GROUND REACTION FORCE AND DORSOPLANTAR BALANCE IN MOTION

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Finally, I want to thank all the horses who have taught me so much over the years.

ABSTRACT

Farriers often work with injured horses and constantly seek innovative ways to assist recovery while respecting the horses' anatomy. However, despite significant differences in anatomy and biomechanics between the limbs, shoeing strategies are frequently applied to the hind limb simply because those strategies have been proven effective on the front limb.

Theoretically, modifications that change the web width of a shoe alter how Ground Reaction Force (GRF) is dispersed on the foot and leg. This research focuses on the hind limbs, using shoe web width modifications and an understanding of GRF to change how the foot interacts dorsoplantar with the ground. The aim of this study is to demonstrate that changes in shoe web width will affect the distribution of GRF, influencing the floatation and penetration of the hind foot.

This study was organized into two parts: GRF theory and real-world application. The pilot study utilized a press device developed specifically to test theory. Digital levels were used to calculate the degree of interaction of the foot in variable footings. The primary study involved 10 horses, with a total of 320 measurements collected. Of these, 120 measurements were relevant to the hind limb and were taken in soft footing. Measurements were only taken in soft footing because the GRF modifications being applied are designed to influence GRF on deformable surfaces.

Measurements were taken with the Hoof Beat. This equipment has four sensors that attach to the hooves, each including a gyroscope and two accelerometers. The results of both studies were conclusive and ultimately supportive of the hypothesis.

DECLARATION

I hereby declare that the work within this Fellowship dissertation is my own. Any sources have been duly referenced and any illustrations or diagrams that are not mine are used with permission of the owner.

Signed by the candidate.

Word count 4311 (includes the main body of text without the Abstract, figures, tables, Contents, References, Manufacturers and Appendices.)

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INTRODUCTION

Ground reaction force has been studied in horses by several researchers, including Dr. Hillary Clayton and Dr. Jenny Hagen. Researchers have explored how the limbs interact with the ground, but not much has been studied about how modifications on the GRF of the shoe would affect the interaction between the foot and the footing on live horses.

THE AIM & HYPOTHESIS

This thesis examines three situations: a control, a wide toe suspensory shoe, and a wide euro-style bar shoe. The aim of this study is to prove that floatation of different parts of the hind foot can be achieved by shoe modifications affecting the Ground Reaction Force (GRF). The hypothesis: altering the web width or section of the shoe changes the way that the foot interacts with the footing and, as a result, affects GRF distribution on that foot.

BACKGROUND

From a biomechanical and anatomical perspective, farriers must understand some basic principles regarding the hind limb. First is the reciprocal apparatus (RA), which affects the degree of influence farriers have when working on the hind limb. The RA consists of the Superficial Digital Flexor tendon on the caudal aspect and the Peroneus Tertius on the cranial aspect of the hind limb. The Peroneus Tertius, located on the cranial aspect of the limb, is smaller and originates at the cranial distal femur, inserting into the dorsoproximal aspect of the third metatarsal bone and the third and fourth tarsal bones. The Superficial Digital Flexor tendon originates from the distal third of the femur and inserts on the calcaneal process of the calcaneal bone at the tarsus (Sisson and Grossman, 1953).

The RA creates an anatomical situation in the hind limb where, when one joint flexes, all joints flex. Conversely, when one joint extends, all joints extend. While the metatarsal phalangeal joint is not as affected as the hock or stifle, it is still part of the RA. As a result, alterations to GRF and trimming strategies on the hind foot do not always lead to the desired or expected changes to the limb. Changing the balance of the foot on the dorsoplantar plane directly influences hindlimb posture. Sharp and Tabor's study concluded that hoof balance plays a role in hind limb orientation (Sharp and Tabor, 2022).

During the stance phase of the stride the foot exerts a force against the ground, and according to Newton's third law of motion, the ground exerts a reaction force against the hoof that is equal in magnitude and acts in the opposite direction (Back and Clayton, 2013). The GRF comes from the interaction between the feet and the ground (Smith, 2020).

Factors influencing GRF include foot balance, speed, weight, the presence of shoes, and the footing the horse is on. Varying the web width or wedging the shoe alters how the foot interacts with the footing, consequently affecting GRF distribution by that foot.

Balance is critical to performance. The basic trim is the most significant aspect of proper farriery (Baxter and O'Grady, 2011, p. 1186). The same evaluation techniques used for front limbs are often applied when balancing hind limbs. The problem is that the anatomy is different, and the way fronts and hinds work is different. In consequence, the way to achieve balance would be different. On the hind end, it is impossible to see the foot in the air in a weight bearing situation. This is due to the reciprocal apparatus. Since the flexing of one joint also flexes the other joints in the hind limb, the simple act of picking up the hind foot folds the fetlock and changes how the plane on the bottom of the hoof relates to the axis of the leg. The appropriate method to evaluate balance on the hind feet is to stand in front of the leg with the foot on the ground. How the foot bears weight is the most important consideration when determining how to balance a foot (Gregory, 2011, p. 232) (Curtis, 2002, p.112). It is generally agreed that a horse is balanced when it lands flat. Regardless of the method used to achieve this, a flat landing is often considered a sign of balance. (Cody Gregory, personal communication, 18 July 2023).

Biomechanics and conformation are related to one another. The way a horse is built influences how the legs are loaded, how the horse moves and, in part, how well the horse can perform. Conformation refers to the physical appearance and outline of a horse, as dictated primarily by bone and muscle structures (Baxter and O'Grady, 2011, p. 73). Conformation has been regarded as an important indicator of performance and soundness (Back and Clayton, 2013). The effects of conformation on lameness and athletic potential have mostly been evaluated subjectively and based on anecdotal evidence or experience of the observer (Were and Denoix, 2006, cited in Equine Locomotion-Second Edition, p. 229).

Shoe attributes and selection are critical when working on therapeutic cases. One strategy for treating lameness is to change the forces around the center of pressure. Understanding the Center of Pressure is a big part of this and goes hand in hand with GRF. Center of Pressure (COP) is the point of application of the GRF beneath the solar surface of the hoof (Clayton and Hobbs, 2019, p. 5). Logically, modifications that change the web width of a shoe must alter how GRF is dispersed on the foot and limb. Combining all this information will educate farriers on trimming and shoeing techniques to prevent sound horses from becoming lame and to rehabilitate lame horses to soundness.

STUDY DESIGN

For the study, the following is assumed to be true and supports the hypothesis; hard surfaces will not allow the foot to sink in and web width modifications will have no effect on GRF. Soft surfaces will allow shoes with web width disparity to sink or float and measurements will reflect GRF variations. Additionally, by increasing the web width of the toe on a shoe, like the suspensory shoe, the foot on soft ground will have less sinking of the toe and more in the heels. Comparable to a reverse wedge or a dorsal elevation of the foot. In opposition, a bar shoe with a wide web on the bar, like the euro-style bar shoe, will allow the heels to stay on the surface and float on the soft arena, resulting in a mechanical plantar wedge and heel elevation.

The study was organized into two parts; a GRF theory in vitro pilot study, and a real-world application live horse study. The pilot study utilized a press device developed specifically for this test. Digital levels were used to calculate the degree of interaction of the foot in variable footings (see Figure 1) (Coobeast, 2021). The primary study involved ten horses, ridden in a dirt arena and on an asphalt road. Measurements were taken with the Hoof Beat System (see Figure 2), which includes four sensors that attach to the hooves, each containing a gyroscope and two accelerometers. Paired with a software application, the system processes and displays the data (Werkman, C., 2024).

FIGURE 1: *The wooden hind foot being readied for the press using two digital levels (see Appendix 1).*

FIGURE 2.
test horse

These two complementary studies enable the evaluation of both an ideal controlled environment and a real-world approach with live horses. Controlling variables on live horses can be very complex, everything from weather to rider weight must be considered. The pilot study ultimately validated the primary study and yielded valuable data.

MATERIALS & METHODS

PILOT STUDY

The initial part of the study was conducted in vitro using a hydraulic press and a wooden foot model. Three different shoes were applied to the model, each attached using the third nail on each side of the shoe. The test shoes included an open heel shoe for control, a wide European-style bar shoe, and a Suspensory Shoe. Specifications for these shoes are as follows.

The control shoe was a 3/4 fullered steel size 0 hind Kahn Forge 'Certifier'. This shoe has a 10mm x 19mm uniform section (see Figure 3).

FIGURE 3:

was the con

The European style bar shoe was a handmade bar shoe forged by Emilio Giannotti AWCF. The final dimensions of the section were 10mm x 19mm where the width of the bar was twice the width of the toe. The toe had a concave inner edge to allow penetration on the footing.

FIGURE 4:
shoe used for testing (see Appendix 1).

The final shoe was an aluminum Grand Circuit Suspensory Hind Shoe. The reason for using a commercial shoe of this type, is to maintain the ratios between toe/branch and heel. It has a wide toe and narr

FIGURE 5: *The Grand Circuit Suspensory Hind Shoe shoe used for testing (see Appendix 1).*

PILOT STUDY PROCEDURE

The shoes were fixed to a hand carved wooden hind foot using one nail on each side. A swivel was placed on the center of the leg side of the wood foot and fitted on the press (see Figure 6).

FIGURE 6:
a swivel joint attached to the leg side (see Appendix 1).

All shoes were tested on two different footings. For each measurement, 1,043 kilograms of pressure was applied for six seconds, repeated four times per shoe. Conditions were chosen that corresponded to the point of footing yield, creating footprints similar to those seen in a live arena with the same type of surface. (see Figure 7).

FIGURE 7*: Casted footprints from the press test showing penetration depth (see Appendix 1).*

The dirt footing was from the arena where the second part of the study was going to be run; the other footing was a synthetic all-weather arena (Kruse Cushion Ride, 2024). The footing was contained in a clear plastic container, and after each measurement the container was replaced and the footing reworked to reset for the next measurement.

The device had two digital angle gauges attached by magnets to a strut welded to the swivel. The Coobeast digital angle gauge is a magnetic tool designed for precise angle measurements. It measures 360°/4×90° and the resulting value on the LED display is automatically adjusted. The gauges can be zeroed and effectively realize absolute or relative angle measurements (Coobeast, 2021). One gauge recorded the dorsoplantar interaction, while the other measured the medial-lateral interaction with the footing. The in vitro study aimed to compare these results with those from the live horse study. Using the hydraulic press eliminated individual animal variables, demonstrating how shoes with different GRF modifications behaved under controlled pressure conditions.

