An investigation of hoof mechanism characteristics following the application of wire trackers for various shoeing treatments involving the shod and unshod foot

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Acknowledgements

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Abstract

This *in vitro* study on 22 front limbs was aimed to compare caudal hoof mechanism characteristics and measurements with the aid of nine externally placed wire trackers, in four set treatment experiments combining both unshod/barefoot, shod, shod with frog support pads/polyurethane and shod with only pour in polyurethane/viscoelastic material. All limbs underwent 3 separate, 7 second compression cycles underneath a 25 ton force press, and were filmed simultaneously on lateral and caudal aspects with two GoPro cameras. A custom Python programme was used to capture tracker measurements in the motion tracker sequences, and the data was formatted in excel for statistical analysis. External foot measurements were also taken at the time of the experiment under the hypothesis that these may have a correlation to the raw data.

The results showed that the shoeing treatments were not a significant predictor of lateral and medial trackers 1 through 4 & 6 through 9. However, these shoeing treatments were a significant predictor of movement for the frog tracker 5.

Hoof moisture had a significant effect on tracker movement for all trackers, with the exception of a few. For trackers located on the lateral and medial aspects, an increase in hoof moisture results in a significant decrease in tracker movement. For frog tracker 5, however, this effect is reversed. An increase in hoof moisture results in a significant increase in movement of tracker 5.

Results concluded that the hoof mechanism responds to both the unshod and shod treatment variations within this study to certain parameters. Further research is warranted.

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.

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Word count: 4816

Abbreviations

COR : Centre Of Rotation

DDFT : Deep Digital Flexor Tendon

DHWA : Dorsal Hoof Wall Angle

DDT : Dorsal Distal Tip

DIP : Distal Interphalangeal Joint

ES : Equithane Superfast

FSP : Frog Support Pads

GP8 : GoPro 8 Black

HPA : Hoof Pastern Axis

HB : Heel Bearing

HA : Heel Angle

IBSL : I Beam Spirit Level Tool

KFC : Kahn Forge Certifier Shoes

PU : Polyurethane Material

TSSC : Three Seven Second Cycles

WCF : Worshipful Company of Farriers

Introduction

Existing studies that have evaluated the effects of biomechanical forces on the equine foot in both *in vivo* and *in vitro* platforms and do not make any specific reference to forelimb palmar/caudal heel movement morphology towards the unshod, shod foot vs viscoelastic support in the form of polyurethane material (PU) combined with frog support pads. The work presented in this thesis will investigate the relationship between hoof heel morphology in comparison to these examples in a standardised and repeatable *in vitro* experiment via load using a force press.

Literature review

The topic of under-run heels along with how to best fit a shoe are both main topics of conversation with-in the farrier and equine veterinary industry along, with the study of the morphology/physiology of the caudal/palmar aspects of the hoof.
Numerous authors of plausible scientific papers have investigated hoof morphology and movement using many forms of technology both *in vitro* and *in vivo* conditions, however to this author's researched knowledge there is no peer review data available similar to the methods and materials used in this study. Many forms of investigation tools were used extensively i.e., the internet for scientific papers via Google Scholar & Wiley Inter Science search engines as-well as various farriery textbooks. Farriery has largely been informed and provided the basis for current conventional farriery teachings, by the historical works of (Russell, 1897) (Dollar and Wheatley, 1898) (Lungwitz, 1891).

Anatomy & physiology of the equine hoof

The hoof has been extensively described along with its internal anatomy as a complex modification of the integument surrounding, supporting and protecting structures within the distal limb of the horse and its ability to bear weight, dissipate shock and that poor hoof confirmation can increase the risk of injury (Ross and Dyson, 2003) (Stashak, 2002) (Grady and Ovncek, 2020) (Kane *et al.*,1998); and that the structural composition of a healthy foot will minimise the stress to structures, thus minimising potential lameness (Barrey, 1990 and Leach, 1983). Correct equine hoof conformation and foot balance for a healthy, biomechanically efficient digit is an important factor affecting performance (Linford, 1993) (Johnston and Black, 2006).

