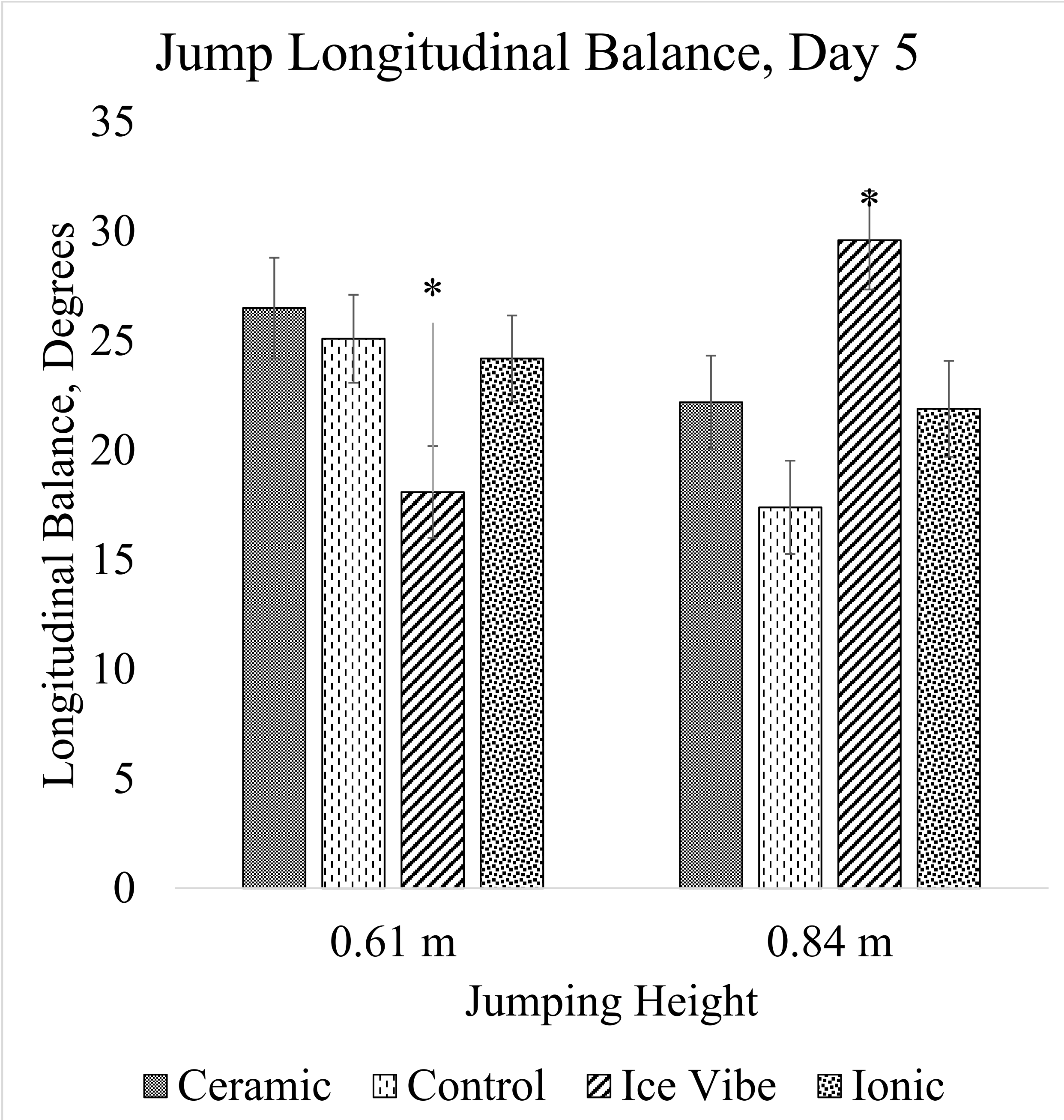

Figure 2.11 Mean Longitudinal Balance on Day 5 Longitudinal balance was measured in degrees and indicates the trajectory of the jump. Mean longitudinal balance was calculated for jump height and treatment. There was influence of treatment and jump height on longitudinal balance (P<0.001). When jumping higher, horses experienced an increase in jump trajectory compared to control. This increase in longitudinal balance was most significant in horses receiving treatment from ice-vibe (*). Standard error bars show variation in the data.

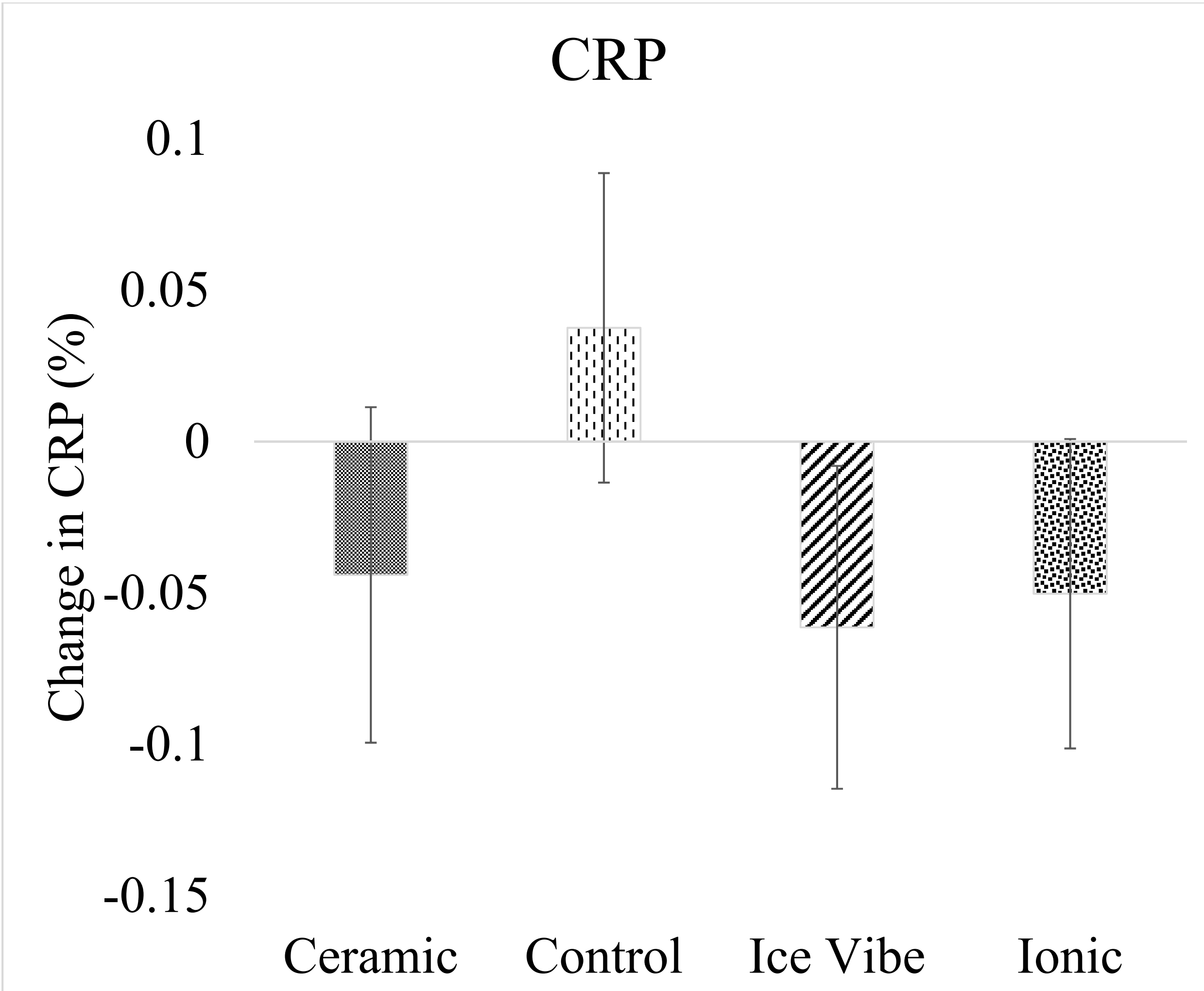

Figure 2.12 Change in CRP Concentration Relative to Baseline C Reactive Protein (CRP) is an inflammatory response as a result of trauma, injury, or disease. Regardless of treatment, there is a decrease of CRP concentrations of nearly 5%, however there is no effect of treatment on concentration (P>0.05). Standard error bars show variation in the data.