LIVE HORSE STUDY PROCEDURE

The primary study involved live horses. All three shoes were applied to each horse, using one nail on each side, with the same nail hole used for each shoe. Measurements were taken using the Hoof Beat.

The Hoof Beat system is a commercial set of sensors used for measuring locomotion. It consists of accelerometers and gyroscopes that mount on each sensor, which attach to the foot with strong. The sensors collect data, which is processed by software. The Motion Map, a software feature, graphically represents how the foot interacts with the footing, and expresses data in degrees. For a valid measurement, the horse must take at least 20 strides on each gait and surface. The software will analyze the data and provide median values for timings and angles during different phases of the stride (Hoof Beat System, 2019).

American Quarter Horses were selected for the study to ensure consistency in gait, foot size, and disposition. The horses ranged in age from 5 to 21 years, with an average age of 10 years.

Measurements were conducted at Heartland Horseshoeing School in Lamar, Missouri. Each horse was ridden by the same person using the same tack to maintain consistent weight across all measurements and minimize variables. Each horse walked and trotted on both hard and soft surfaces twice with each shoe applied. Only the measurements on soft footing were considered relevant, as the modifications did not affect the hard surface. The sample consisted of 10 horses, resulting in n=40 for each shoe and gait.

The arena where the study was performed was worked and dragged with a tractor. It was reconditioned after each horse was ridden, ensuring each measurement was taken on a fresh path.

The trimming and balancing of the hind feet followed the criteria outlined by Chris Gregory in his book, as mentioned in the introduction (Gregory, 2011, p.232). All feet were trimmed by assessing medio-lateral balance by standing in front of the tarsus and looking at the plumb line from the stifle joint. The dorso-plantar balance was assessed from the side of the horse (Hood, 2006, p.7). The shoes were changed every four measurements while the data was downloaded to the Hoof Beat software on the tablet.

Each horse took at least 20 steps at the walk and 20 steps at the trot to ensure valid measurements, as required by the Hoof Beat System (Hoof Beat System, 2019). Each measurement began with the horse standing still.

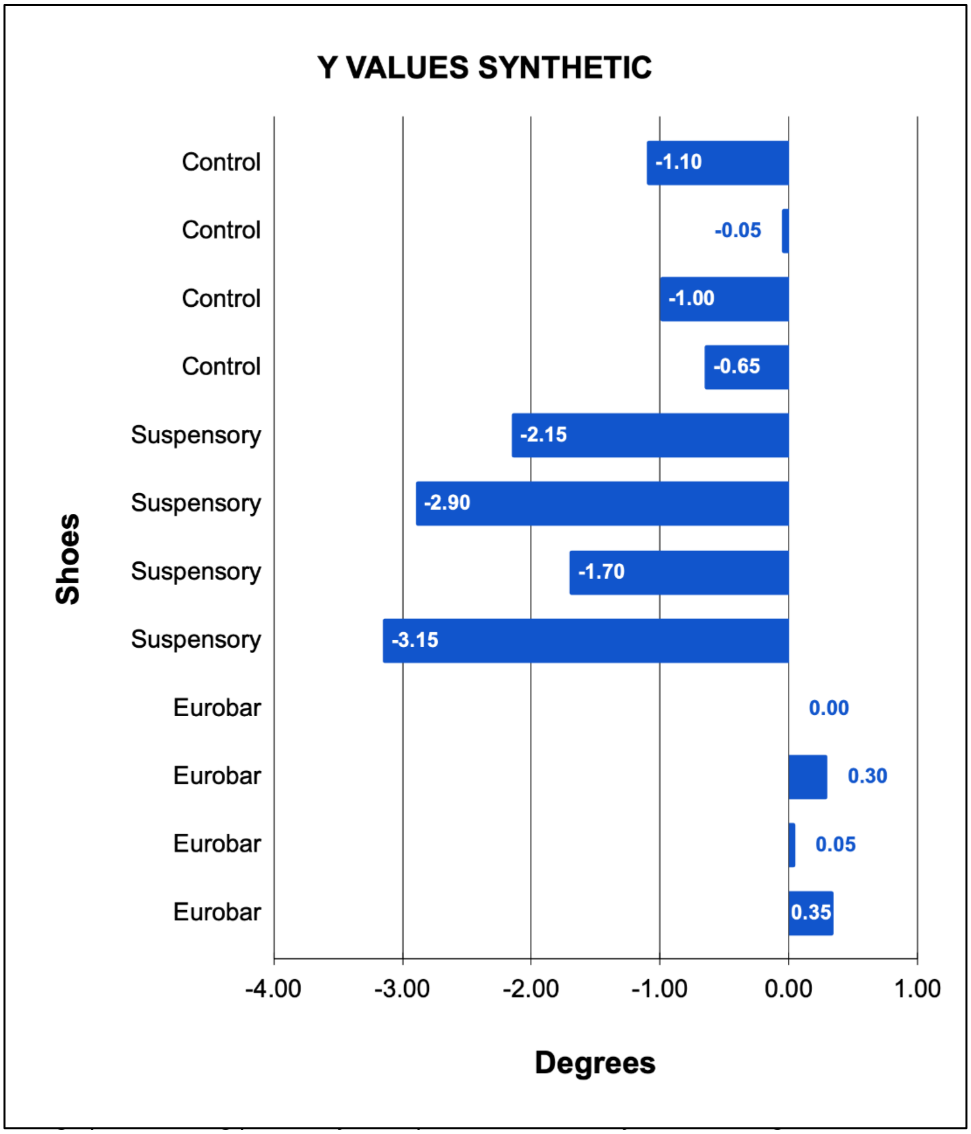
DATA ANALYSIS AND RESULTS

For both parts of the study, the same operators collected the data. The data needed to be manually read from the Hoof Beat System and recorded in Google Sheets for analysis (Google LLC, 2024).

After the data was entered into Google Sheets for processing and analysis, left and right legs were considered to be the same for measurement purposes. Other studies have proven that left and right legs are comparable (Hagen, 2021). A total of 32 measurements were taken from each horse, with 24 used for this study. This resulted in 40 data points for each shoe in each gait, with 120 data points analyzed for trot and 120 for walk.

The pilot study provided a reference to test the physics of GRF on different mediums without the additional variable of the horse. Negative values, in the context of graphs, refer to the amount of heel sinkage on the dorsoplantar axis. Positive values reflect degrees of heel floatation. Rephrased, the negative values represent plantar penetration, while the positive values show toe sinkage.

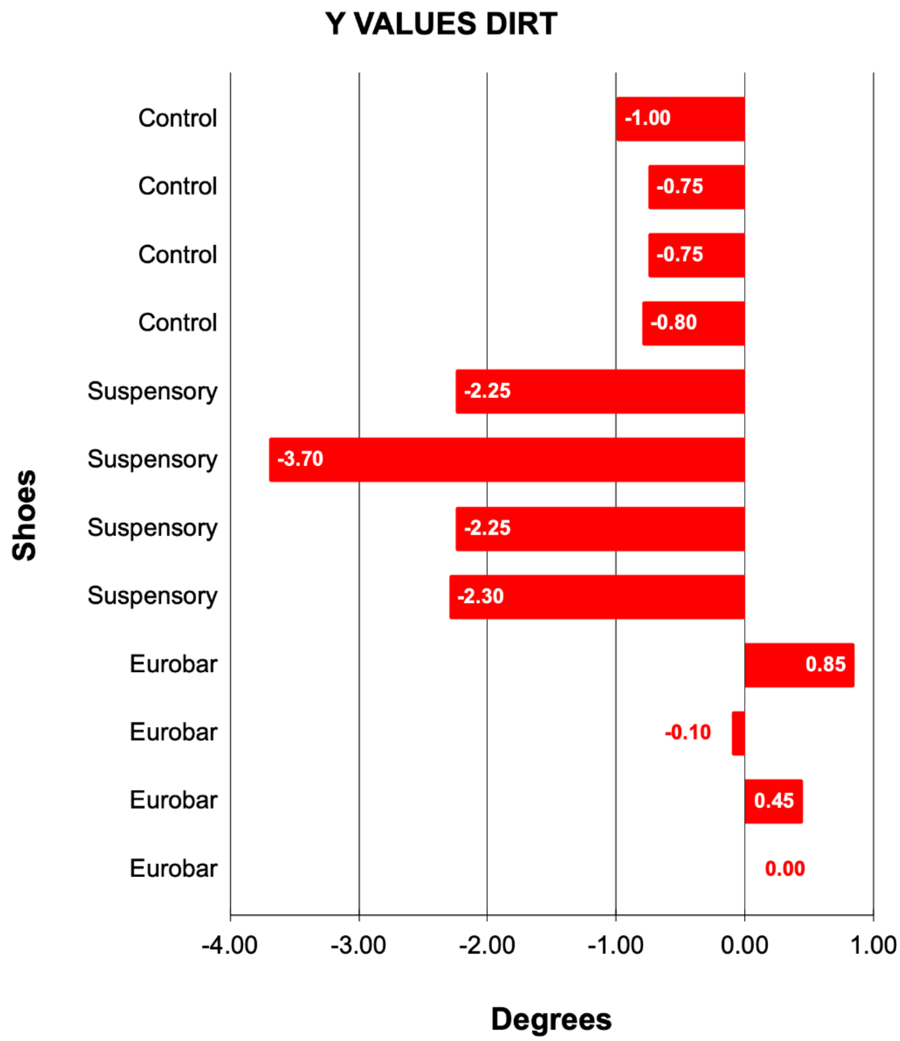
Please refer to Graph 1 for the following pilot study synthetic footing comparisons. The suspensory shoe sinks plantarly on synthetic footing compared to the control shoe. The euro-bar shoe, in contrast, does not show any plantar sinkage and remains on the surface, often referred to as "floating," even under press load. The median plantar sinkage was -0.825° for the control shoe and -2.525° for the suspensory shoe, while the euro-bar shoe showed 0.175° of dorsal sinkage.



Graph

Negative numbers refer to heel sinkage, positive to toe sinkage (see Appendix 1).

Please refer to Graph 2 for comparisons on dirt footing, the same used in the live horse study. Once again, the suspensory shoe shows significantly more plantar sinkage compared to the control shoe, while the euro-bar shoe exhibits no plantar sinkage and slightly more dorsal sinkage. The median plantar sinkage values are -0.775° for the control shoe and -2.275° for the suspensory shoe. The euro-bar shoe has a median dorsal sinkage of 0.225°.