Hoof morphology and horseshoeing

The equine hoof is a highly sophisticated flexible living structure. During loading of the limb, it causes hoof deformation that induces the dorso-proximal area of the hoof wall to move while the frog and sole descend causing the heel quarters to flare laterally giving rise to heel expansion (Thomason 1998) (Hinterhofer *et al.,* 2000).
Colles (1989) described the relationship between frog pressure and heel expansion rather supporting the pressure theory. This theory claims that the lateral movement of the heels is dependent on pressure to the frog. Dyhre-Poulsen (*et al.,* 1994) measured the pressure within the digital cushion and presented results that supported the depression theory, which claims that the lateral movement of the heels is dependent on the lowering and backward rotation of the middle phalanx. Hunt (2012) noted that the palmar aspect of the foot plays a significant role in the condition and maintenance of the equine foot. Although the original reason for applying shoes to horses was to protect against excessive wear (Balch, 2007). in the domesticated shod horse, friction occurs between the expanding heel and the shoe, inducing greater wear at the heel (Eliasha, 2007) (Weishaupt, 2017).
Various farriery techniques has been shown to maintain or enhance functionality, decrease the natural damping properties of the hoof, improve shock absorption, help compensate for hard surfaces with the application of horseshoes, heart-bar shoes, frog support pads, leather/plastic pads and material with viscoelastic properties which may be helpful in transferring weight from the heels (Weishaupt *et,al.,* 2017) (Grady and Poupard, 2003) (Willemen *et al.,*1999) (Eliashar, 2007).

Hoof Pastern Axis (HPA)

The past works of Russell (1897) have provided the basis for modern, conventional farriery teachings in the resting horse, relationships between limb conformation and static foot balance (Figure 1).

There is much documented importance of achieving and maintaining correct HPA. Being described as the parallel alignment of the dorsal hoof wall angle (DHWA) and heel angle (HA), with the angle of the central axis of the phalanges. These angles are defined as being within the range of 50 to 55 degrees (Stashak, 2002). Foot conformation (shape) is important because of its relation to the foot's biomechanical function. Any changes made to the bottom of the horse's foot affect the angulation of the hoof, the HPA, and the alignment of the hoof capsule under the centre of rotation. Variation away from optimum for these parameters may result in decreased biomechanical efficiency (O Grady and Poupard, 2003). The vertical height of the heel is also said to be one third that of the toe (Stashak, 2002).