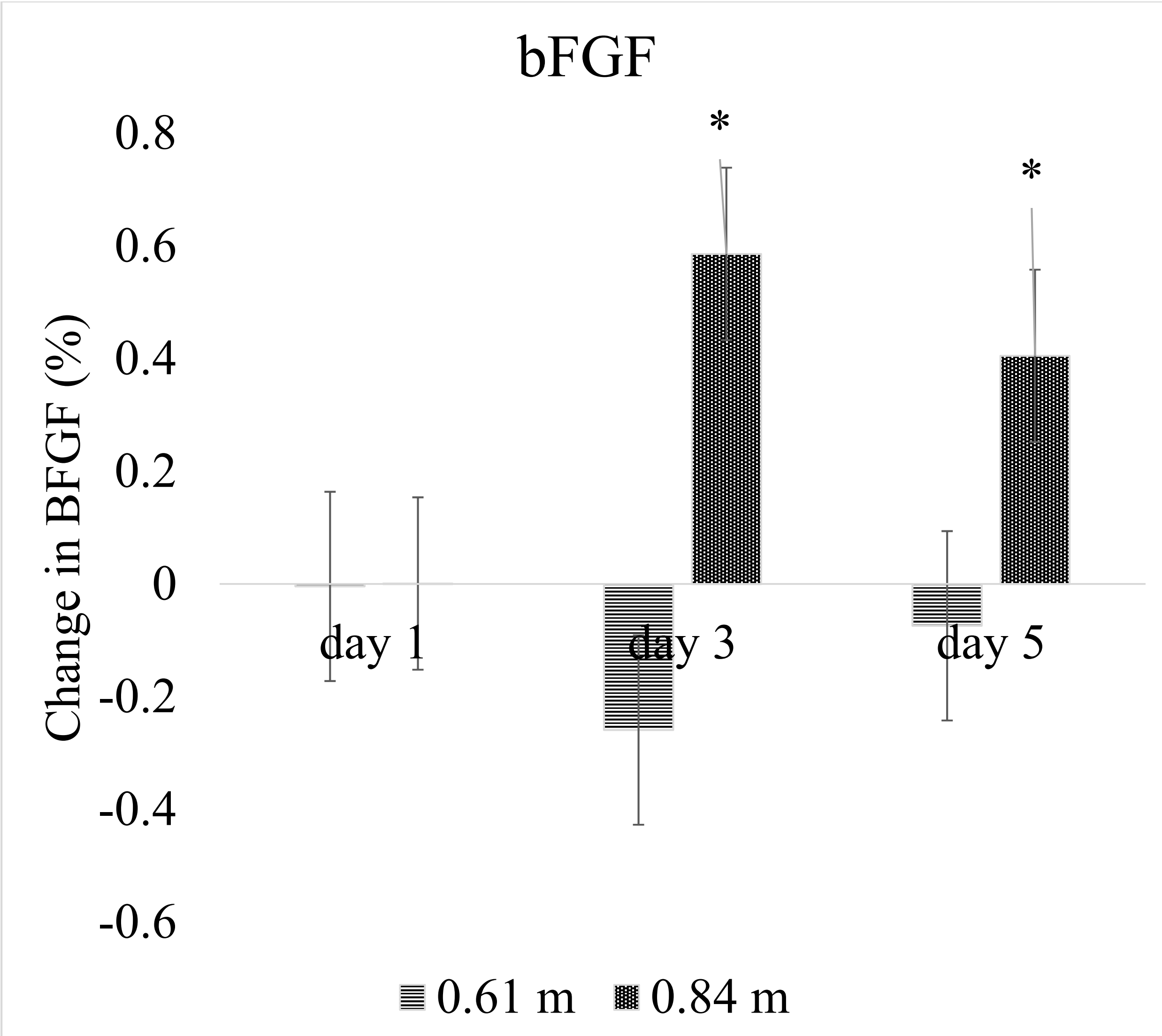

Figure 2.13 Change in bFGF Relative to Baseline Basic Fibroblast Growth Factor (bFGF) is responsible for cellular proliferation and self-renewal. There was an effect of day and jump height on bFGF concentrations. This is significant in horses jumping higher (0.84 meters) on days 3 and 5 where bFGF concentrations show nearly a 60% and 40% increase (P=0.051). When compared to baseline, there were higher concentrations of bFGF as each period progressed (P=0.002). Standard error bars show variation in the data.

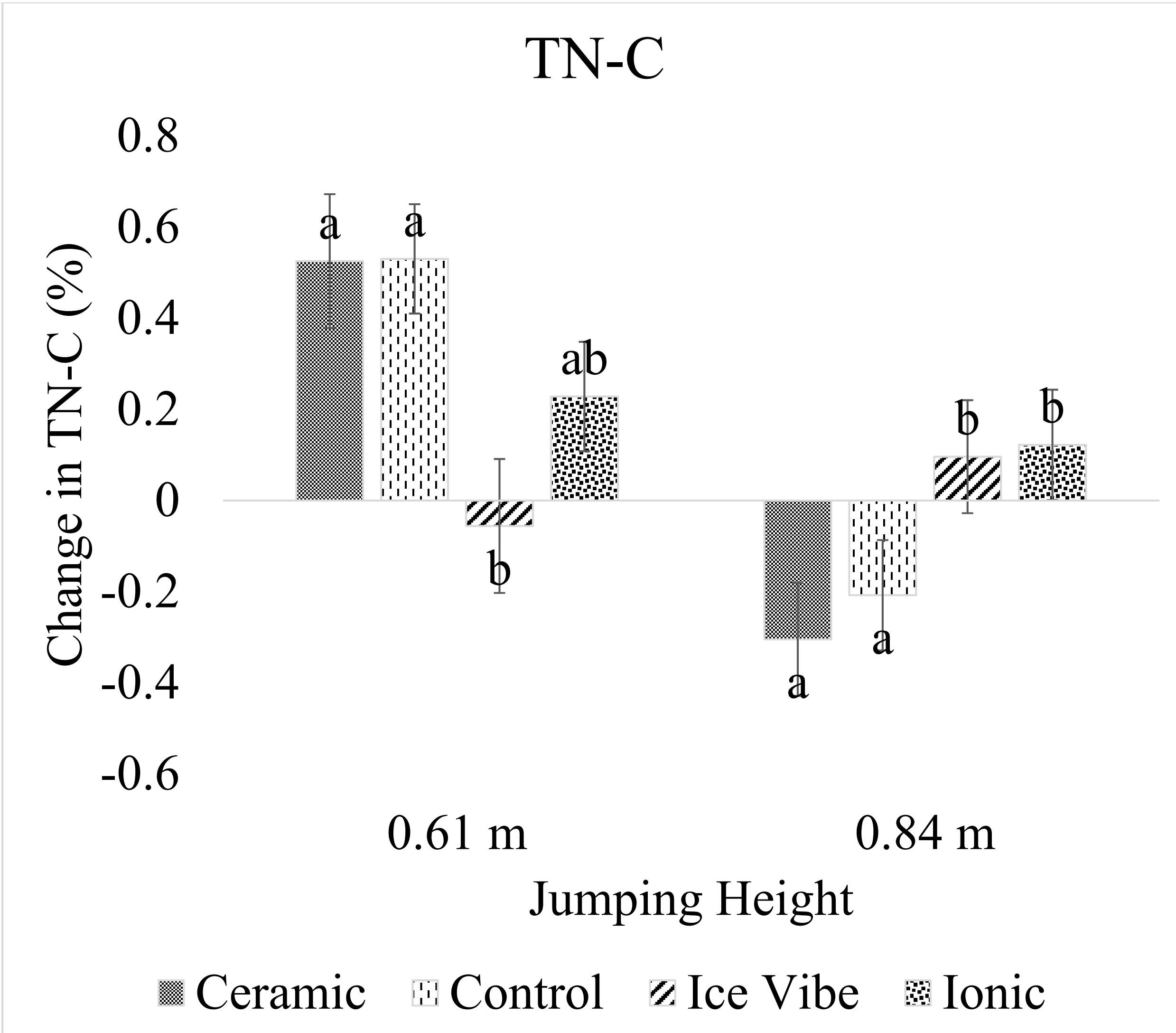

Figure 2.14 Proportional Change in TN-C Relative to Baseline Tenascin C (TN-C) is produced for tendon repair. There was an interaction between treatment, day, and jump height (P=0.02). When receiving ceramic treatment, horses had decreased concentrations of TN-C when jumping higher (0.84 meters). However, there was an increase in TN-C concentrations when receiving ice-vibe and ionic treatment. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

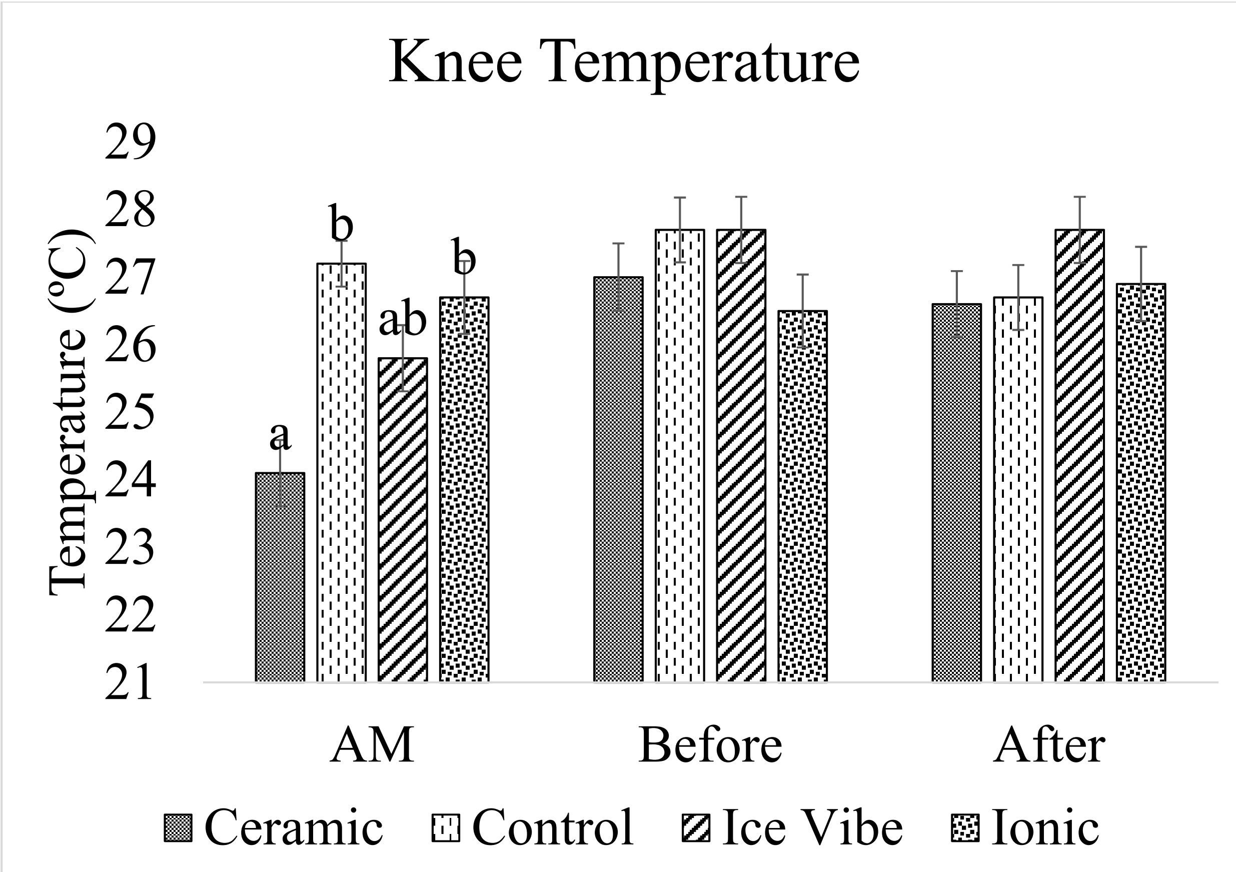

Figure 2.15 Knee Temperature Knee temperature was measured in degrees Celsius (ºC). Thermal images were captured at 3 time points (morning (AM), pre-exercise (before), and post-exercise (after). Mean knee temperature was calculated for the 3 time points as well as for treatment. There was an influence of time and treatment on the localized temperature of the knee ($P<0.001$). Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