Graph

Negative numbers refer to heel sinkage, positive to toe sinkage (see Appendix 1).

Summarily, the press data supports the hypothesis; altering the web width of the shoe or section changes the way that the foot interacts with the footing, directly affecting GRF distribution on that foot.

In synthetic footing, the suspensory shoe averaged 1.7° of heel sinkage, relative to the control, and an average of 1.8° in the arena footing. Comparatively, the euro-bar gained an average 0.875° of heel floatation in synthetic footing, and an average of 1.125° in dirt. The difference in degrees demonstrates how the modification of the GRF on the shoes works compared to the control or normal shoe.

In the primary study, the sample size was n=40 for each shoe, surface, and gait. Derived from a total of 240 measurements, each horse provided 24 hind shoe measurements. Each horse underwent two measurements per shoe for each gait, considering the left and right sides as equal. The surface tested was the same dirt arena footing as the pilot study. Three critical data points were transcribed from the Motion Map of the Hoof Beat. The original data consisted of X and Y coordinates, where X represents degrees of change towards medial or lateral, and Y represents degrees of change dorsal or plantar. The data points were specifically taken from the landing phase to the beginning of breakover in the stride.

Using the Motion Map the following points were transcribed. Point 1 “Landing Point”; the first point of hoof loading after contact with the ground. Point 2, also referred to as “Point Z”; the furthest point the foot rotates plantarly. Point 3 “Breakover Point”; the transition of the stance phase into the break over phase (see Figure 7).

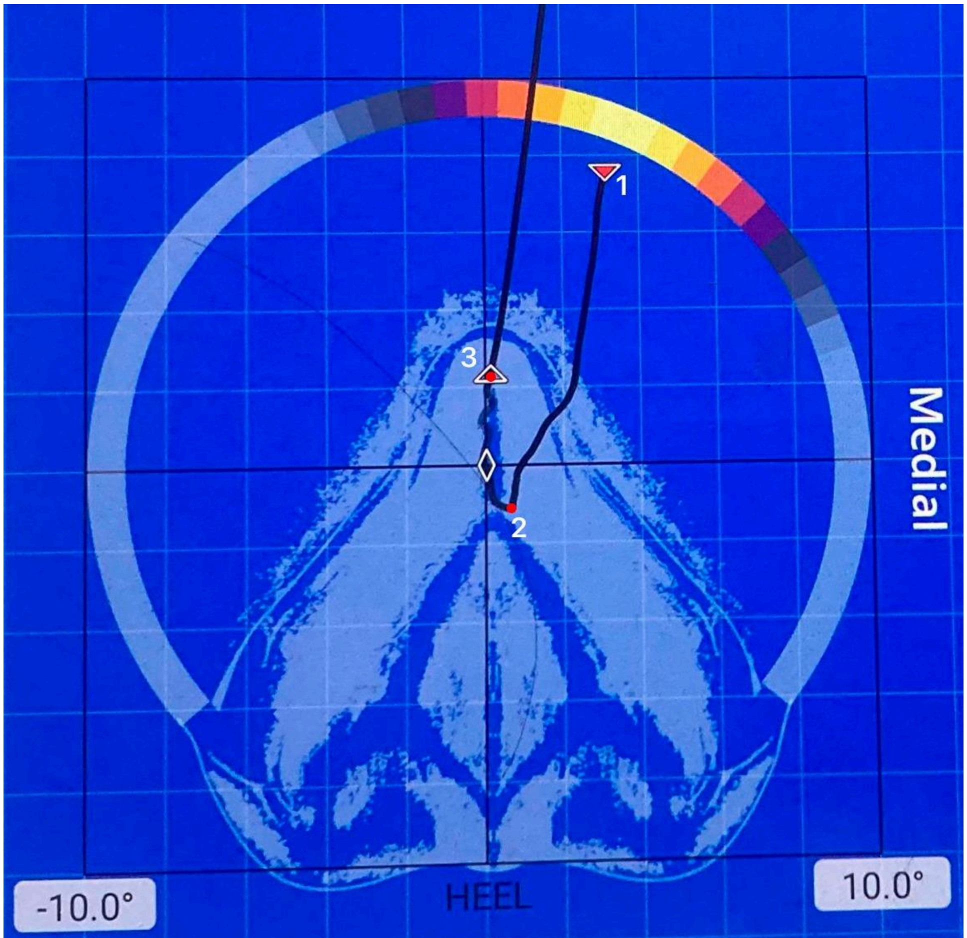


FIGURE 7: *A screenshot of the Motion Map on the Hoof Beat.*
The numbered points are referenced in the paragraph below (see Appendix 2).

The data was analyzed using the Kruskal-Wallis (KW) non-parametric test, which is designed to compare three or more independent groups (see Table 1). This test aims to identify significant differences between data sets. The null hypothesis (Ho) states that there are no differences between the medians (med or Q2) of the groups. A 95% confidence level was used to decide whether to accept or reject Ho. If Ho is rejected (p-value < 0.05), the post hoc Dunn test is conducted to further compare the groups identified by the KW test, ensuring the detection of statistically significant differences (see Tables 2, 3). The statistical analysis was performed using RStudio software (RStudio Team, 2022).

In scholarly contexts, delta (Δ) typically represents a difference or change in a specific variable. For example, in mathematics and science, it often signifies the change in a quantity, such as Δy for a change in the variable "y" (Day, 1981; Morgan, 1970).

The deltas discussed here represent the movement of the foot when contacting the ground. Delta LBy represents the plantar sinking of the heels after landing and is the difference between the first point of contact to the deepest point the foot penetrates the ground. While Delta Z represents the dorsal rotation of the foot before breakover starts.

Table 1: *The results for the Kruskal Wallis Test for soft ground, walk and trot (see App*

DELTA	TROT	WALK
ΔLBy	p - value = 0.0007236	p – value = 0.002
ΔZ	p – value = 0,001398	p – value < 0.0001

Table 2: *Results for the post Hoc Dunn Test for soft ground, trot (see Appendix 1).*

TROT COMPARISON	Δ L β γ	Δ Z
Control vs Euro-bar	0.004	0.005
Control vs Suspensory	1	1
Euro-bar vs Suspensory	0.002	0.005

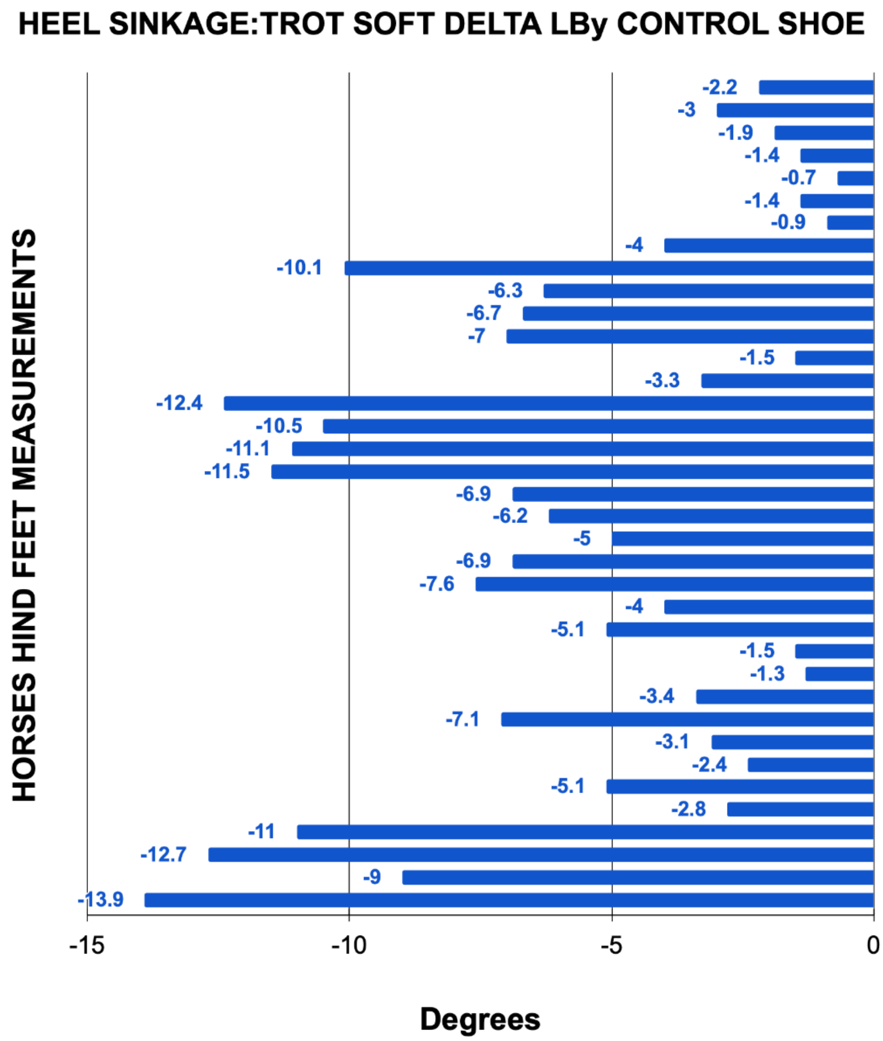
Table 3: *Results for the post Hoc Dunn Test for soft ground, walk (see Appendix 1).*

WALK COMPARISON	Δ L β γ	Δ Z
Control vs Euro-bar	0.01	> 0.0001
Control vs Suspensory	1	1
Euro-bar vs Suspensory	0.0005	> 0.0001

With these results, it can be inferred that the control and suspensory shoes are statistically similar. However, the euro bar shoe exhibits a statistical divergence that is present in both gaits.