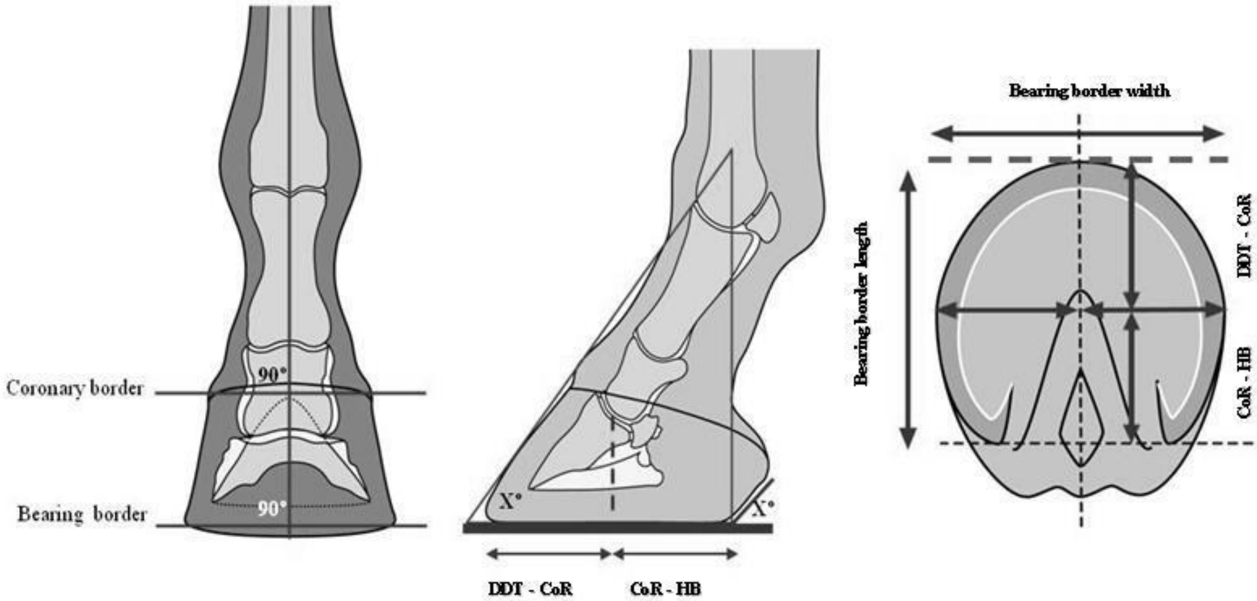

Figure 1: *A Schematic illustration of Professor William Russell's 1897 interpretation of ideal foot balance model. Russell suggested that coronary circumference was of equal height at any two opposing medial or lateral points and perpendicular to the sagittal axis of the limb (left) and that the ideal foot should exhibit heel / toe angle parallelism with the phalangeal axis. Russell further argued that the bearing border was symmetrical about its centre which he placed palmar of the frog apex. To this day Russell's (1897) model of symmetry within the equine foot remains the basis for current farriery teaching. Dorsal distal tip (DDT); Centre of rotation (COR); Heel bearing (HB) Modified after parks.*

Research

The past three decades have provided equine veterinarians, as well as farriers with new information relating to limb biomechanics and the effects of various farriery methods, this has become possible with new technological advances. These advances have allowed finer analysis of shoeing treatments and biomechanical studies (Eliasher, 2012). An *in vitro* study by Hinterhofer *et al.,* (2006) using kinematic system with reflective markers to the hoof capsule/sole and frog found that the fixation of horseshoes to hooves in general resulted in an obvious restriction of the hoof capsules deformation. They stated that bare hooves had the largest displacement deformation compared to shod hooves. C.M Colles (1989) noted using uniaxial foil strain gauges in an *in vivo* study concluded the use of a conventional nailed on horseshoes also restricts flexion and spreading of the hoof wall at the ground surface, but has little effect on the degree of expansion of the heels of the foot. Using an instrument sandwiched between the hoof and the shoe, in a *in vivo* study, comprising of load cells and a strain gauge at all gaits (Kia *et al.,* 2000), noted that vertical ground reaction forces recorded at the lateral and medial sides of the heel were greater than those recorded than that of the lateral and medial sides of the toe, whilst Yoshihara *et al.,* (2010) in a study between a glued shoe and nailed shoes with location displacement sensors found in all running speeds, the heels expanded in the first 70-80% of the stance phase. Brunsting et al., (2019) using a displacement sensor secured to the heels, concluded that heel expansion with a split toe shoe did not differ significantly from when the horse was barefoot, in contrast with the significant restriction of the heel movement when a conventional shoe was used.

A study was conducted to evaluate the effects of PU underneath the hoof and shoe by Mieke *et al.,* (2006) using a pressure/force device, regular steel shoes were applied and with PU filling the bearing surface underneath the shoe did not increase significantly, nor did the means pressure decrease. On a firm surface the pressure distribution pattern is similar in both shoeing conditions. In relation to frog pressure (Colles, 1989) for an *in vivo* study using foil strain gauges concluded that, where as frog pressure affects hoof expansion, it is only one of several factors. The variable results of changing frog pressure should be taken into account when considering therapeutic shoeing.

An *in vitro* and *in vivo* study by Roepstorff *et al.,* (2001) using optical kinematic analysis, the i*n vitro* portion noted the relatively larger distal expansion seen in the frog pressure situation suggests that frog pressure primarily expands the hoof at the ground level. He also noted that heel expansion does also occur despite the frog not being in contact with the ground.

Aim

This *in vitro* study is to investigate the effects of palmar-caudal hoof movement/mechanism under load via a force press in three shod treatments and one unshod/barefoot treatment. The aim is to apply and combine with a shod foot, PU material and the application of frog support pads (FSP). To gather measurements via location wires attached to the palmar aspect of the hoof and collate data in relation to any movement in these four stages.

Hypothesis

That the palmar-caudal hoof area may show capsular movement during these barefoot and shoeing treatments.

Methods & Materials

This study was an investigation into the effects of movement in the caudal/palmar aspect of the hoof using 22 Horse cadaver limbs (Figure 2) Conboys Enterprises. Nine Copper Marker wires, Hillman Group Inc, were attached to the caudal aspect of the hooves externally using Superfast Equithane (ES) material, Vettec Inc. Eight wires fixed both laterally and medially to the heels, of these, four wires faced out laterally/medially whilst the other four faced to the rear. One wire was placed in the mid frog central sulcus. All the wires had standard 10mm x 5mm blue electrical wire termination caps, Home Depot GA, attached to the ends which would act as visual locators for data collection. All limbs were shod three times during their individual experiments with unclipped 3/4 fullered Kahn Forge Certifiers steel shoes (KFC), Kahn Forge, with two treatments involving the application of flat FSP, 3rd Millennium, and clear PU material, Farriers Choice, Castle Plastics.