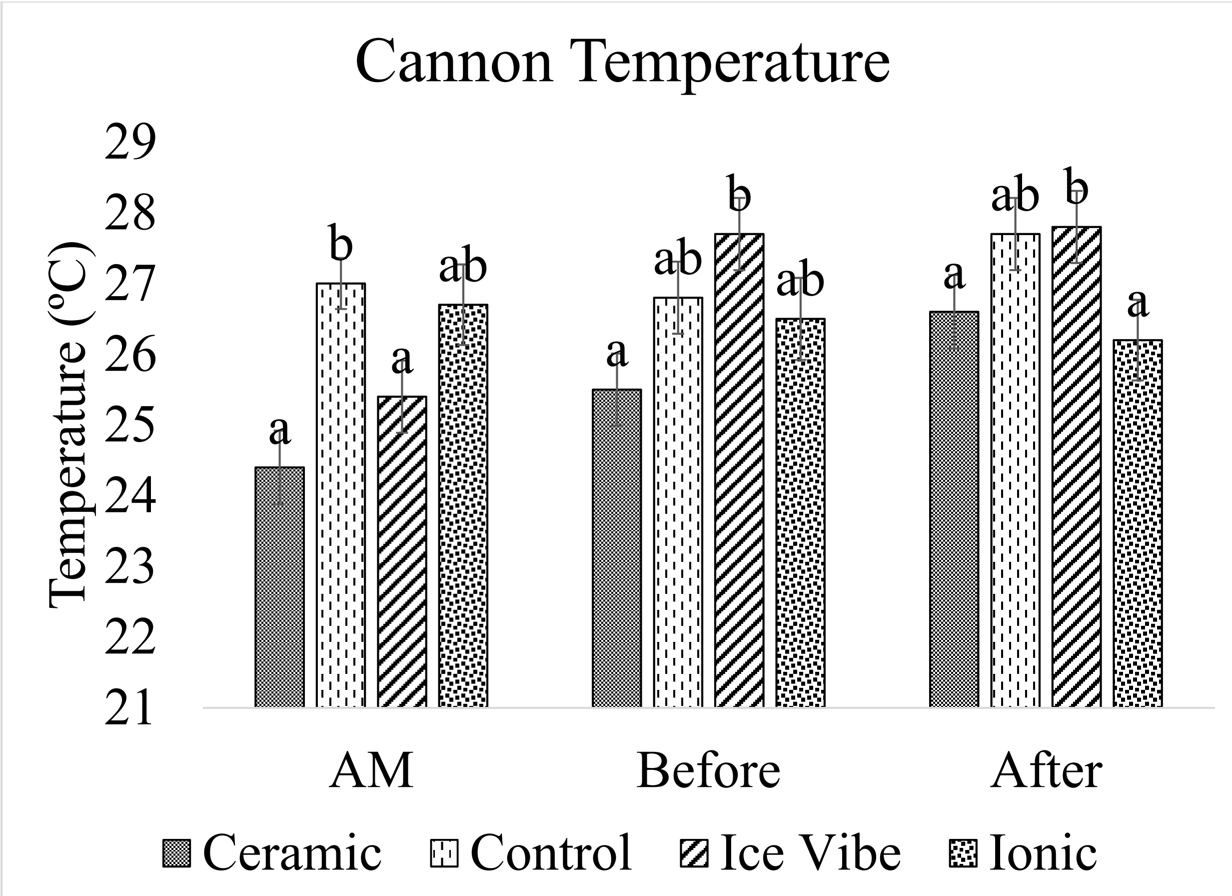

Figure 2.16 Cannon Temperature Cannon temperature was measured in degrees Celsius (ºC). Thermal images were captured at 3 time points (morning (AM), pre-exercise (before), and post-exercise (after). Mean cannon temperature was calculated for the 3 time points and treatment. There was an influence of time and treatment on the localized temperature of the cannon ($P<0.001$). Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

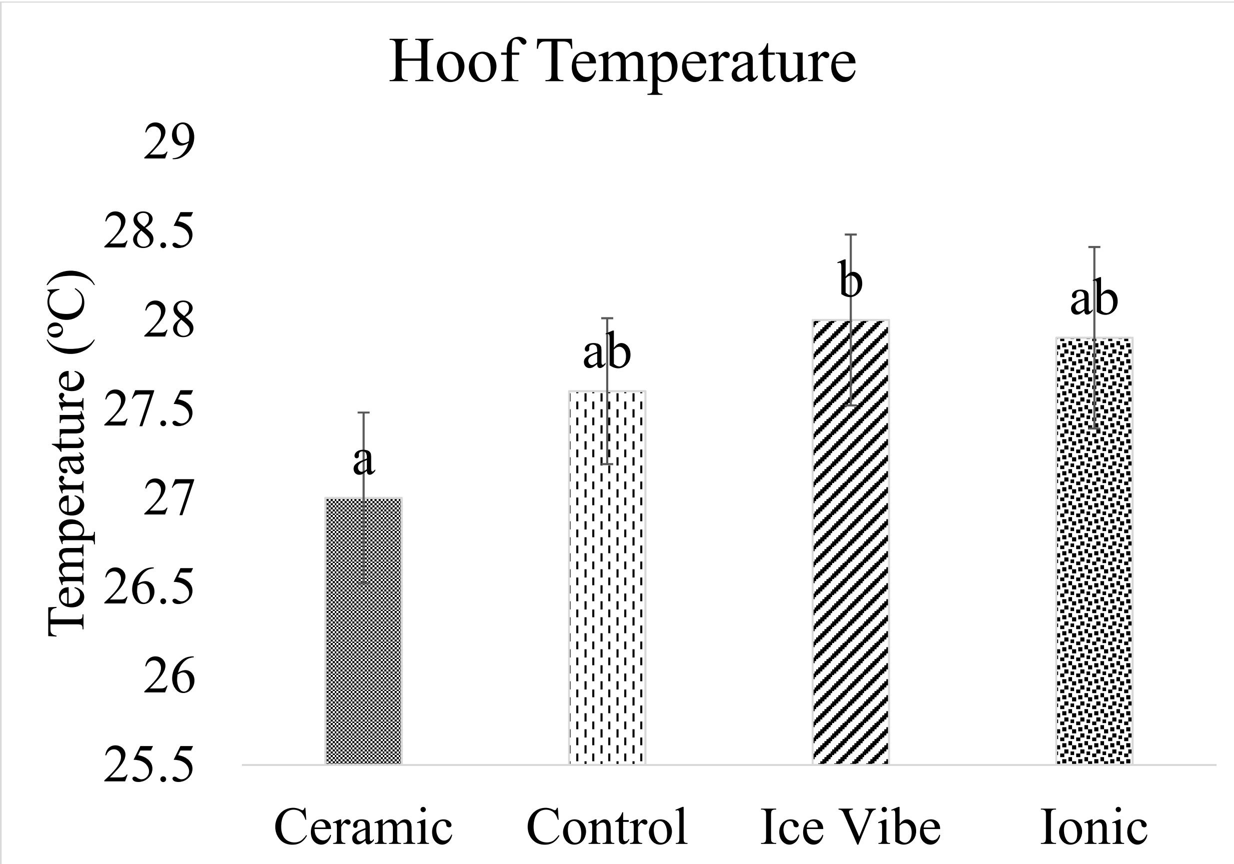

Figure 2.17 Hoof Temperature Hoof temperature was measured in degrees Celsius (ºC). Mean hoof temperature was calculated for each treatment. There was an influence of treatment on mean hoof temperature (P=0.013). Ceramic treatment resulted in a lower hoof temperature compared to controls, whereas ice-vibe experienced higher hoof temperature. Ionic expressed similar values as control. Standard error bars show variation in the data. Letters represent similarities in the data between two treatment groups.

Literature Referenced

Baxter, G. M., Stashak, T. S., & Keegan, K. G. (2020). Examination for Lameness. In *Adams and Stashak's Lameness in Horses* (pp. 67-188). John Wiley & Sons, Ltd. http://onlinelibrary.wiley.com/doi/abs/10.1002/9781119276715.ch2
files/25/9781119276715.html

Chen, C.-H., Lin, Y.-H., Chen, C.-H., Wang, Y.-H., Yeh, M.-L., Cheng, T.-L., & Wang, C.-Z. (2018). Transforming growth factor beta 1 mediates the low-frequency vertical vibration enhanced production of tenomodulin and type I collagen in rat Achilles tendon. *PLoS ONE*, *13*(10), e0205258. https://doi.org/10.1371/journal.pone.0205258

de Godoi FN, d. A. F., Toral FL, de Miranda AL, Kaipper RR, Bergmann JA. (2014). Repeatability of kinematics traits of free jumping in Brazilian sport horses. *Livestock Science*, *168*, 1-8.

Doug Thal, D. (2016). Understanding Lameness. *American Association of Equine Practitioners*. https://aaep.org/horsehealth/understanding-lameness

Du Clos, T. W. (2000). Function of C-reactive protein. *Annals of Medicine*, *32*(4), 274-278. https://doi.org/10.3109/07853890009011772

Flück M, M. S., Schittny JC, Klossner S, Durieux AC, Giraud MN. (2007). Mechano-regulated tenascin-C orchestrates muscle repair. *Proceedings of the National Academy of Sciences*, *105*(36), 13662 - 13667.