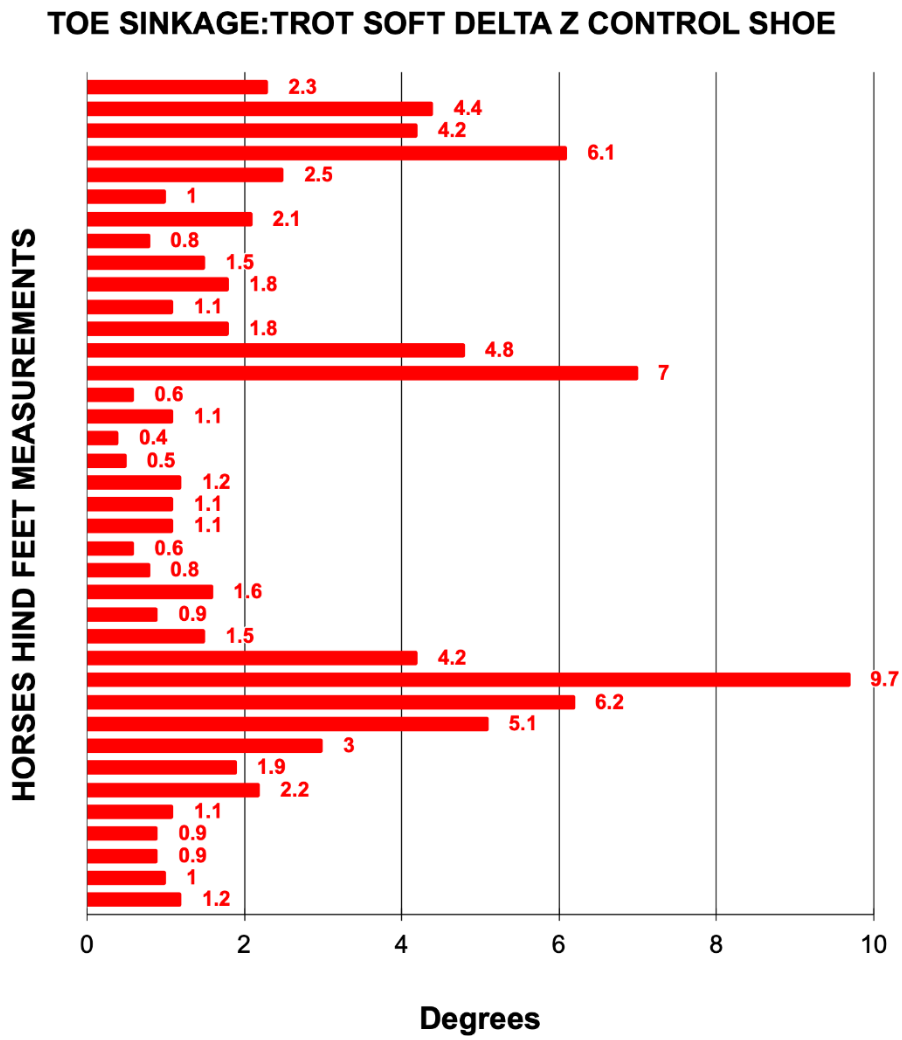
TROT COMPARISONS

Graphics 3 and 4 illustrate the behavior of the control shoe at the trot on live horses. The blue bars indicate the heel sinkage, Delta LBy, after the initial point of loading, while the red bars represent the dorsal movement, Delta Z, of the foot before the breakover begins.



Graph

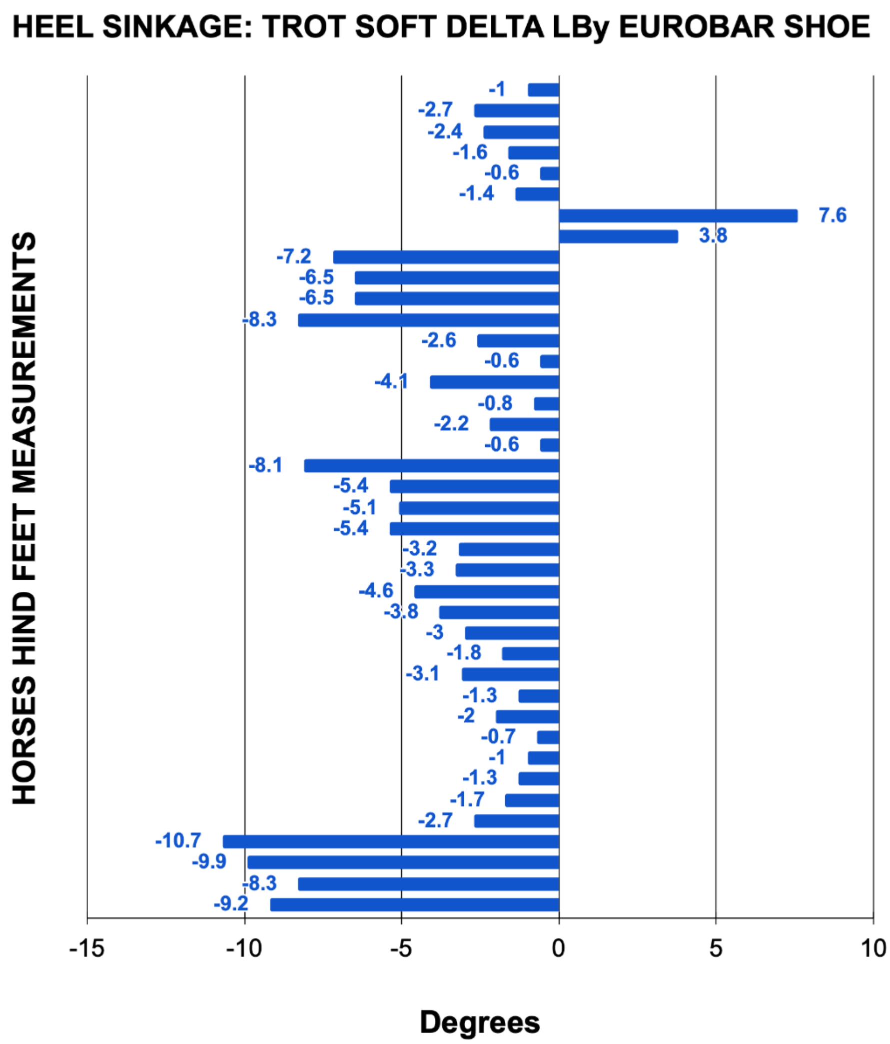
across all feet on all horses (see Appendix 1).



Graph

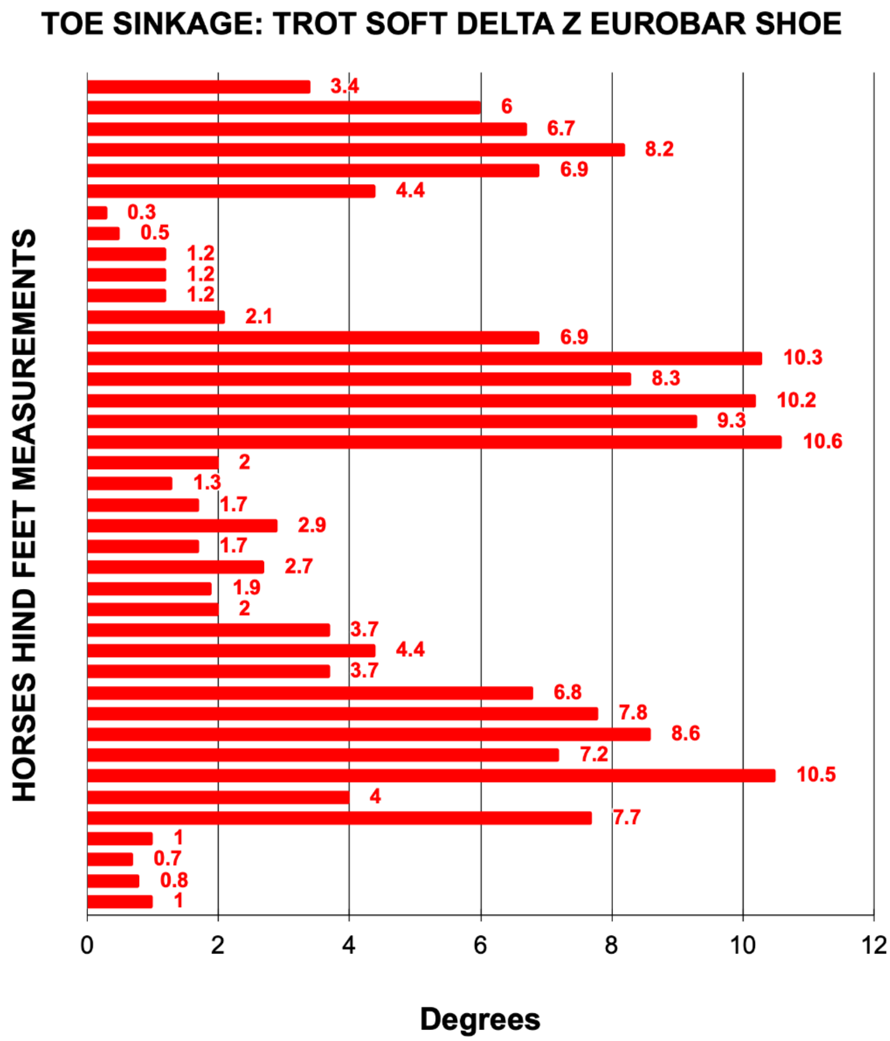
across all feet on all horses. (see Appendix 1).

Graphics 5 and 6 represent the action of the euro-bar shoe. It shows less foot sinkage compared to the control shoe at the trot, with 2.25° less plantar sinkage on average. The Delta LBy indicates notable dorsal sinkage of the toe. When comparing the averages across all horses, the euro-bar shoe provides 1.89° more heel floatation than the control shoe.