Limbs/feet were marked in 2 groups, one in the 200 group/batch which are left forelimbs from 201 to 211. Right forelimbs in the 300 group/batch marked 301 to 311. Each limb was put under force in a 25-ton hydraulic press, Ingersoll-Rand Air, for three separate seven second cycles (TSSC), with an approximate pause between each compression of three seconds for the purpose of data collection during these phases of compression, this was to hypothesis an assumption in standing load, walk, trot and canter.

Prior to the limbs undertaking the test, 10 pre-cycle compression checks under the press were carried out to assert consistent limb positioning. Once this was achieved, each limb was set up under the force load in the press to assume a horse's standing load before the TSSC commenced. This was assessed by vertical cannon bone assessment both laterally and dorsally using an I-beam spirit level tool (IBSL) General Tools & Instruments. The IBSL was placed in a mid-cannon position whilst the limb was set in the press, the press was engaged slowly and once the IBSL became true, the press was stopped and a visual correct HPA was attained to an assumed standing load.

Prior to the loading of any limbs, the floor area being used for the location of the force press was also checked with the IBSL to assert a correct level working foundation for the press to work upon and give a correct level frame for the limbs to be loaded.

Experiment

Each limb was filmed simultaneously by two GoPro 8 Black cameras (GP8), GoPro C.A. Palmar/caudal and lateral view footage was taken, but ultimately only lateral view footage proved usable for analytical purposes, since too many trackers were obscured in the side views, leading to missing data. There were 4 set scenarios and each limb underwent the following tests;

1, Unshod - the hoof was barefoot and put under load for TSSC.

2, Shod - KFC shoe was nailed to the foot and put under load for TSSC.

3, Shod - KFC shoe with a FSP & PU material injected under the pad and put under load for TSSC.

4, Shod- KFC shoe with a full pour of PU in the sole to fill to the surface of the shoe and put under load for TSSC.

5, Each loaded limb prior to their respective pressure tests underwent two further assessments. Hoof capsule Hydration readings were taken using a digital hydrometer, General Tools & Instruments, and once initial limb loading for correct HPA & vertical limb alignment was correct, a digital protractor, General Tools & Instruments, was used to determine DHWA.