H. T. Yang, R. W. O., and Ronald L. Terjung. (1998). Exercise training enhances basic fibroblast growth factor-induced collateral blood flow. *American Journal of Physiology-Heart and Circulatory Physiology*, *274*(6), H2053-H2061.

Hyldahl, R. D., Hafen, P. S., Nelson, W. B., Ahmadi, M., Pfeifer, B., Mehling, J., & Gifford, J. R. (2021). Passive muscle heating attenuates the decline in vascular function caused by limb disuse. *The Journal of Physiology*, *599*(20), 4581-4596. https://doi.org/10.1113/jp281900

Kunutsor, S. K., Laukkanen, T., & Laukkanen, J. A. (2018). Longitudinal associations of sauna bathing with inflammation and oxidative stress: the KIHD prospective cohort study. *Annals of Medicine*, *50*(5), 437-442. https://doi.org/10.1080/07853890.2018.1489143

Li, M., Huang, C., Zhao, B., Liu, H., Liu, Z., & Wang, J. (2018). Crack-healing behavior of Al₂O₃-TiB₂-TiSi₂ ceramic material. *Ceramics International*, *44*(2), 2132-2137. https://doi.org/10.1016/j.ceramint.2017.10.164

Licurci MD, d. A. F. A., Arisawa EA. (2018). Acute effects of whole body vibration on heart rate variability in elderly people. *Journal of Bodywork and Movement Therapies*, *22*(3), 618-621.

Lochner FK, M. D., Mills EJ, Groom JJ. (1980). In vivo and in vitro measurement of tendon strain in the horse. *American Journal of Veterinary Research*, *41*.

Merritt, J., Starke, S., & Clayton, H. (2014). The Point of Application of the Ground Reaction Force Moves in Circling Horses. *Equine Veterinary Journal*, *46*, 43-43. https://doi.org/10.1111/evj.12267_132

Midwood, K. S., & Orend, G. (2009). The role of tenascin-C in tissue injury and tumorigenesis. *Journal of Cell Communication and Signaling*, *3*(3-4), 287-310. https://doi.org/10.1007/s12079-009-0075-1

Nadler SF, W. K., Kruse RJ. (2004). The physiologic basis and clinical applications of cryotherapy and thermotherapy for the pain practitioner. *Pain Physician*, *7*(3), 395-400.

P.N.R Powers, A. J. H. (2000). A study on the techniques used by untrained horses during loose jumping. *Journal of Equine Veterinary Science*, *20*(12), 845-850.

Pournot, H., Bieuzen, F., Louis, J., Fillard, J.-R., Barbiche, E., & Hausswirth, C. (2011). Time-Course of Changes in Inflammatory Response after Whole-Body Cryotherapy Multi Exposures following Severe Exercise. *PLoS ONE*, *6*(7), e22748. https://doi.org/10.1371/journal.pone.0022748

Valdivieso, P., Toigo, M., Hoppeler, H., & Flück, M. (2017). T/T homozygosity of the tenascin-C gene polymorphism rs2104772 negatively influences exercise-induced angiogenesis. *PLoS ONE*, *12*(4), e0174864. https://doi.org/10.1371/journal.pone.0174864

Wang L, Z. M., Ma J, Tian S, Xiang P, Yao W, Fan Y. (2014). Effect of combining traction and vibration on back muscles, heart rate and blood pressure. *Medical Engineering & Physics*, *36*(11), 1443-1448.

XiaokunLi. (2018). Chapter 6 - Design and Discovery of FGF/FGFR Inhibitors. In *Fibroblast Growth Factors* (pp. 339-383). Academic Press.

Zou, Q., Cai, B., Li, J., & Li, Y. (2017). In vitro and in vivo evaluation of the chitosan/Tur composite film for wound healing applications. *Journal of biomaterials science. Polymer edition*, *28*(7), 601-615. https://doi.org/10.1080/09205063.2017.1289036

Chapter 3 Efficacy of wearable therapy on equine performance and behavior under saddle

Abstract

Many equestrians of all disciplines keep the equine athletes' best interest in mind during exercise. In most cases, this constitutes applying protection to the distal limb to prevent injury and support the tendons and ligaments. However, increasing body temperature during exercise along with the heat-trapping nature of the leg protection can lead to the breakdown of the associated structures, resulting in tear or injury if not properly tended to. Commercial equine therapeutic products have become popular in recent years. The objective of this study was to evaluate the efficacy of negative ion and cryo-vibration therapy on the behavior and performance of sport horses in an equitation lesson program. Rambo®Ionic (Horseware, Dundalk, Ireland) and Ice-Vibe® (Horseware, Dundalk, Ireland) therapeutic boots were applied to the horses as per manufacturer recommendation before and after the horse was ridden in a 60-minute lesson consisting of both flat and jumping exercise. The ALOGO™ MovePro (Alogo Technologies, Switzerland) stride sensor was calibrated and secured to the horse's girth during exercise and recorded stride parameters such as longitudinal and lateral balance, straightness, strike power, cadence, and jump height, and stride height. During each lesson, a blind behavioral evaluation was performed. Data suggests correlations for lateral and longitudinal balance on day when jumping. On the flat, stride height, strike power at the walk and canter, and cadence were also influenced by day. However, there was an association between treatment and lateral balance at the walk and trot. Behavioral analysis showed no notable changes in performance or behavior under saddle except for a decrease in flexion from those treated with Ice-Vibe® boots. In conclusion, there is no significant influence of treatment from the Rambo®Ionic or Ice-Vibe® boots on the performance or behavior of horses in an equitation lesson program.

Introduction

It is common practice in the equestrian industry to leverage protective boots or wraps during exercise to prevent injury to the equine distal limb that could be caused by interference with other limbs or the riding environment, as well as to support tendons and ligaments. As the horse's body acclimates to exercise by increasing cardiac output, a corresponding increase in body temperature occurs (FabíolaFarinelli et al., 2021). Protective legwear will trap heat against the skin which can be detrimental to the fibrous structure of the tendons and ligaments even after the protection has been removed (Smith, 2011). Over time this can lead to a weakening of the tendons and ligaments, allowing the potential for rupture.

Pain and discomfort not only alter the horse's ability to perform, but also impacts the horse's behavior. Behavioral habits under saddle are often attributed to the horse's personality and are easily ignored; however, often these behavioral habits can be a sign of lameness (Dyson & Van Dijk, 2020). Poor behavior limits performance because the horse is less inclined to respond to the rider's aids and can protest any commands that cause discomfort. When poor behavior is excused as personality, the horse, and in extreme cases the rider, are at greater risk for injury. However, there is a myriad of other factors which can influence equine behavior, and more effective diagnostic tools to help owners, riders, and veterinarians understand when undesirable behavior under saddle is a symptom of pain are essential.

Commercially available equine therapeutics are a relatively new and popular item amongst equestrians of all disciplines, which may contribute to this need. Most use these products when the horse already has a pre-existing injury, or the horse is aging and needs the extra support. Anecdotally, horse owners often assume these technologies are effective at supporting athletic activity of the horse because changes in behavior under saddle are observed, perhaps indicating the technology is alleviating a source of pain that is causing a limitation or resistance during exercise prior to therapy application. Previous research supports this idea because many commercial technologies leverage therapies that have been demonstrated to interact with the body to promote healing. Although the evaluation of these technologies in a clinical setting has been favorable, less is understood regarding how these technologies may impact performance or behavior in the absence of clinical lameness.

This study was performed to test the efficacy of Rambo®Ionic (Horseware, Dundalk, Ireland) and Ice-Vibe® (Horseware, Dundalk, Ireland) therapeutic boots on the performance and behavior of sport horses during regular use in a lesson. Behavioral and stride analyses were performed while each horse was ridden as a part of regularly scheduled lessons to determine if the treatments had a measurable impact on horses' behavior and performance. We hypothesized that horses would perform more consistently and willingly in response to the rider's aids as well as show an improvement in behavior in response to either therapeutic treatment when compared to periods during which no treatment was applied.

Materials & Methods

Animals, Treatments, and Experimental Design

All animal use and procedures described within this study were approved by the Institutional Animal Care and Review Committee (IACUC) of Virginia Tech. Eighteen horses (11 warmbloods, 3 quarter horses, 4 thoroughbreds; 4 mares, 14 geldings) consistently performing moderate-intensity exercise in a lesson program were used for data collection. Horses were stalled during weekdays and were turned out into designated paddocks (n=7) on weeknights and weekends. Prior to the start of the study, height and girth were measured for calibration of the ALOGO™ MovePro (Alogo Technologies, Switzerland) stride sensor calculations. Horses were subject to participate in at least one lesson per day lasting approximately one hour each.

The study consisted of three periods lasting five days each with a ten-day washout in between each period. A Latin square was used to assign treatments to each animal. The Latin Square allowed for the prevention of repetition of treatment for animals in each period. Horses received treatment from control, Rambo®Ionic, and Ice-Vibe® boots.

Rambo®Ionic boots (Horseware Ireland, Dundalk, Ireland) were applied at 0800h to the distal front limb while the horse was stalled during the day as per the manufacturer's recommendation; with the exception that no adjustment period was granted in each period. Two modes of application were used: a Velcro boot and a traditional standing wrap. The boots were only removed for exercise, lessons, and turn out at 1730h.

Horseware®Ireland's Ice-Vibe boots (Horseware Ireland, Dundalk, Ireland) were applied immediately before and after exercise. The boots have three vibration settings, but only the first two settings were used in this study as per the manufacturer's recommendation for use with exercise. Setting one was used prior to exercise for ten minutes at a low frequency. After exercise, cold packs were placed underneath the Ice-Vibe® boot and were worn for twenty minutes at a slightly higher frequency.