Graph

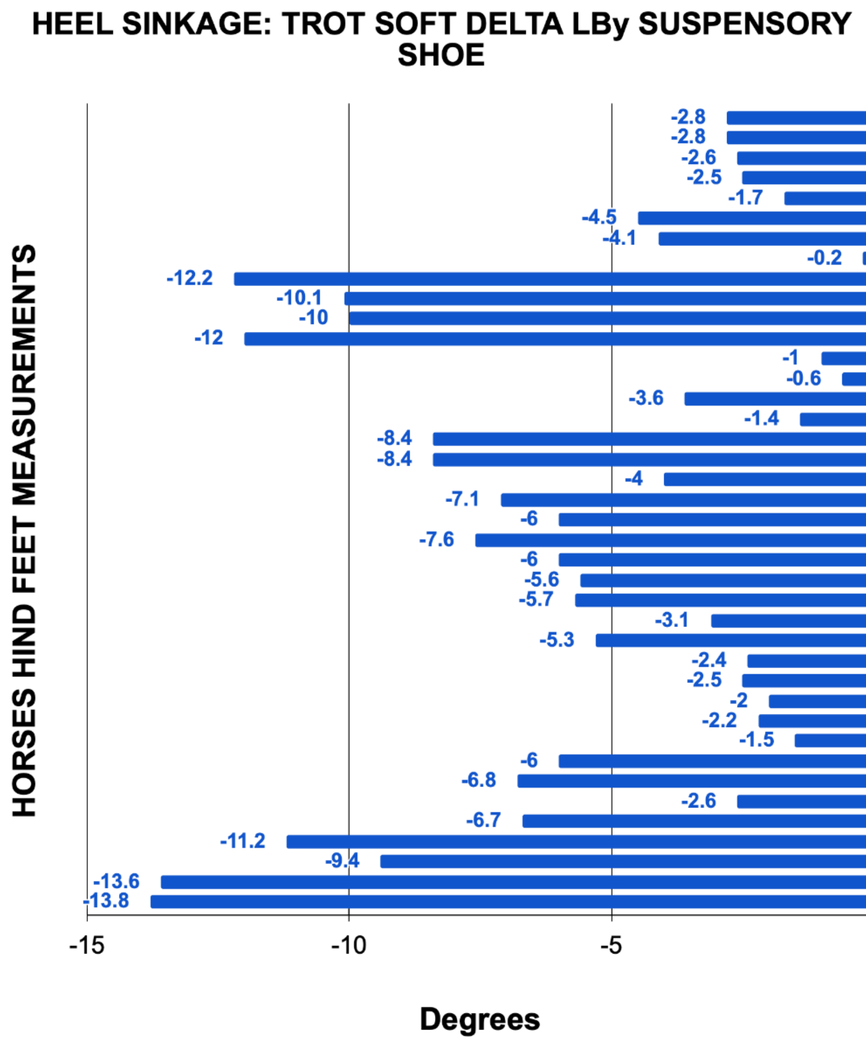
across all feet on all horses (see Appendix 4).



Graph

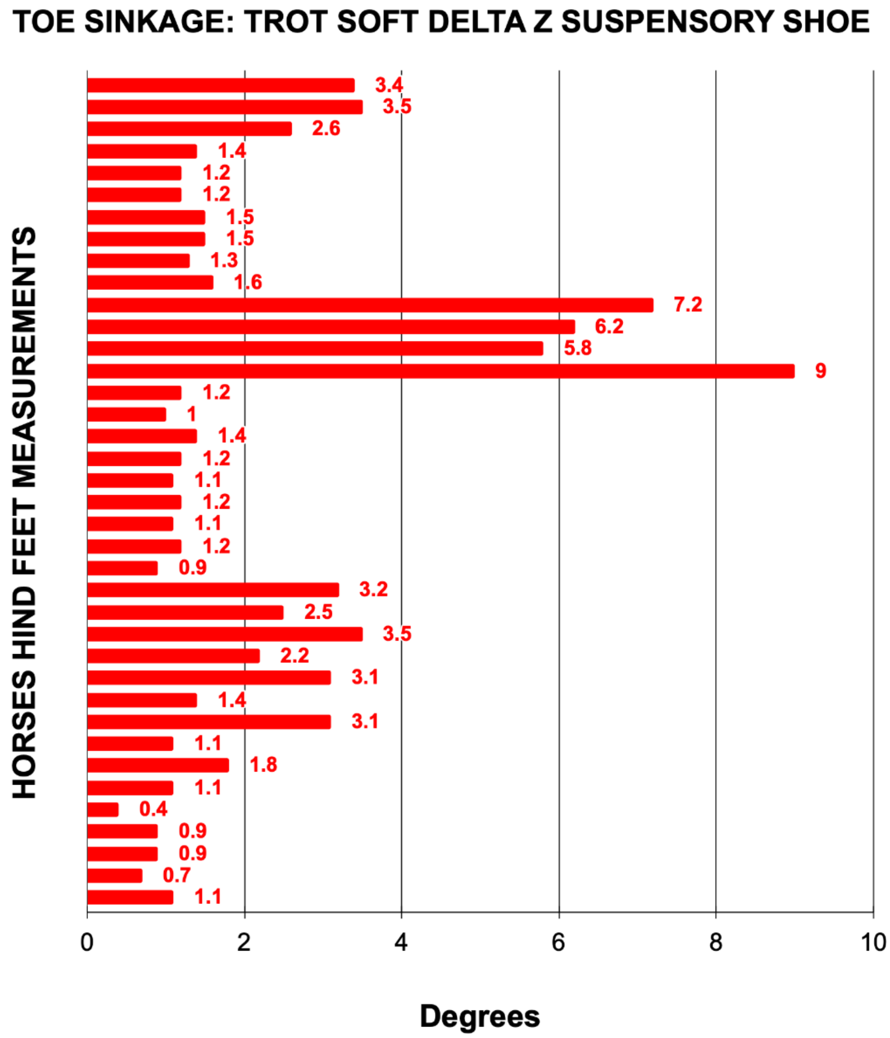
across all feet on all horses (see Appendix 1).

Graphics 7 and 8 depict the performance of the suspensory shoe. This shoe shows minimal difference compared to the control. On average, it has 0.08° less heel sinkage and 0.11° less toe sinkage than the control shoe.



Graph

across all feet on all horses (see Appendix 1).



Graph

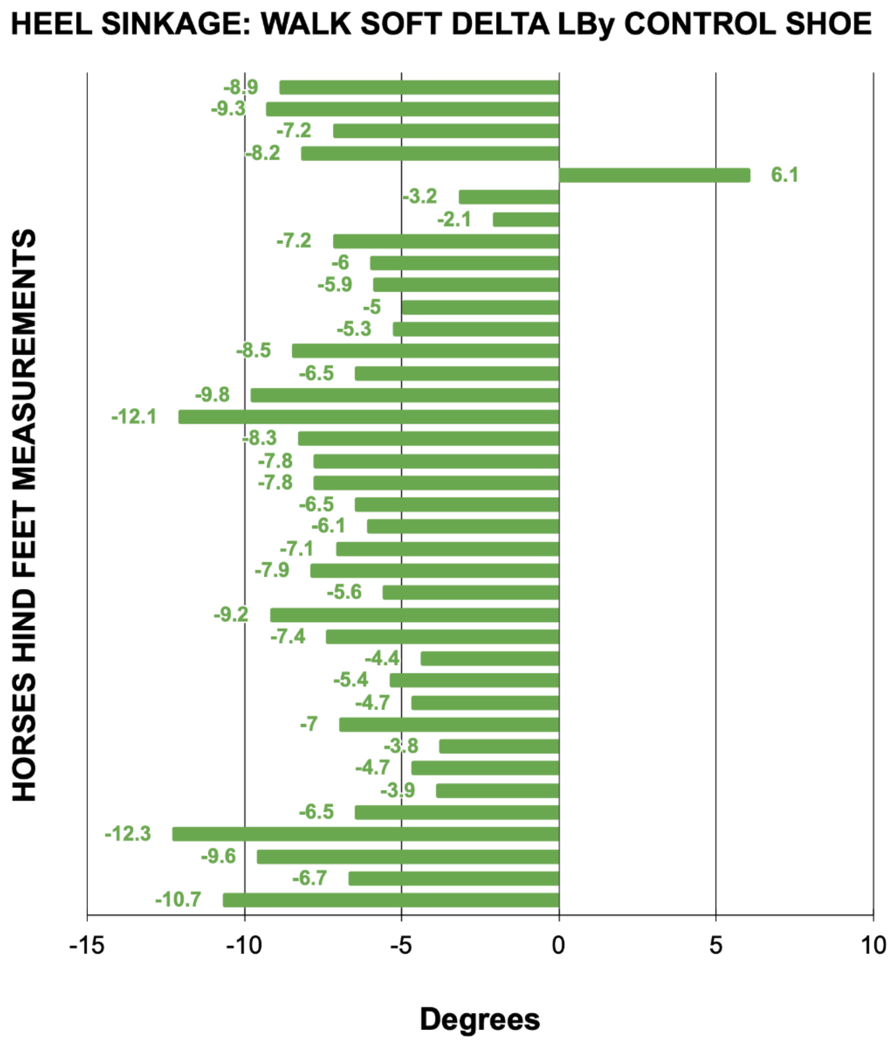
across

After evaluating the median values, the control and suspensory shoes show insignificant variance: -5.05° for the control versus -4.9° for the suspensory shoe on Delta LBy. A minimum difference of 0.5° was considered significant for this study. For Delta Z, the control value is 1.5° and the suspensory value is 1.35°. This does not align with the press results, where the suspensory shoe demonstrated that under straight-forward pressure, the GRF modification was working as expected.

The median for euro bar is -2.7° for Delta LBy and 3.7° for Delta Z. These values support the press results by showing that the euro bar has floated the heels, thus preventing the plantar rotation that occurs after foot contact with the ground.

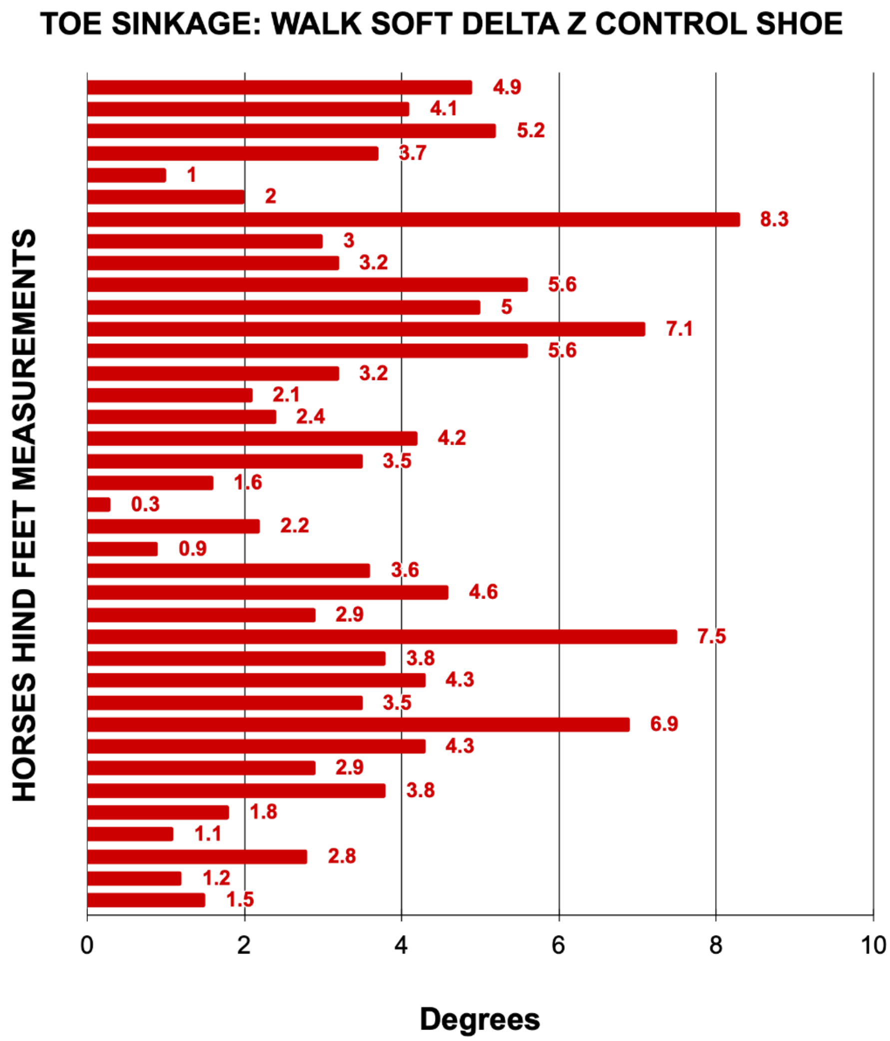
WALK COMPARISONS

Graphics 9 and 10 show the behavior of the control shoe during the walk. The green bars indicate the normal plantar sinkage of the foot after the initial point of loading, while the dark red bars represent the dorsal rotation of the foot before the breakover phase.