Figure 2: *22 cadaver limbs*

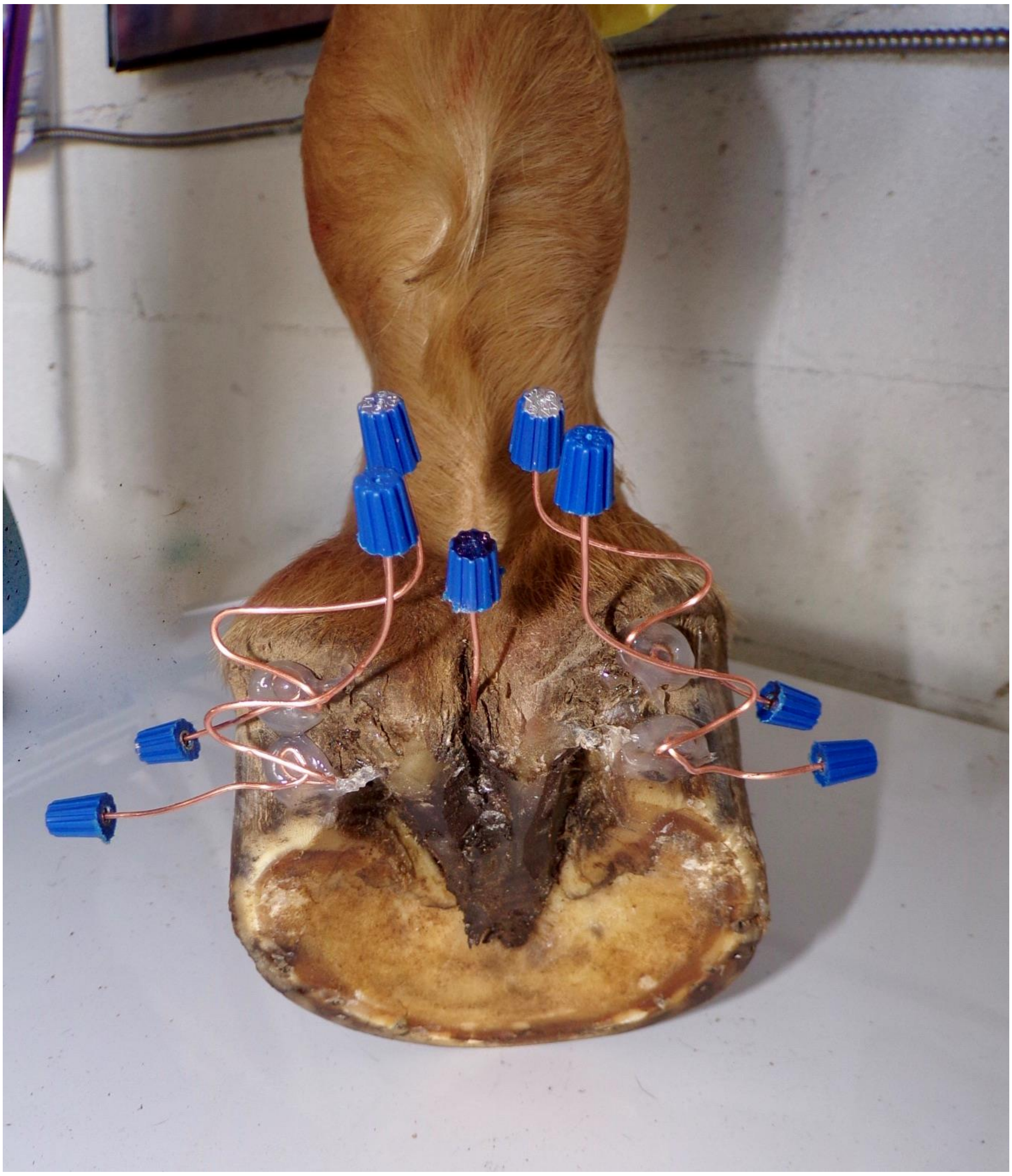

Figure 3: *Fixed Copper wire markers and electrical blue termination caps for locational data analysis.*

Figure 4: *Pre-limb positional test for I beam spirit level dorsally to the mid-cannon upon compression to assert correct vertical & HPA set up*.

Figure 5: *Pre-limb positional test for IBSL laterally to the mid-cannon upon compression to assert correct vertical & HPA set up.*

Figure 6: *Pre-limb set up showing camera positions, copper hoof wire locators, IBSL checks & Digital angle protractor (DHWA).*