Experimental Protocol

For the 5 days of data collection during each period, each horse was brought in from the field by Virginia Tech farm staff and volunteers at approximately 0600h and placed into an assigned 12 by 12 box stall. At 0730h horses were restrained and vitals (pulse, temperature, and respiration) were collected. For the horses ionic treatment during any given period, boots were applied as described immediately following vitals measurements.

Daily lessons were scheduled for 0900h, 1000h, 1400h, and 1600h. Days 1 and 2 of each period emphasized flatwork and days 3 and 4 focused on jumping. Day 5 was reserved for Virginia Tech Equestrian team practices where horses were used for both flat and jump lessons. Jump heights did not exceed 0.80m in any of the lessons regardless of a horse's ability to jump higher. Students were assigned to horses by the coaches based on riding level. Students were responsible for tacking up their horse and securing the ALOGO™ sensor to the girth prior to the lesson. After tacking up, students walked the horses to the riding arena. Prior to getting on, the girth was tightened evenly on each side to ensure the sensor's balance, and the sensor was manually turned on to start the recording designated by a flashing green light. Approximately the first 30 minutes of each lesson was allotted to warm up which consisted of basic walk, trot, and canter in each direction. During the last 30 minutes, riders practiced flat exercises or jump courses at the coach's discretion.

At the completion of each lesson, students were asked to manually turn off the sensor prior to leaving the riding arena. Horses were then led back to their stalls to be untacked and groomed to remove any sweat or dirt accumulation. Boots were reapplied as previously described by students and removed prior to turnout at 1630h. A blind behavioral survey was filled out by the coach to monitor any behavioral changes made by each horse during the lesson. The coach had options to agree or disagree (with varying strength) with 10 statements that could be categorized by the horse's typical behavior under saddle, response to the rider's aids, general performance, and rider interference.

Statistical Analysis

Raw data collected from the study was compiled into a data set and organized by flatwork, jumping, behavioral survey, and vitals. Statistical analysis was conducted using RStudio (Version 1. 4. 1717, Boston, MA). This study utilized a linear effects model and had fixed effects for boot type and day of exposure. Random effects accounted for period and animal. An analysis of variance using Satterthwaite's method was performed to assess behavior, jump strike power, jump height, jump longitudinal balance, jump lateral balance, and jump straightness. Stride cadence ($P \leq 0.05$), stride height, stride strike power, stride longitudinal balance, stride lateral balance, and stride straightness were also analyzed using Satterthwaite's method to determine response by treatment or day. Mean data separations were calculated for with least square means and the Tukey method.

Results & Discussions

The conditions under which each horse performed accurately represented work for the average sport horse. With this study occurring in a lesson program, the horses are subject to a variety of rider styles and experiences, each of which can influence the natural gait and behavior. It is possible that with the use of therapeutic boots the horse will have more opportunities to recover from a variety of rides.

Vital signs were recorded at rest each morning prior to boot application. Body temperature (BT), respiration rate (RR), and heart rate (HR) were used to determine if the horse was healthy and capable of partaking in the study as well as to measure response to treatment (Figure 3.1). Regardless of treatment, there was no significant response in HR, RR, or BT. These findings contradict literature that suggests an increase in HR as a response to whole-body vibration therapy (Wang L, 2014). These results may differ due to the different applications of the vibration therapy.

While performing flat work, horses' experienced changes in lateral balance (LatB) at the walk, trot, and canter as well as the strike power at the trot (TSP). Figure 3.2 shows the significant influence of boot type on LatB at the walk, trot, and canter ($P=0.093$). Lateral balance refers to the degree to which the horse leans left or right. A horse that is experiencing discomfort in one limb may compensate by shifting weight to the other side of the body to alleviate pressure. The control group expressed a left lean at all three gaits (W:-4.057±2.62, T:-4.22±2.73, C:-3.06±2.85). Horses receiving Ice-Vibe treatment tended to have a stronger right lean for all three gaits (W: 3.48±2.78, T: 3.49±2.92, C:3.79±3.13). The Ionic treatment group, although had a slight right lean, maintained the most balance at all three gaits (W: 0.628±1.95, T:1.07±2.06, C: 0.914±2.1). Results from the control group suggest that the horses naturally tend to lean left. Response to treatment shows a tendency to redistribute body weight in an opposite or more proportional manner.

Improved balance at symmetrical gaits, such as walk and trot, indicates that the horse may be equally comfortable on all limbs, mitigating the need to redistribute the weight.

A quality jump is produced by the horse's ability to propel itself up and across the ground without touching the rails. The trajectory of the jump can be determined by longitudinal balance (LonB). Figure 3.3 represents the significant influence of boot type on LonB (P=0.041). Compared to control (10.5±2.02), there were significant increases in LonB for both Ice-Vibe (22.6±2.26) and Ionic (23.9±1.21). The more elevated LonB is, the less chance the horse will have of hitting a jump, a mishap that is penalized in equestrian competition. Stride velocity in the approach to the jump determines the elevation of LonB. Literature suggests that wider jumps such as oxers or open water benefit most from vertical trajectory is highly correlated with horizontal trajectory and was elevated in horses that successfully cleared wide jumping efforts (Clayton et al., 2010).

The design of the behavioral assessment allows for the evaluation of equine behavior and performance based on typical symptoms of discomfort and acceptance. Responses to the survey showed to have a relatively uniform distribution for each treatment as seen in Table 3.1. Data suggests that treatment did not influence the horses' behavior under saddle. This can be seen as most of the mean values for each question are relatively similar. However, when analyzing question 8, horses receiving Ice-Vibe treatment expressed less willingness to bend and flex according to the riders' aids. Bending and flexing refers to the "shape" of the horse's body and the term is used when referencing the horses head, neck, torso, and haunches. Ionic treatments, although applied to the distal limb like Ice-Vibe®, are used to promote muscle relaxation. The vibration of the Ice-Vibe® treatment focuses on increasing circulation locally in the distal limb to prepare the tendons and ligaments for exercise. Variability in behavior has the potential to alter the horses' performance. Arousal occurs during a ride in response to the rider's aids, a jump, or an uncontrollable environmental factor. A study evaluating the psychological factors that influence performance found a change in mood was an indicator of change in performance. Typically, horses presenting with poor behavior were at higher risk of injury during exercise due to negative over-arousal from stimuli (McBride & Mills, 2012). If a horse consistently expresses specific behavior under saddle, it is easier to indicate when a behavioral change occurs that could ultimately result in an injury.

Limitations

This study includes limitations that attribute to user error of materials and jump height. Riders in the lesson program were responsible for removing and applying therapeutic boots prior to and after each lesson as well as securing and activating the ALOGO stride sensor. Horses receiving treatment from the Ice-Vibe® boots would occasionally not experience the full treatment due to the rider not supplying adequate time to apply the boots before the lesson, forgetting to turn on the vibration panel, or failing to apply cold packs under the boots after the lesson. Occasionally, the ALOGO stride sensor would be improperly secured or not turned on which hindered data collection. Finally, the jump heights ridden by some lessons were not significant enough to register with the ALOGO sensor, also resulting in a loss of data.

Conclusions

This paper analyzed the effects of treatment from Ionic and Ice-Vibe® boots on the performance of horses in a collegiate lesson program. Based on the data collected in this study, it can be concluded that there are correlations between treatment and performance, specifically in LatB, TSP, and LonB which are indicators of improved performance. Although literature suggests there should be a response to treatment for vital signs the data collected in the current study suggests otherwise. This could be due to inaccuracies in boot application hindering potential results. Future research efforts can be made to monitor behavior while the horse is actively wearing the therapy as well as focus on the efficacy of the therapeutic boots in a setting that is more representative of competitive riding. This will help further verify results in a non-clinical setting as well as see how response changes based on level of performance.

Tables and Figures

Table 3.1 Behavioral Assessment Survey Questions:1. Horse appeared calm and relaxed prior to the start of the lesson. 2. Horse presented with lameness at the trot. 3. Horse was accepting of riders aids. 4. Horse expressed agitation when asked to perform tasks. 5. Transitions were smooth and organized. 6. Horse expressed discomfort when landing from a jump. 7. Rider maintained steady contact with the horse. 8. Horse was able to bend and flex comfortably. 9. Horse was willing and compliant. 10. Rider was an appropriate fit and rode correctly.

	Survey Questions 1-10									
	1	2	3	4	5	6	7	8	9	10
Control	4.02 ±0.185	1.91 ±0.142	3.33 ±0.195	2.28 ±0.260	3.18 ±0.221	2.24 ±0.193	3.39 ±0.168	3.20 ±0.194	3.67 ±0.240	3.76 ±0.150
Ice-Vibe	4.01 ±0.183	1.76 ±0.139	3.15 ±0.191	2.55 ±0.258	3.01 ±0.221	2.38 ±0.195	3.16 ±0.165	2.88 ±0.193	3.52 ±0.241	3.76 ±0.144
Ionic	4.01 ±0.180	1.96 ±0.137	3.16 ±0.189	2.63 ±0.254	3.15 ±0.217	2.44 ±0.187	3.19 ±0.163	3.092 ±0.188	3.44 ±0.236	3.68 ±0.144