Graph

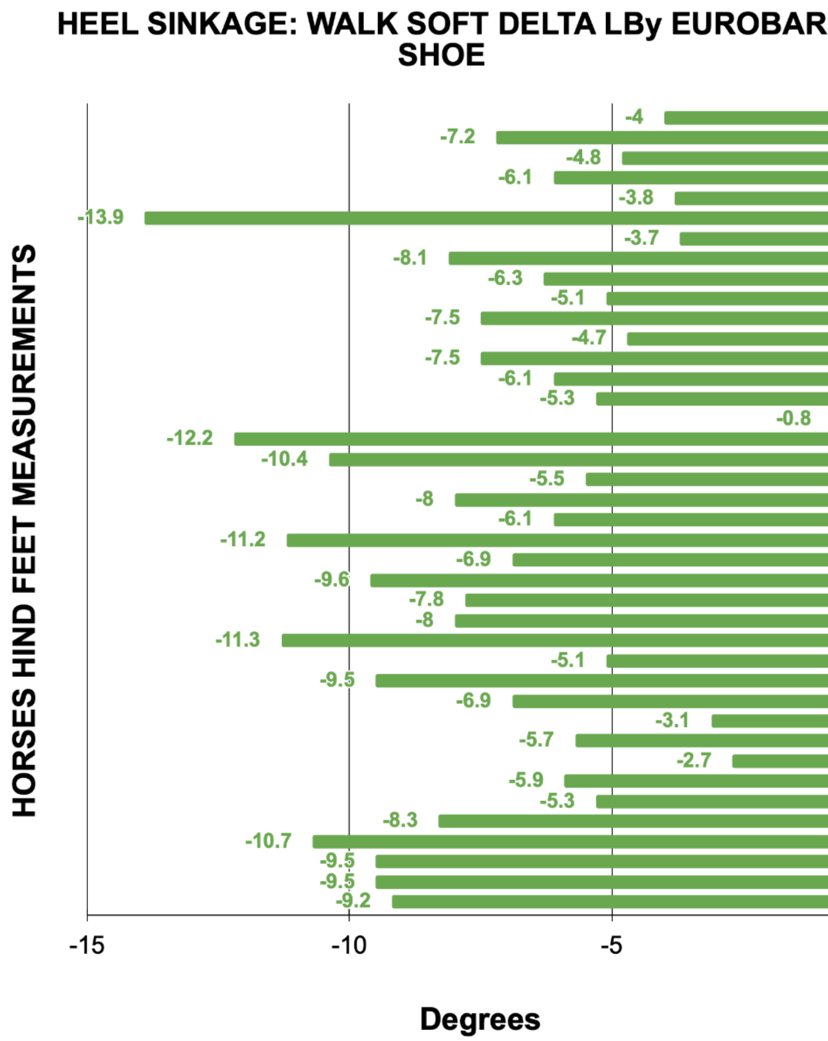
across all feet on all horses (see Appendix 1).



Graph

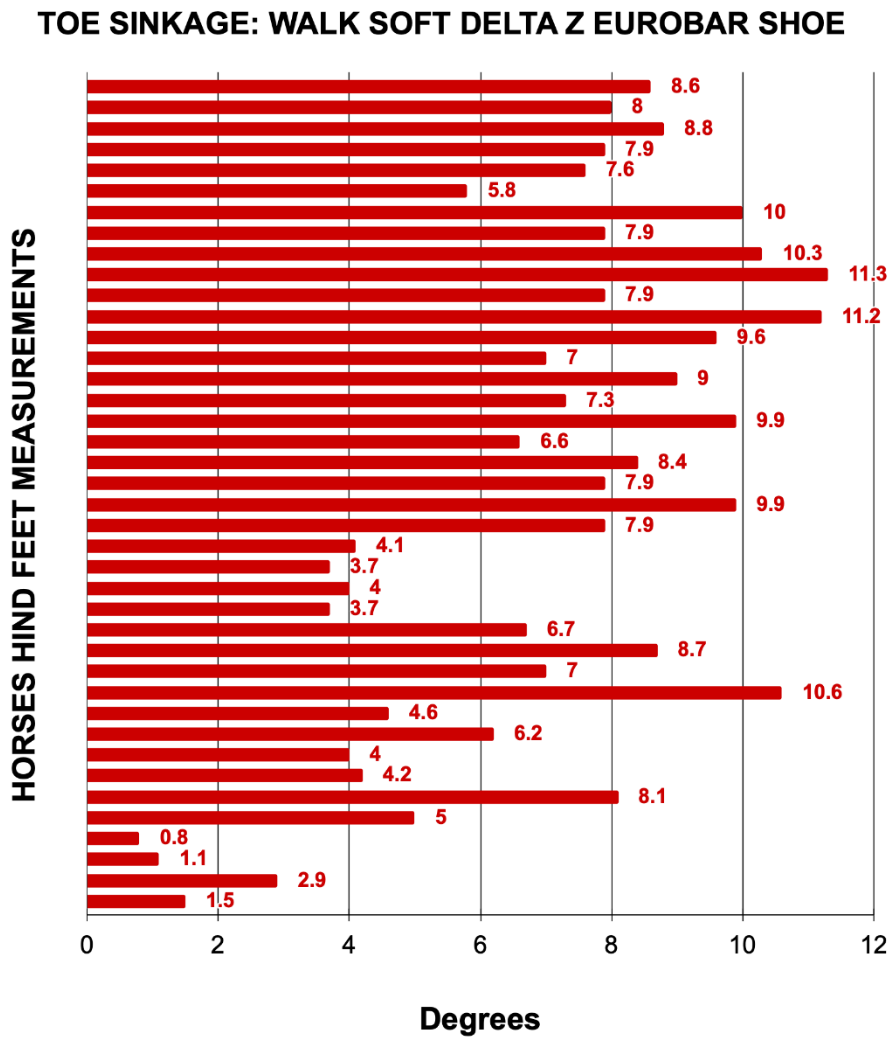
across all feet on all horses (see Appendix 1).

Graphics 11 and 12 show the behavior of the euro-bar shoe at the walk. Graphic 11 indicates that the plantar sinkage at the walk for the euro-bar shoe does not differ from control, it has an average of 0.55° deeper sinkage. Conversely, the dorsal sinkage shows an average increase of 3.25° at the heels compared to the control.



Graph

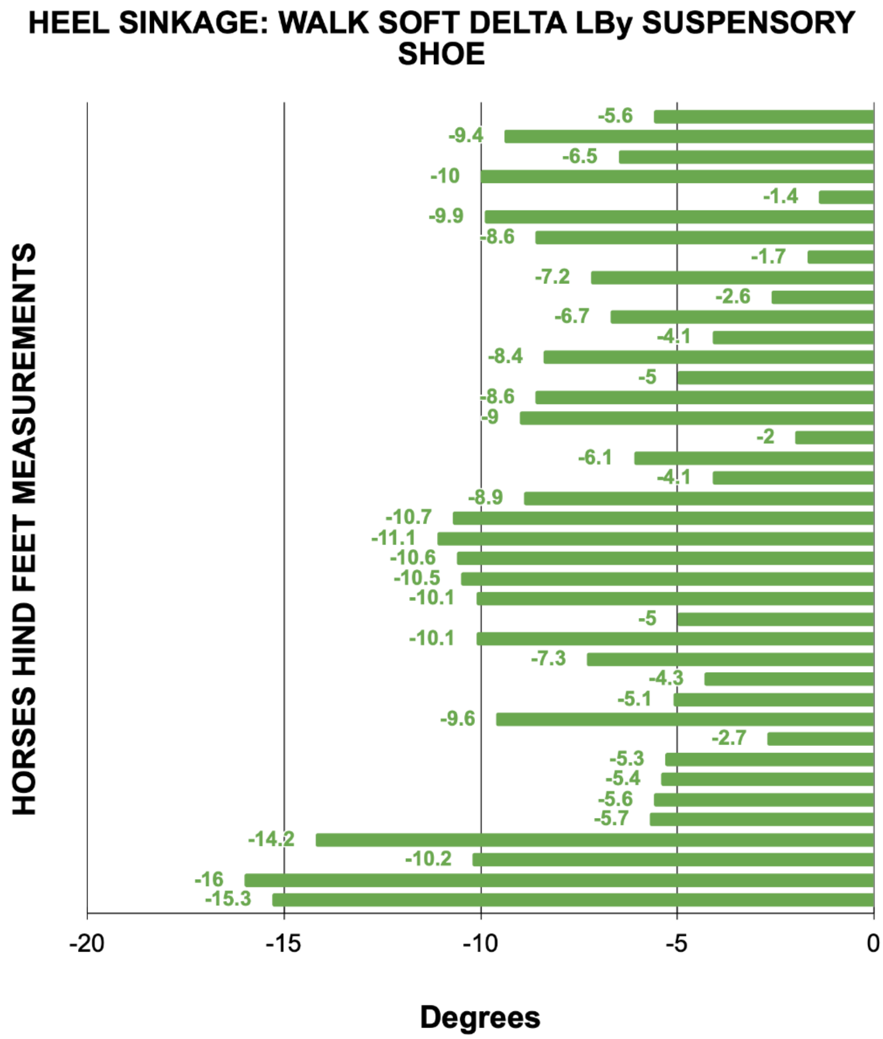
across all feet on all horses (see Appendix 1).