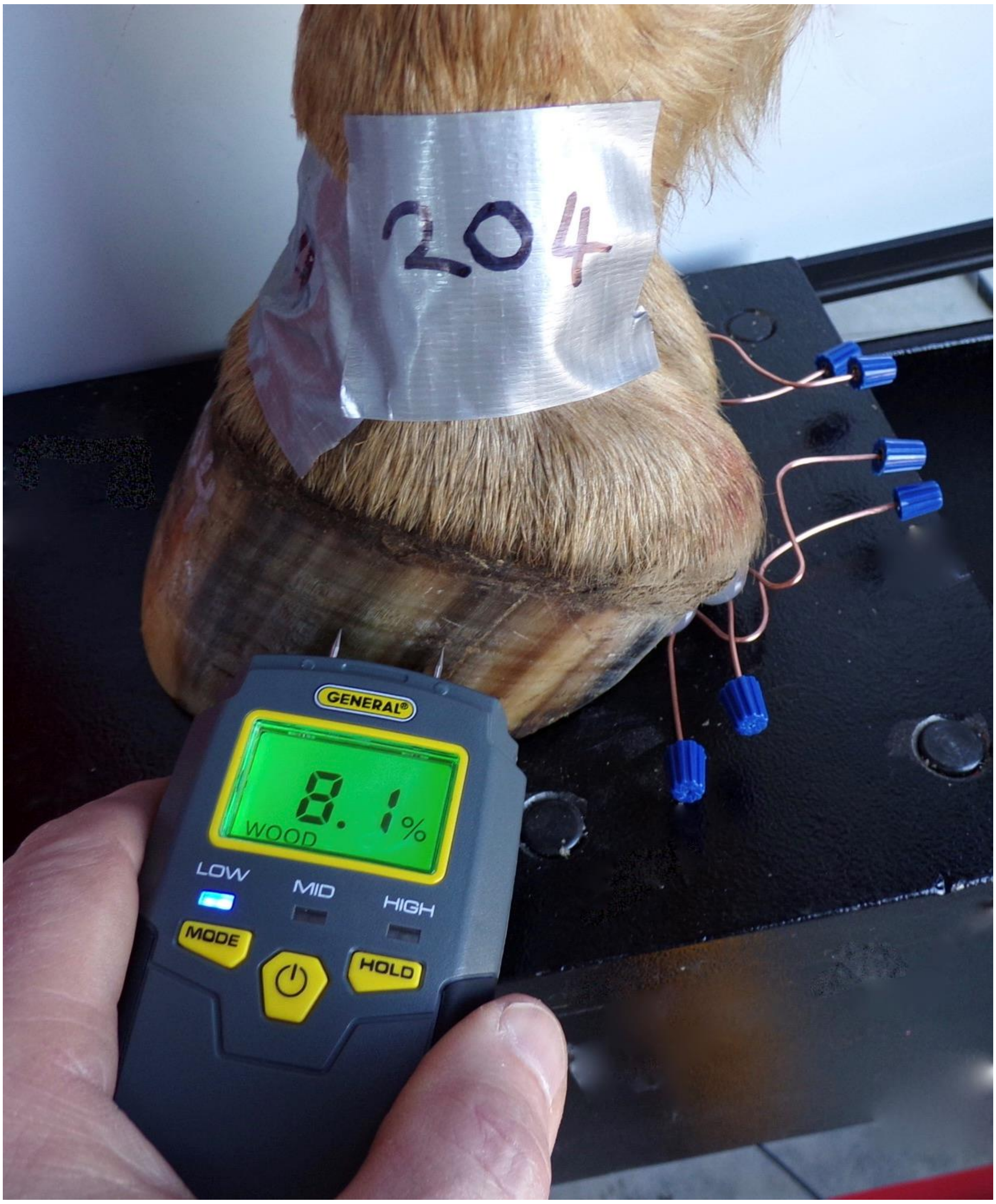

Figure 7: *Pre-test digital hydrometer readings.*

Limb treatment protocol

All cadaver specimens were from horses that were euthanised, for reasons other than this study, within a 14-day period of the experiment. The author requested that all the forelimbs for this study be cut approximately 5 inches above the carpus, to allow for the use of a steel pin in the force press which would be inserted into the medullary cavity of the radius as a secure location point. The limbs were defrosted for 12 hours before their preparation and were all on a pre-set rotation system to be trimmed, and all the shoes/pads pre-fitted prior to the first day of the experiment. All the shoes were fitted cold, this was to remove any hypothesised data interference from hot shoeing. The shoes were fitted in two stages, stage 1, heat the shoe accordingly and then produce a close fit visually. Stage 2, the shoes were left to cool down and any further small discrepancies in fit were executed cold. Once the shoe fit was attained, the shoes were heated again to produce a flat level bearing surface and then left to cool down for the last time.

The shoes and pads were number marked in respect of the limbs they belonged to (Figure 8). This was to save time on the day of the test and keep the limbs as fresh as possible during the experiment. It was noted that four pairs of the 22 limbs were from the same horses and the other fourteen limbs were independent. This was because at the time of limb collection the selection was limited for pertaining to a relative limb/foot type and size. Both left fore batch 200 (for day 1) and right fore batch 300 (for day 2), were pre-prepared and returned to the freezer. Both limb batches were defrosted for 17 hours overnight before their respective day experiment. The temperature was noted at 60 degrees F on both days, however day one was sunny and day two was humid and raining.

Trimming and Shoeing Protocol

The Worshipful Company of Farriers (WCF) produces detailed guidelines for the acceptable standards of trimming and shoeing horses in the UK. These guidelines outline the critical acceptable tolerances and standards of farriery craftsmanship for which the historical authors previously mentioned, have had a direct influence (ref to Farriery national standards). To ensure consistency of required standards all 22 feet/limbs were trimmed and prepared for the reception of their respective shoes by the author. The trimming protocol was based on Farriery National Occupational Standards (Lantra 2010). Machine made 3/4 fullered KFC shoes fitted by the author to a leisure fit according to (Lantra 2010) shoe sizes used, pertained to only size 1 and 2 of the KFC range. To ensure a consistency of standards, all the nailing/finishing of the shoes (Figure 10) FSP (Figure 11) & PU (Figure 12) was carried out by David Hallock AWCF to the Farriery National Occupational Standards (Lantra 2010). This was to ensure the experiment was carried out in a timely, efficient manner in respect of working with cadavers, whilst the author was collating chart information and preparing equipment. Six evenly spaced nails Combo 4 & 5 slims, Royal Kerckhaert, were used for all shoe reception and the same nail holes were used in each shoe application. The PU Material extended to the heels of the fitted shoes and up to the widest part of the frogs.