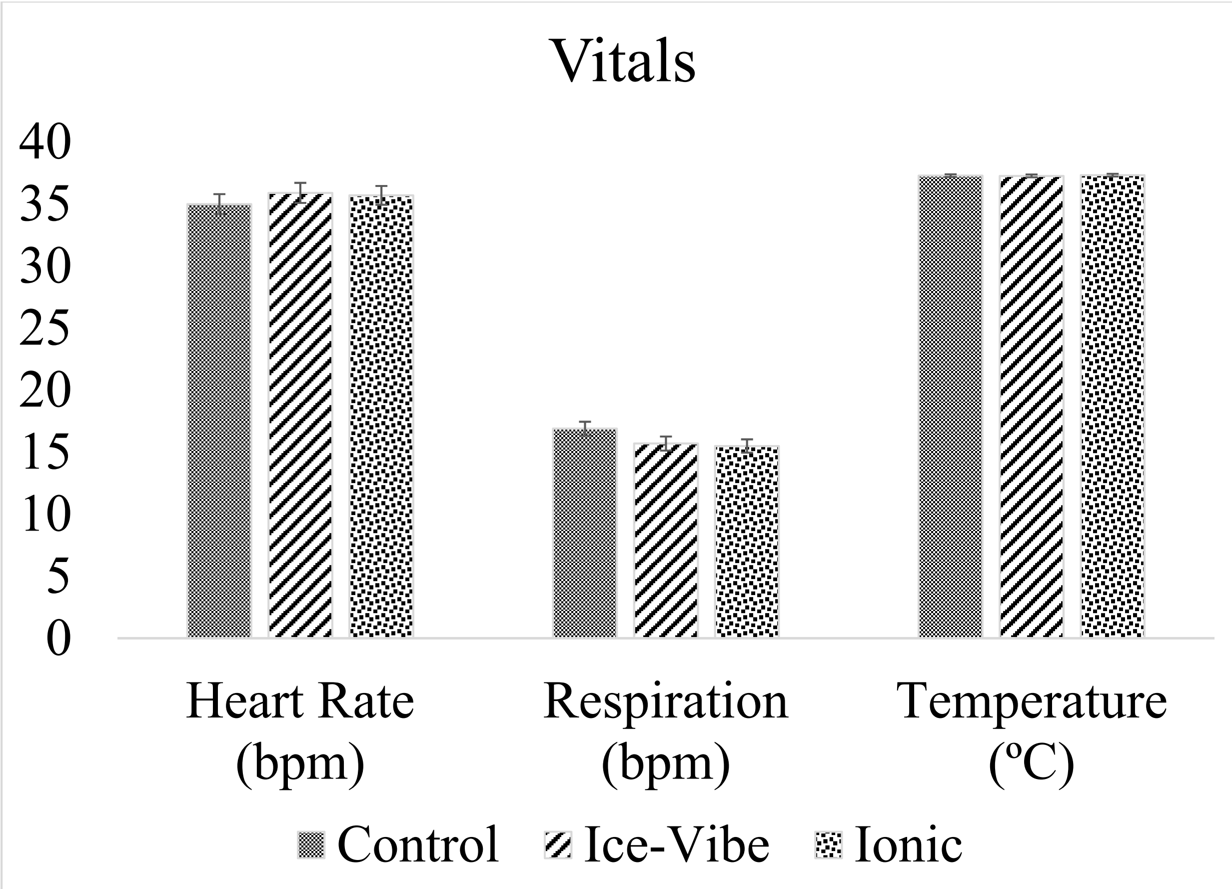

Figure 3.1 Mean Vitals Heart rate in beats per minute (bpm), respiration rate in breaths per minute (bpm) and body temperature (ºC) were measured at rest prior to boot application each morning. Bars represent the mean response to Control, Ice-Vibe, and Ionic treatment. There was no significant response on vital signs in response to treatment (P>0.05). Lines represent standard error.

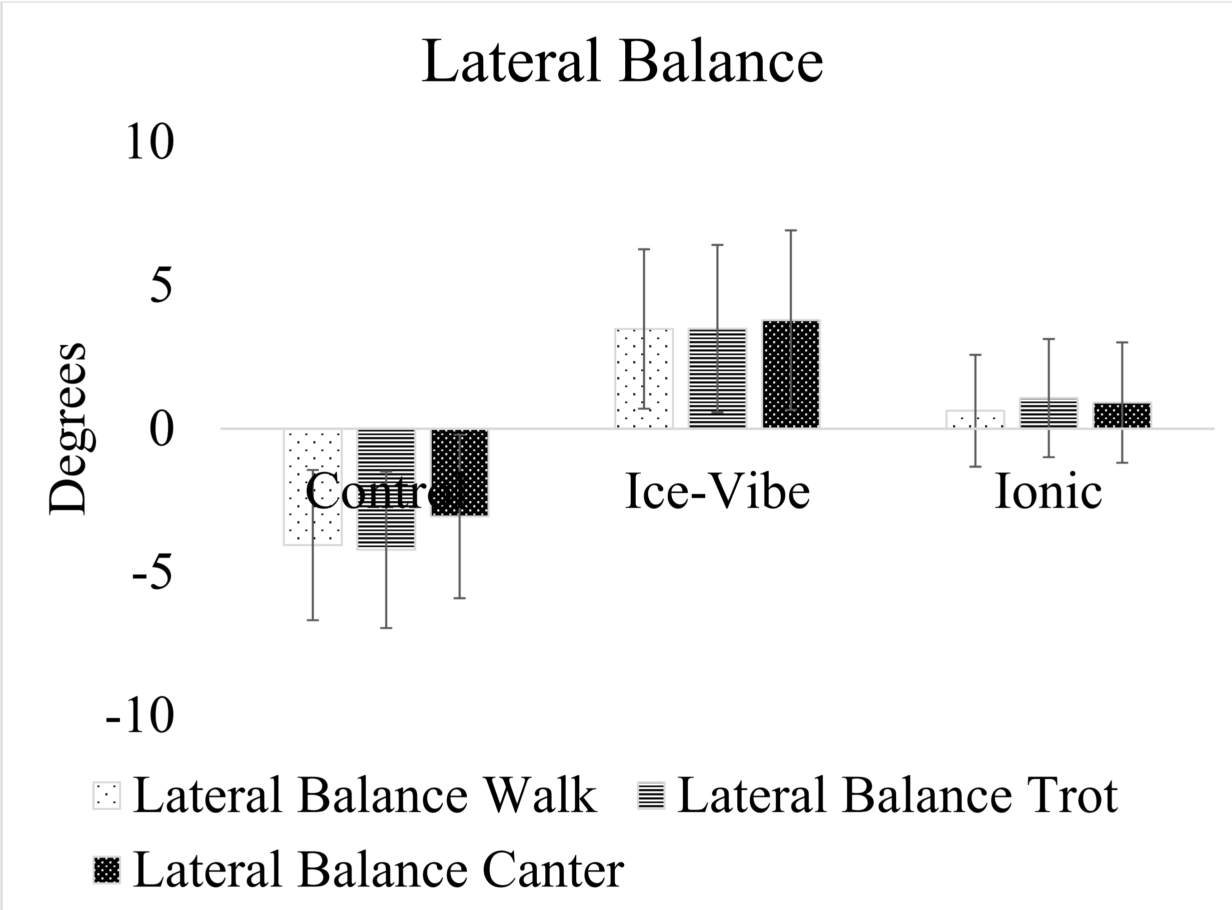

Figure 3.2 Mean Lateral Balance at the Walk, Trot, and Canter Lateral balance was measured in degrees (º). A negative value indicates a left lean whereas a positive value indicates right lean. Mean lateral balance was calculated at the walk trot and canter for each treatment. There was a significant effect of treatment on lateral balance (P=0.093). Lines are representative of standard error.

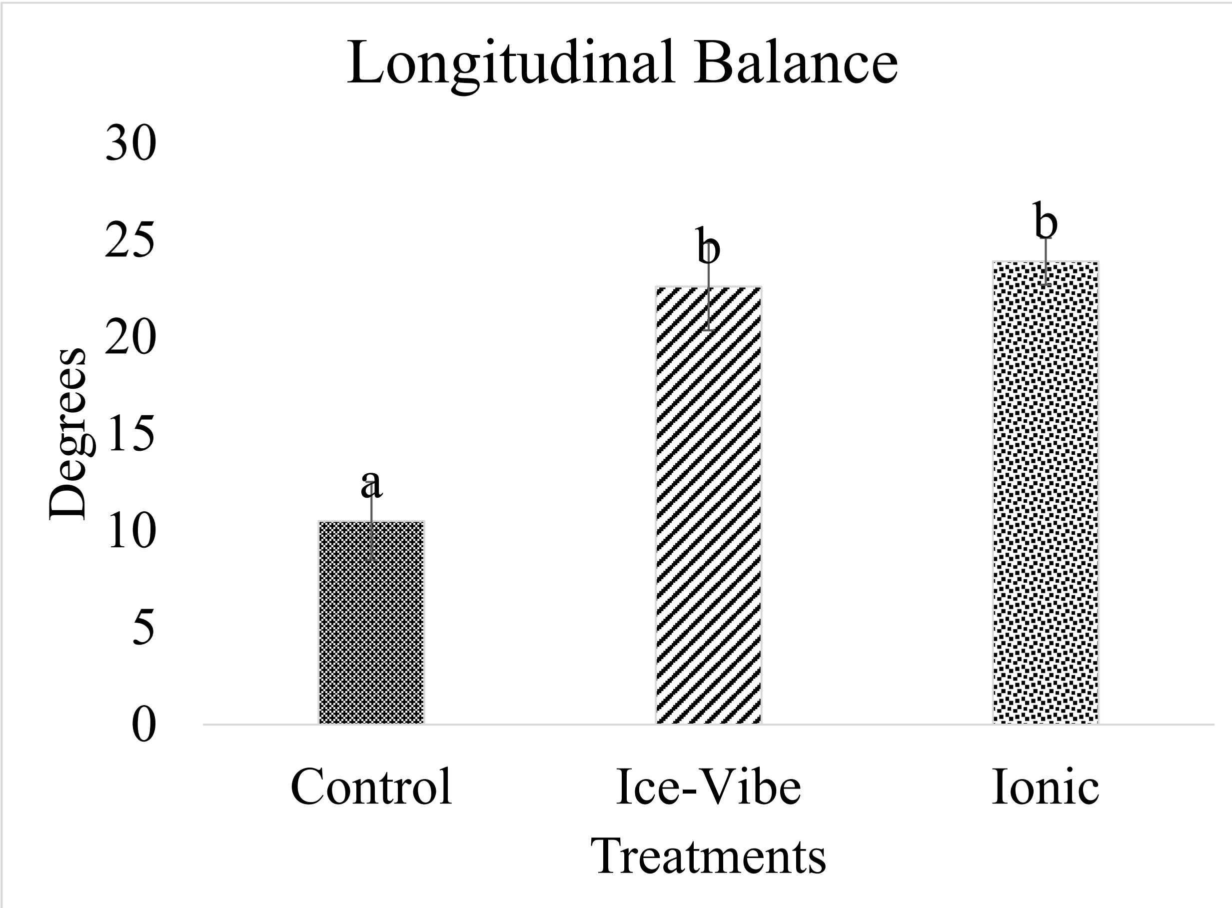

Figure 3.3 Longitudinal Balance Over Jumps Longitudinal balance refers to the balance of the horse's weight on the fore and hind limbs and is measured in degrees (º). Elevated longitudinal balance over a jump is ideal and allows for adequate clearance of the obstacle. Mean longitudinal balance was calculated for each treatment. There is a significant effect of treatment on longitudinal balance (P=0.041). Lines represent standard error.