Graph

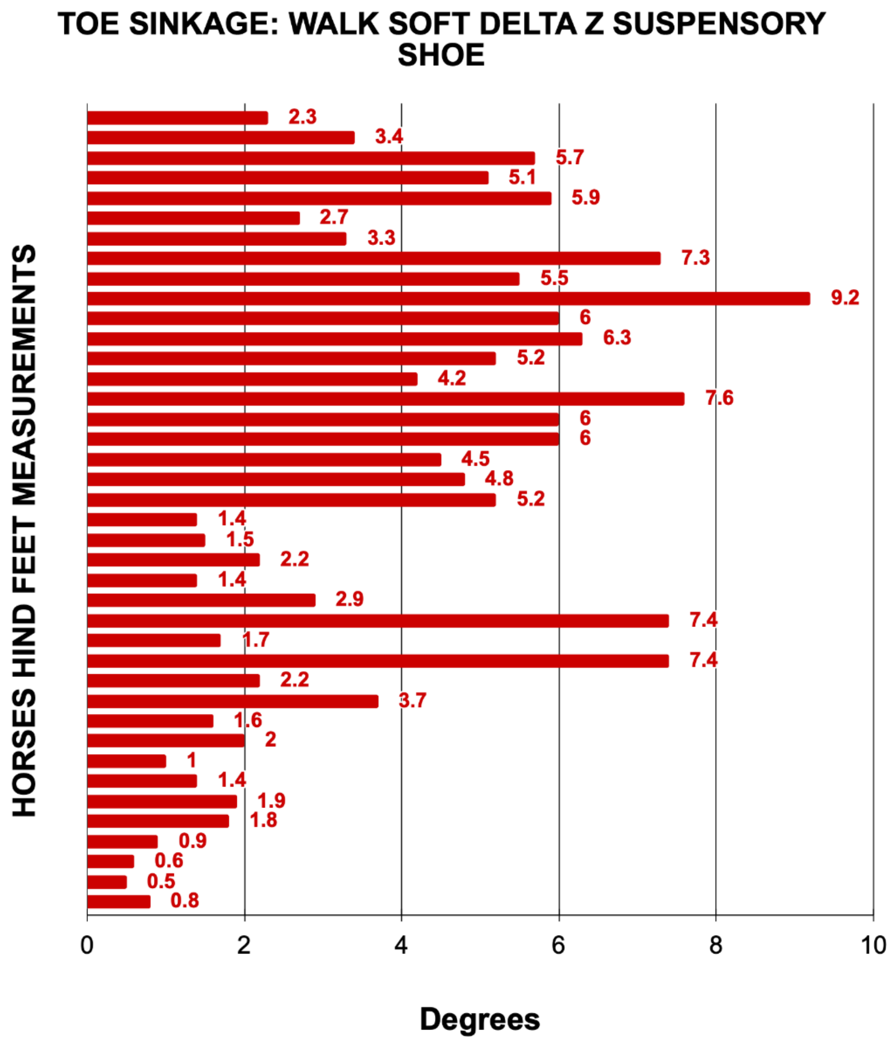
across all feet on all horses (see Appendix 1).

Graphics 13 and 14 illustrate that at the walk, the suspensory shoe exhibits an average of 0.88° more heel sinking than the control, with a dorsal rotation that is almost the same, showing only 0.19° more than the control. When analyzing the medians for the walk, the control LBy is –6.85°, compared to –7.25° for the suspensory shoe, indicating a 0.5° difference towards heel sinkage with the suspensory shoe. Delta Z shows only a 0.15° difference between the two shoes, with 3.5° for the control and 3.35° for the suspensory shoe.



Graph

across all feet on all horses (see Appendix 1).



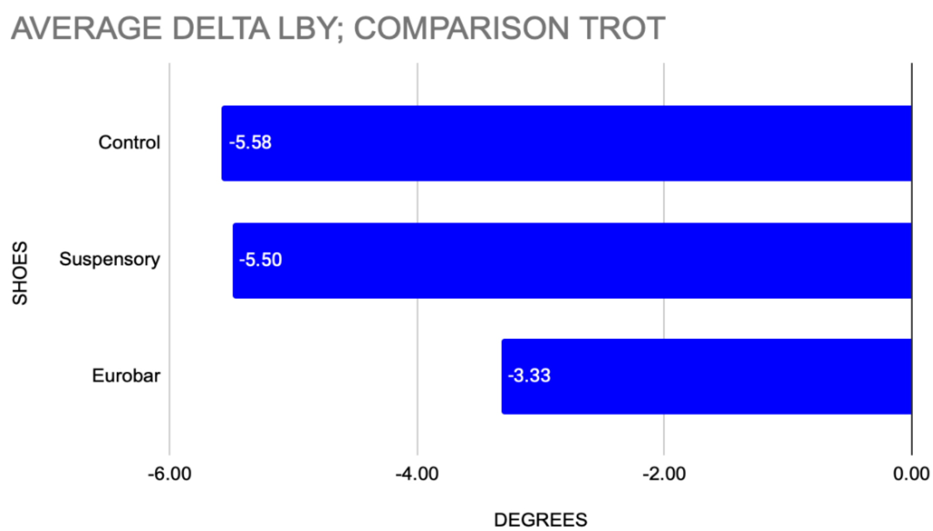
Graph

across all feet on all horses (see Appendix 1).

OVERVIEW: AVERAGE DELTA VALUES COMPARISON

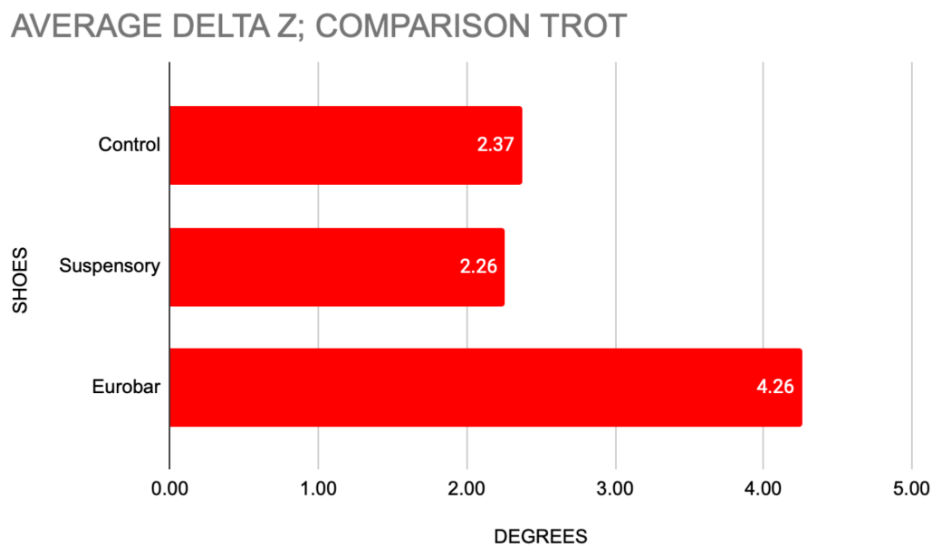
The average of all delta values for each shoe type were analyzed and compared, providing a clearer visual reference of the study's findings. Averaging the deltas offered a better understanding of the overall performance and behavior of each shoe under various conditions. This comparative analysis identified significant trends and differences in the mechanical properties and effects of each shoe design, facilitating a more comprehensive evaluation of their impact on the horses. The visual representation of these averages highlights noteworthy variations and supported the conclusions with more robust data.

In summary, the euro-bar shoe diminishes heel sinkage on the footing during plantar rotation after initial loading, with no difference observed between the other two shoes (see Graph 15).



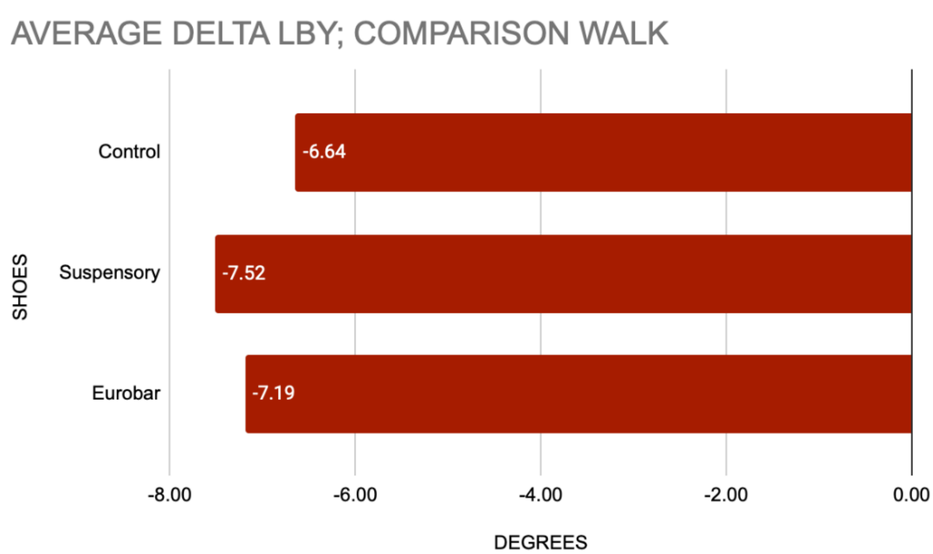
Graph
across all horses, trot (see Appendix 1).

In terms of dorsal rotation, the euro-bar shoe exhibits a notable difference compared to the other two shoes, showing that the GRF modification has a significant effect on foot and footing interaction. Specifically, there is a 2° difference compared to the suspensory shoe and 1.89° compared to the control (see Graph 16).