Figure 8: *Pre-fitted shoes & Frog support pads.*

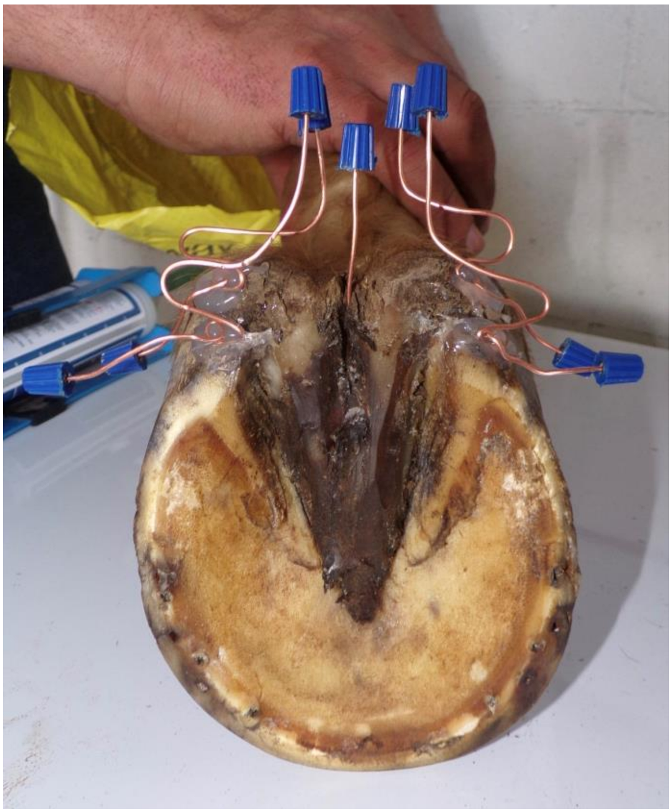

Figure 9: *Unshod/barefoot.*

Figure 10. *Shod foot.*

Figure 11: *Shod foot with FSP & PU material.*

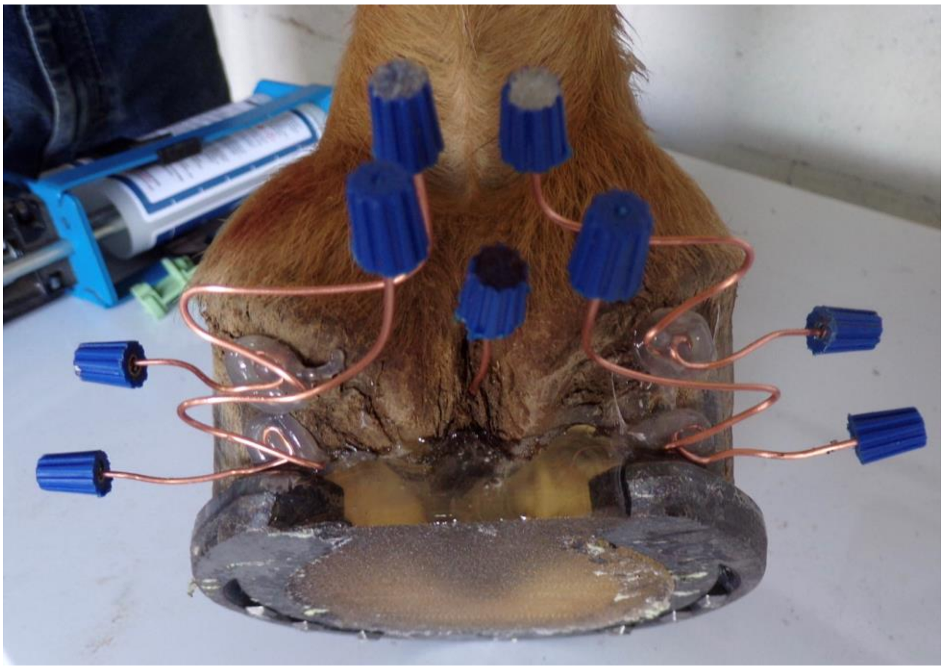

Figure 12: *Shod foot with only PU material.*

Data Collection

External limb/foot information measurement charts were collated with digital calipers, Walmart Inc. The foot parameters measured can be found in Table 1. DHWA were recorded with a digital protractor, the depth of the sulcus was measured with a standard farriers brass ruler. All measurements were recorded in millimetres (mm). A custom Python programme, Python.org, was used to capture measurements from the recorded videos. The programme consisted of four separate processing steps. First, the experimenter identified the video time code corresponding to the beginning of the experiment, the intervals between the 7 second timed cycles and the end of the experiment. Each of these video frames were extracted and used for the subsequent steps. Second, the