Literature Referenced

5 Major Types of Horses Defined. Copper Mare Media, Ltd. . https://www.equinespot.com/types-of-horses.html

Back W, M. C., van Heel MCV, et al. . (2007). Vertical Frontlimb Ground Reaction Forces of Sound and Lame Warmbloods from those in Quarter Horses. *Journal of Equine Veterinary Science*, 123-129.

Baxter, G. M., Stashak, T. S., & Keegan, K. G. (2020). Examination for Lameness. In *Adams and Stashak's Lameness in Horses* (pp. 67-188). John Wiley & Sons, Ltd. http://onlinelibrary.wiley.com/doi/abs/10.1002/9781119276715.ch2

files/25/9781119276715.html

Benjamin Espy, D., DACT, & Justin Harper, D., MS, DACVS, LA. (2016). *Lameness and Joint Medications*. American Association of Equine Practitioners.

Biermann, N. M., Rindler, N., Buchner, H. H. F. E. S. D. f. C. A., & Horses, U. o. V. M. V. A. (2014). The Effect of Pulsed Electromagnetic Fields on Back Pain in Polo Ponies Evaluated by Pressure Algometry and Flexion Testing—A Randomized, Double-blind, Placebo-controlled Trial. *Journal of Equine Veterinary Science*, *34*(4), 500-507. https://doi.org/10.1016/j.jevs.2013.10.177

Boswell, R. P., Mitchell, R. D., Ober, T. R., Benoit, P. H., Miller, C. B., & Dyson, S. J. (2011). Chapter 115 - Lameness in the Show Hunter and Show Jumper. In M. W. Ross & S. J. Dyson (Eds.), *Diagnosis and Management of Lameness in the Horse (Second Edition)* (pp. 1096-1112). W.B. Saunders. https://www.sciencedirect.com/science/article/pii/B9781416060697001152

files/17/B9781416060697001152.html

Bruin, G., Kuipers, H., Keizer, H. A., & Vander Vusse, G. J. (1994). Adaptation and overtraining in horses subjected to increasing training loads. *JOURNAL OF APPLIED PHYSIOLOGY*, *76*(5), 1908.

Chen, C.-H., Lin, Y.-H., Chen, C.-H., Wang, Y.-H., Yeh, M.-L., Cheng, T.-L., & Wang, C.-Z. (2018). Transforming growth factor beta 1 mediates the low-frequency vertical vibration enhanced production of tenomodulin and type I collagen in rat Achilles tendon. *PLoS ONE*, *13*(10), e0205258. https://doi.org/10.1371/journal.pone.0205258

Clayton, H. M., Colborne, G. R., & Burns, T. E. (2010). Kinematic analysis of successful and unsuccessful attempts to clear a water jump. *Equine Veterinary Journal*, *27*(S18), 166-169. https://doi.org/10.1111/j.2042-3306.1995.tb04912.x

Committee, U. H. Q. C. P. Horsemanship Quiz Challenge Study Guide. In. USHJA: United States Hunter Jumper Association, Inc.

DACVIM, J. N. V. (2017). The Equine Circulatory System. https://equimed.com/health-centers/general-care/articles/the-equine-circulatory-system

DACVS, J. C. J. D. M. (2019). Neurologic Lameness.

Dave, H. D., Shook, M., & Varacallo, M. (2021). Anatomy, Skeletal Muscle. *National Center for Biotechnology Information*. https://www.ncbi.nlm.nih.gov/books/NBK537236/

de Godoi FN, d. A. F., Toral FL, de Miranda AL, Kaipper RR, Bergmann JA. (2014). Repeatability of kinematics traits of free jumping in Brazilian sport horses. *Livestock Science*, *168*, 1-8.

Debra A. Hembroff, R. Equine Exercise Physiology.

Distal Limb Bones: Lower Leg Bones. http://www.anatomy-of-the-equine.com/distal-limb-bones.html

Dittmer, C. W. R. a. K. E. (2019). Does Juvenile Play Programme the Equine Musculoskeletal System? *Animals*. https://doi.org/10.3390/ani9090646

Doug Thal, D. (2016). Understanding Lameness. *American Association of Equine Practitioners*. https://aaep.org/horsehealth/understanding-lameness

Douglas, H. *Etymology of lame*. https://www.etymonline.com/word/lame

Du Clos, T. W. (2000). Function of C-reactive protein. *Annals of Medicine*, *32*(4), 274-278. https://doi.org/10.3109/07853890009011772

DVM, B. C. Degenerative Suspensory Ligament Desmitis (DSLD).

Dyson, S., & Van Dijk, J. (2020). Application of a ridden horse ethogram to video recordings of 21 horses before and after diagnostic analgesia: Reduction in behaviour scores. *Equine Veterinary Education*, *32*(S10), 104-111. https://doi.org/10.1111/eve.13029

FabíolaFarinelli, AdalgizaSouzaCarneirodeRezende, MayaraGonçalvesFonseca, ÂngelaMariaQuintãoLana, FabíoladeOliveiraPaesLeme, BárbaradeOliveiraNacifKlein, RafaelHenriquePradoSilva, AndersonPereiradeAbreu, ManoelladeJesusDamazio, & MaríliaMartinsMelo. (2021). Influence of Stretching Exercises, Warm-Up, or Cool-Down on the Physical Performance of Mangalarga Marchador Horses. *Journal of Equine Veterinary Science*. https://doi.org/https://doi.org/10.1016/j.jevs.2021.103714

Flück M, M. S., Schittny JC, Klossner S, Durieux AC, Giraud MN. (2007). Mechano-regulated tenascin-C orchestrates muscle repair. *Proceedings of the National Academy of Sciences*, *105*(36), 13662 - 13667.

FRCVS, R. S., & Schramme, M. (2020). The risks and benefits of using boots or bandages on horses' legs.

Freeman, C. (2019). *The Effects of Pre and Post Exercise Low-Level Laser Therapy on Biochemical Markers of Skeletal Muscle Fatigue in Equines* [Undergraduate Honors, University of Arkansas]. Scholarwork@UARK.

Grant Miller, D. (2014). The Basics of Nerve Blocks. *Equisearch*.

Gregory, B. (2014). Conformation. In (pp. 253-265). Elsevier. https://doi.org/10.1016/b978-0-7216-0075-8.00024-1

A guide to Equine Lasers. ColdLasers.Org.

Gyulai, F., Rába, K., Baranyai, I., Berkes, E., & Bender, T. (2015). BEMER Therapy Combined with Physiotherapy in Patients with Musculoskeletal Diseases: A Randomised, Controlled Double Blind Follow-Up Pilot Study. *Evidence-Based Complementary and Alternative Medicine*, *2015*, 1-8. https://doi.org/10.1155/2015/245742

H. T. Yang, R. W. O., and Ronald L. Terjung. (1998). Exercise training enhances basic fibroblast growth factor-induced collateral blood flow. *American Journal of Physiology-Heart and Circulatory Physiology*, *274*(6), H2053-H2061.

Head, M. J., & Barr, A. (2012). Orthopaedics 3. The proximal limbs. In (pp. 369-388). Elsevier. https://doi.org/10.1016/b978-0-7020-2801-4.00017-1

Hinz, B., & Pahl, A. (2007). Cyclooxygenase-1. *xPharm: The Comprehesive Pharmacalogical Reference*, 1-5.

How Does PEMF Work on Horses? Magnawave PEMF.

Hyldahl, R. D., Hafen, P. S., Nelson, W. B., Ahmadi, M., Pfeifer, B., Mehling, J., & Gifford, J. R. (2021). Passive muscle heating attenuates the decline in vascular function caused by limb disuse. *The Journal of Physiology*, *599*(20), 4581-4596. https://doi.org/10.1113/jp281900

Ice-Vibe. Horseware Ireland.

Johnston, C., Gottlieb-Vedi, M., Drevemo, S., & Roepstorff, L. (2010). The kinematics of loading and fatigue in the Standardbred trotter. *Equine Veterinary Journal*, *31*(S30), 249-253. https://doi.org/10.1111/j.2042-3306.1999.tb05228.x

Juneja, P., Munjal, A., & Hubbard, J. B. (2021). Anatomy, Joints. *National Center for Biotechnology Information*. https://www.ncbi.nlm.nih.gov/books/NBK507893/

Kemp, L. *Tools You Can Use: Guidelines and Cautions for Equine Therapy Equiptment*. Holistic Horse.

Kevin G. Keegan DVM, M., DACVS. Objective Measures of Lameness Evaluation. *ACVS*, 127-130. https://www.acvs.org/files/proceedings/2012/data/papers/037.pdf

Knych, H. K. (2017). Nonsteroidal Anti-inflammatory Drug Use in Horses. *Veterinary Clinics of North America: Equine Practice*, *33*(1), 1-15. https://doi.org/10.1016/j.cveq.2016.11.001

Kunutsor, S. K., Laukkanen, T., & Laukkanen, J. A. (2018). Longitudinal associations of sauna bathing with inflammation and oxidative stress: the KIHD prospective cohort study. *Annals of Medicine*, *50*(5), 437-442. https://doi.org/10.1080/07853890.2018.1489143

Li, M., Huang, C., Zhao, B., Liu, H., Liu, Z., & Wang, J. (2018). Crack-healing behavior of Al₂O₃-TiB₂-TiSi₂ ceramic material. *Ceramics International*, *44*(2), 2132-2137. https://doi.org/10.1016/j.ceramint.2017.10.164

Licurci MD, d. A. F. A., Arisawa EA. (2018). Acute effects of whole body vibration on heart rate variability in elderly people. *Journal of Bodywork and Movement Therapies*, *22*(3), 618-621.