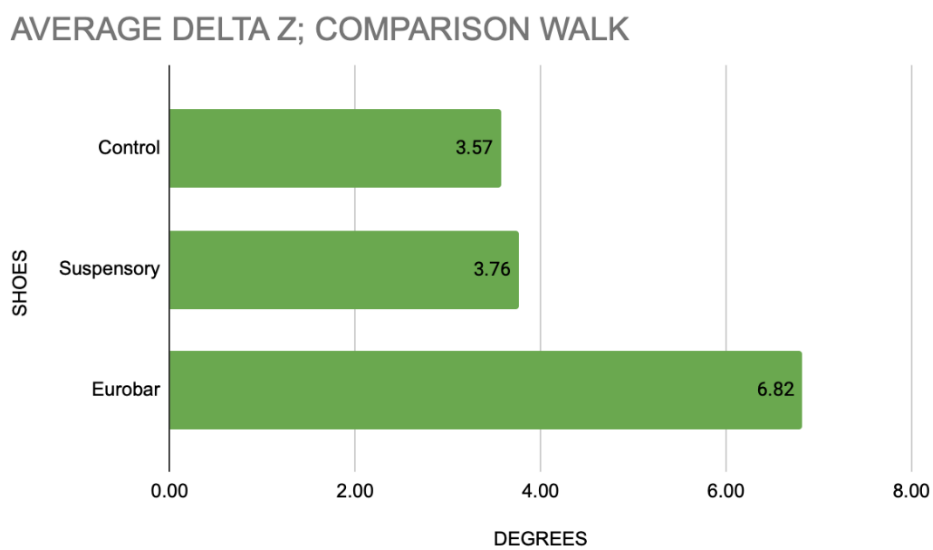
Graph 16: *Average toe sinkage measurements of all shoes across all horses, trot (see Appendix 1).*

At a walk, the reaction to the GRF modification differs from its performance at the trot. The suspensory shoe exhibits 0.88° more heel sinkage, aligning with theoretical predictions. However, the euro-bar shoe does not behave as expected in this scenario (see Graph 17).



Graph 17: *Average heel sinkage measurements of all shoes across all horses, walk (see Appendix 1).*

The dorsal rotation at the walk reveals a similar trend to the trot, with the euro-bar shoe showing 3.25° more rotation than the control. Once again, there is no difference between the suspensory and control shoes (see Graph 18).



Graph
across all horses, walk (see Appendix 1).

DISCUSSION

The study focused on hind limbs due to frequent requests from veterinarians to apply suspensory shoe modifications for suspensory ligament injuries. Although originally designed for front limbs, concerns arose about the suitability and effectiveness of these shoes on hind limbs due to the distinct anatomical and biomechanical differences. Theoretical principles suggest that widening the shoe at the toe would achieve flotation on the ground based on GRF principles, causing the foot to operate at a mechanically broken-back axis with each step. Conversely, using a wider heel surface or bar shoe should logically produce the opposite effect. If validated, this knowledge could be therapeutically applied to unload specific anatomical structures.

These principles seem clear when applied to the thoracic limb: lowering the foot angle shifts the load from the suspensory ligament to the deep digital flexor tendon, while raising the angle decreases stress on the deep flexor tendon, transferring it to the superficial flexor tendon and suspensory ligament. However, when considering modifications on the hind limb, the mechanics of the RA must be accounted for, particularly the lack of independent flexion or extension at the hock and stifle. Altering the foot angle on the hind limb changes the leg's position relative to the horse's body, raising questions about whether these shoe modifications function as intended.

The “in vitro” pilot study results suggested that the modifications should achieve their intended effects. However, the primary study on live horses did not support these findings. No statistical differences were observed between the suspensory shoe and the control shoe, and in some cases, the control shoe's heels sank more than those of the suspensory shoe. This could be due to the metatarsophalangeal joint's reliance on the RA, where the joint’s extension depends on the hock and stifle's reduced flexion.

The euro-bar shoe results indicate that it successfully floats the heels, preventing the plantar rotation typically seen after ground contact, and promotes deeper toe sinkage, creating a steeper angle before reaching breakover. However, the variation among individual horses was significant. Some horses adapted to the shoeing changes immediately, resulting in different responses to GRF modifications. While this does not necessarily mean the modifications will have no effect throughout the shoeing cycle, further research is needed to explore these effects.

CONCLUSION

The study's primary findings suggest that the euro-bar shoe successfully modifies GRF on hind feet, reducing heel sinkage after initial loading and increasing dorsal rotation. The wider toe of the suspensory shoe, however, shows no significant difference compared to the open heel shoe in live horses, although it responded positively in press tests. This observation supports the theory that the physics governing the front and hind feet differ, likely due to the reciprocal apparatus (RA) and the varying biomechanical functions of the hind limbs.

In the "in vitro" pilot study, the shoes performed as expected without the complexities of live horse interaction. However, when applied to live horses, responses varied significantly, with some horses adapting immediately to the shoe changes. Horses naturally adjust their hoof placement to maintain their natural gait, ensuring efficiency and comfort (Clayton et al., 2013). An example of this concept is depicted by Figures 8 and 9. The euro-bar shoe was particularly effective in reducing heel sinkage on soft surfaces, with 2.25° less sinkage at the trot and 1.89° more dorsal rotation compared to the control shoe, primarily due to the bar. Both the pilot and primary studies confirmed the euro-bar shoe's effectiveness, with the primary study revealing an additional 1.59° improvement.

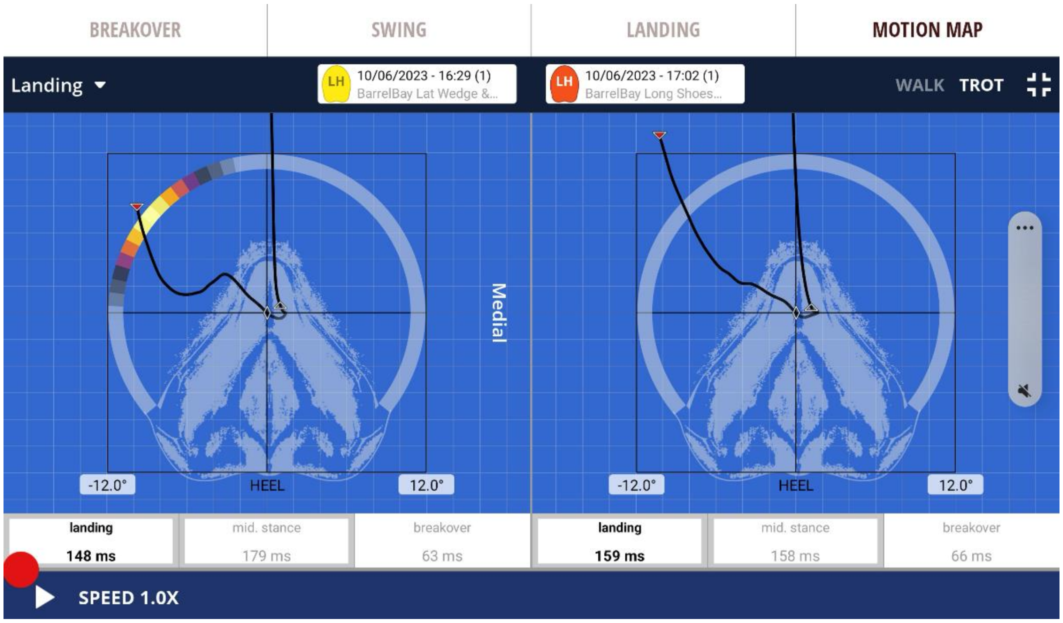
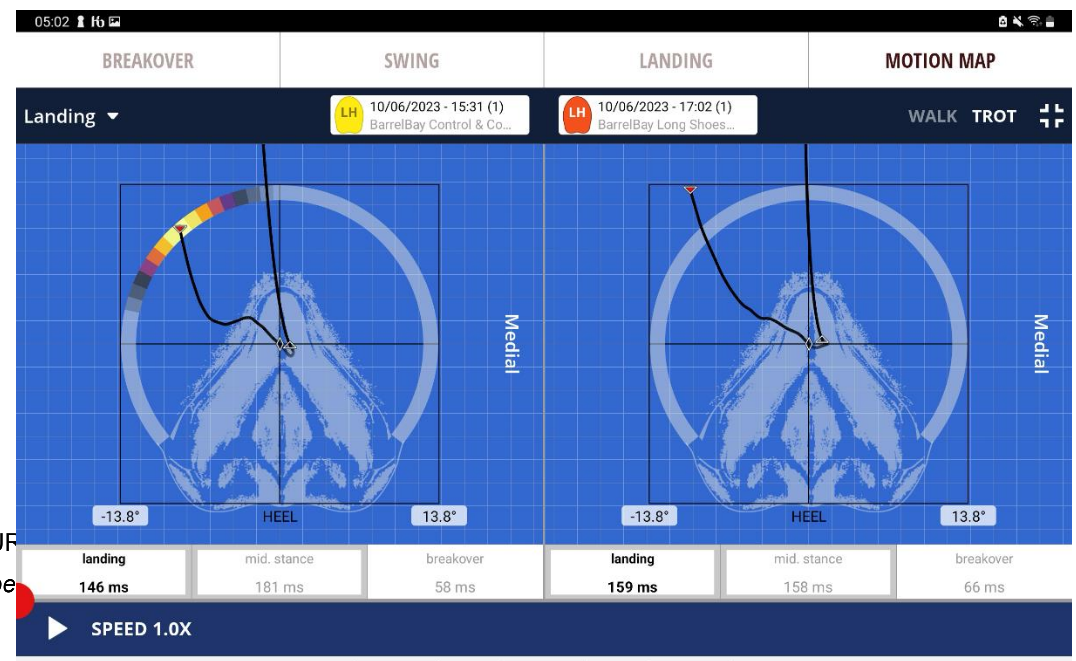


FIGURE 8: *An example of a horse adapting to different shoes using the Motion Map for comparison. Euro-bar on the left and Suspensory on the right; the results are the same (see Appendix 2).*



FIGUR

Suspe

The results demonstrate the significance of modifying GRF on the heels using bar shoes, which reduces plantar sinkage and enhances dorsal rotation. However, GRF modifications at the toe showed no significant difference compared to an open heel shoe. Further research is essential to understand how different sized horse respond to these modifications and to measure the tension on various anatomical structures during movement, helping to identify which structures in the hind limb are unloaded or overloaded.

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APPENDIX

APPENDIX A: PERMISSIONS

A.1 Permission from Rachel Herrington C.F.

Permission was granted by R. Herrington of Herrington Forge & Farriery LLC to use the photographs, tables, and graphs she created or edited (R. Herrington, personal communication, December 2022).

A.2 Permission from Christel Werkman

Permission was granted by C. Werkman of Hoof Beat Systems to use data and snapshots from proprietary software (C. Werkman, personal communication, 1 July 2024).

A.2 Permission from Conrad Trow

Permission was granted by Conrad Trow of Grand Circuit by personal communication to use the suspensory shoe for this study.