Lochner FK, M. D., Mills EJ, Groom JJ. (1980). In vivo and in vitro measurement of tendon strain in the horse. *American Journal of Veterinary Research*, *41*.

Lusi, C. M., & Davies, H. M. S. (2018). *Fascial anatomy of the equine forelimb*. CRC Press. https://doi.org/10.1201/9781351172929.

McBride, S. D., & Mills, D. S. (2012). Psychological factors affecting equine performance. *BMC Veterinary Research*, *8*(1), 180. https://doi.org/10.1186/1746-6148-8-180

Merritt, J., Starke, S., & Clayton, H. (2014). The Point of Application of the Ground Reaction Force Moves in Circling Horses. *Equine Veterinary Journal*, *46*, 43-43. https://doi.org/10.1111/evj.12267_132

Mesa, S. (2007). *American Horse Council Study Finds Equestrian Recreation Industry has Significant Economic Impact*. https://www.usef.org/media/press-releases/1992_american-horse-council-study-finds-equestrian-recreation-industry-has-significant-economic-impact

Midwood, K. S., & Orend, G. (2009). The role of tenascin-C in tissue injury and tumorigenesis. *Journal of Cell Communication and Signaling*, *3*(3-4), 287-310. https://doi.org/10.1007/s12079-009-0075-1

Nadler SF, W. K., Kruse RJ. (2004). The physiologic basis and clinical applications of cryotherapy and thermotherapy for the pain practitioner. *Pain Physician*, *7*(3), 395-400.

Nerve Blocking Horses as Part of a Lameness Exam. Momentum Equine.

Omoigui, S. (2007). The biochemical origin of pain: The origin of all pain is inflammation and the inflammatory response. Part 2 of 3 – Inflammatory profile of pain syndromes. *Medical Hypotheses*, *69*(6), 1169-1178. https://doi.org/10.1016/j.mehy.2007.06.033

P.N.R Powers, A. J. H. (2000). A study on the techniques used by untrained horses during loose jumping. *Journal of Equine Veterinary Science*, *20*(12), 845-850.

Pournot, H., Bieuzen, F., Louis, J., Fillard, J.-R., Barbiche, E., & Hausswirth, C. (2011). Time-Course of Changes in Inflammatory Response after Whole-Body Cryotherapy Multi Exposures following Severe Exercise. *PLoS ONE*, *6*(7), e22748. https://doi.org/10.1371/journal.pone.0022748

Product Innovation. Back On Track.

Rambo Ionic. Horseware Ireland.

Rebecca Bishop, D. (2018). Osteoarthritis and the Equine Athlete.

RN, L. R. W. M., PA-C, R. T. J., & MD, T. G. *What are White Blood Cells?* University of Rochester Medical Center. https://www.urmc.rochester.edu/encyclopedia/content.aspx?ContentID=35&ContentTypeID=160

Rosenkrans, A., Freeman, C., Oberhaus, E. L., Dias Morse, P., & Rosenkrans, C. (2020). 122 Physiological effects of low level laser therapy on exercised horses. *Journal of Animal Science*, *98*(Supplement_2 ASAS Southern Section 2020 Meeting Abstracts), 80-81. https://doi.org/10.1093/jas/skz397.189

Ryan, T., & Smith, R. (2007). An investigation into the depth of penetration of low level laser therapy through the equine tendon in vivo. *Irish Veterinary Journal*, *60*(5), 295. https://doi.org/10.1186/2046-0481-60-5-295

Sellnow, L. (2006). The Perfect Engine. *The Horse*, 83-88.

Shockwave Therapy. (2019).

Smith, R. K. W. (2011). Chapter 68 - Pathophysiology of Tendon Injury. In M. W. Ross & S. J. Dyson (Eds.), *Diagnosis and Management of Lameness in the Horse (Second Edition)* (pp. 694-706). W.B. Saunders. https://www.sciencedirect.com/science/article/pii/B9781416060697000687

files/11/B9781416060697000687.html

Sopakayang, R. (2010). *Viscoelastic Models for Ligaments and Tendons* Virginia Polytechnic Institute and State University]. https://vtechworks.lib.vt.edu/handle/10919/77298

Splint Bones. https://www.atlantaequine.com/pages/client_lib_splint.html

Stacey Oke, D., MSc. (2021). Understanding the Equine Muscular System. https://thehorse.com/193585/understanding-the-equine-muscular-system/

Staff, E. (2017). *Causes of Equine Lameness*. Equimed, LLC.

Stephan B. Adams, D., MS, DACVS. (2015, June 2016). *Overview of Lameness in Horses*. Merck & Co., Inc.

Stephan B. Adams, D., MS, DACVS. (2019). *Components of the Musculoskeletal System of Horses*. Merck Sharp & Dohme Corp. https://www.merckvetmanual.com/horse-owners/bone,-joint,-and-muscle-disorders-in-horses/components-of-the-musculoskeletal-system-of-horses

Structure and Function of Ligaments and Tendons. http://sites.bsyse.wsu.edu/pitts/be120/Handouts/animal%20tssue%20descriptions%20and%20mechanical%20proprties.htm

Thomas, H. S. (2019). The Power of Cold Therapy. *Equus Magazine*, (457).

Valberg, S. J. (2014). Muscle anatomy, physiology, and adaptations to exercise and training. In (pp. 174-201). Elsevier. https://doi.org/10.1016/b978-0-7216-0075-8.00021-6

Valdivieso, P., Toigo, M., Hoppeler, H., & Flück, M. (2017). T/T homozygosity of the tenascin-C gene polymorphism rs2104772 negatively influences exercise-induced angiogenesis. *PLoS ONE*, *12*(4), e0174864. https://doi.org/10.1371/journal.pone.0174864

Wakim, S., & Grewal, M. (2021a). *Muscle Contraction*. https://bio.libretexts.org/Bookshelves/Human_Biology/Book%3A_Human_Biology_(Wakim_and_Grewal)/15%3A_Muscular_System/15.4%3A_Muscle_Contraction

Wakim, S., & Grewal, M. (2021b). *Structure of Bone*. https://bio.libretexts.org/Bookshelves/Human_Biology/Book%3A_Human_Biology_(Wakim_and_Grewal)/14%3A_Skeletal_System/14.4%3A_Structure_of_Bone

Wang L, Z. M., Ma J, Tian S, Xiang P, Yao W, Fan Y. (2014). Effect of combining traction and vibration on back muscles, heart rate and blood pressure. *Medical Engineering & Physics*, *36*(11), 1443-1448.

Weeren, P. R., & Crevier-Denoix, N. (2006). Equine conformation: clues to performance and soundness? *Equine Veterinary Journal*, *38*(7), 591-596. https://doi.org/10.2746/042516406x159007

What is Ionic Therapy?

XiaokunLi. (2018). Chapter 6 - Design and Discovery of FGF/FGFR Inhibitors. In *Fibroblast Growth Factors* (pp. 339-383). Academic Press.

Zou, Q., Cai, B., Li, J., & Li, Y. (2017). In vitro and in vivo evaluation of the chitosan/Tur composite film for wound healing applications. *Journal of biomaterials science. Polymer edition*, *28*(7), 601-615. https://doi.org/10.1080/09205063.2017.1289036

Zschäbitz, A. (2005). Anatomie und Verhalten von Sehnen und Bändern. *Der Orthopäde*, *34*(6), 516-525. https://doi.org/10.1007/s00132-005-0799-4

Zucchini, P., Zaffe, D., Botti, P., Grande, A., Cavani, F., Cadossi, M., Ferrari, S., Cadossi, R., Fini, M., & Canè, V. (2002). IN VIVO EFFECTS OF LOW FREQUENCY LOW ENERGY PULSING ELECTROMAGNETIC FIELDS ON GENE EXPRESSION DURING THE INFLAMMATION PHASE OF BONE REPAIR. *Electromagnetic Biology and Medicine*, *21*(3), 197-208. https://doi.org/10.1081/jbc-120015991

Chapter 4 Conclusions

As equestrian sports gain more recognition as an athletic effort rather than recreational activity, there will be a homogenization between the care of the horse and human athlete. Since the concept of equine physiotherapy erupted in the early twentieth century there has been international acceptance of the equine athlete which has progressed into the production of commercial therapeutic technologies to support sport horses of all disciplines, ages, and ailments. Some of the most accessible technologies being negative ion, ceramic, cryotherapy, and vibration therapy are convenient for maintenance purposes, but the more effective and reparative therapies still require the assistance of a veterinarian or trained professional. The purpose of these experimental efforts was to evaluate the efficacy of commercially available therapeutic boots in a non-clinical setting on the effects of performance, behavior, and physiology of sport horses. The current research shows that as the horse experiences treatment, they exhibit improved performance both during flatwork and while jumping.

Future directions may include testing the therapeutic boots on a wider variety of horses. This may include studying them when used for non-jumping disciplines as well as at higher competition levels of the sport. Although the riding performed in this research was indicative of what some horses may experience, a great amount of variability came from the lack of consistent horse and rider pairings which is typical of most competition pairings. Future research can also be performed to measure the effectiveness of the therapies on horses with preexisting injuries where scar tissue is present and there is a loss of elasticity to the injured site. Equine physiotherapy is an ever-evolving concept. Recent trends suggest the usage of wearable therapies as preparation for exercise to prevent injury and the need for rehabilitation in hopes of mitigating lameness as well as improving physical health in sport horses.