experimenter visually identified each of the markers with a number (1 to 9) (Figure 13.) Third, for each of the visible markers, the experimenter measured the pixel distance along either radius or a length of the marker. From the pixel distance the programme calculated the ratio of pixels to mm using the known radius and length of the markers. Fourth, the experimenter visually tagged the location of each of the markers at each captured frame (Figure 14.) Using the ratio of pixels to mm for each marker, the programme calculated the position of each marker in mm in frame (Figure 15.) The data were collated and transferred to Microsoft Excel for further analysis.

Limb/foot information	Limb number
Width	
Length	
Heel width	
Heel length	
Dorsal wall length	
Dorsal wall angle	
Frog length	
Sulcus depth	
Hoof hydration (pre-tests)	

Table 1. *External limb/foot information charts example.*

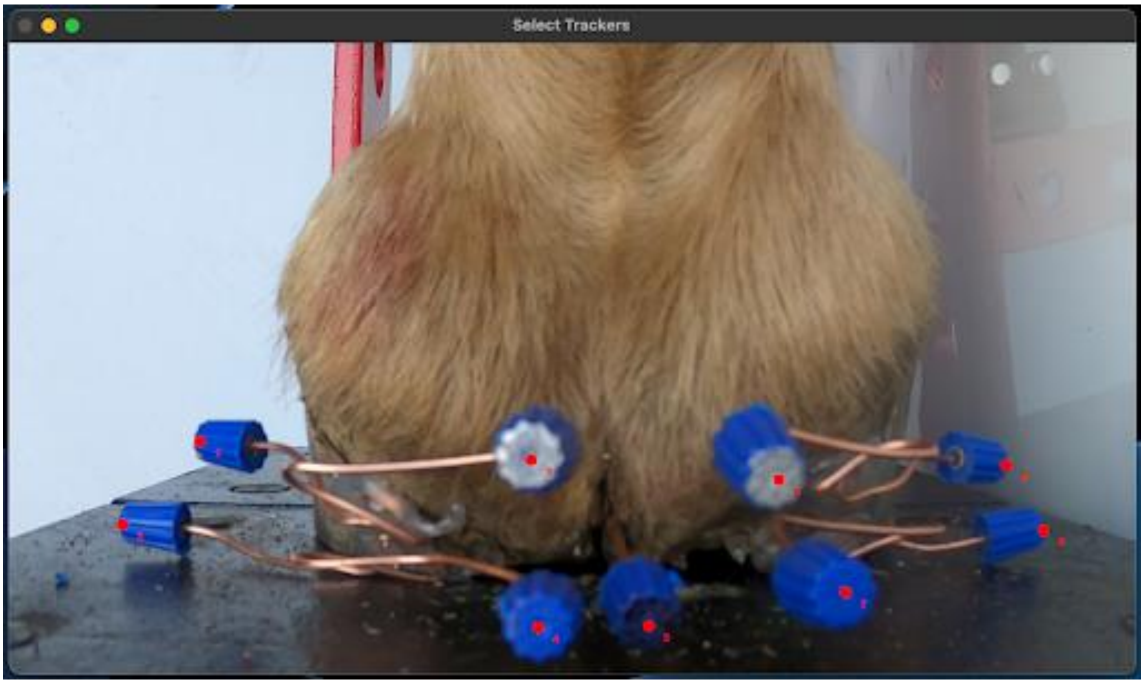

Figure 14. *Visually identified markers through Python numbered 1 to 9 to translate from pixels to millimetres.*

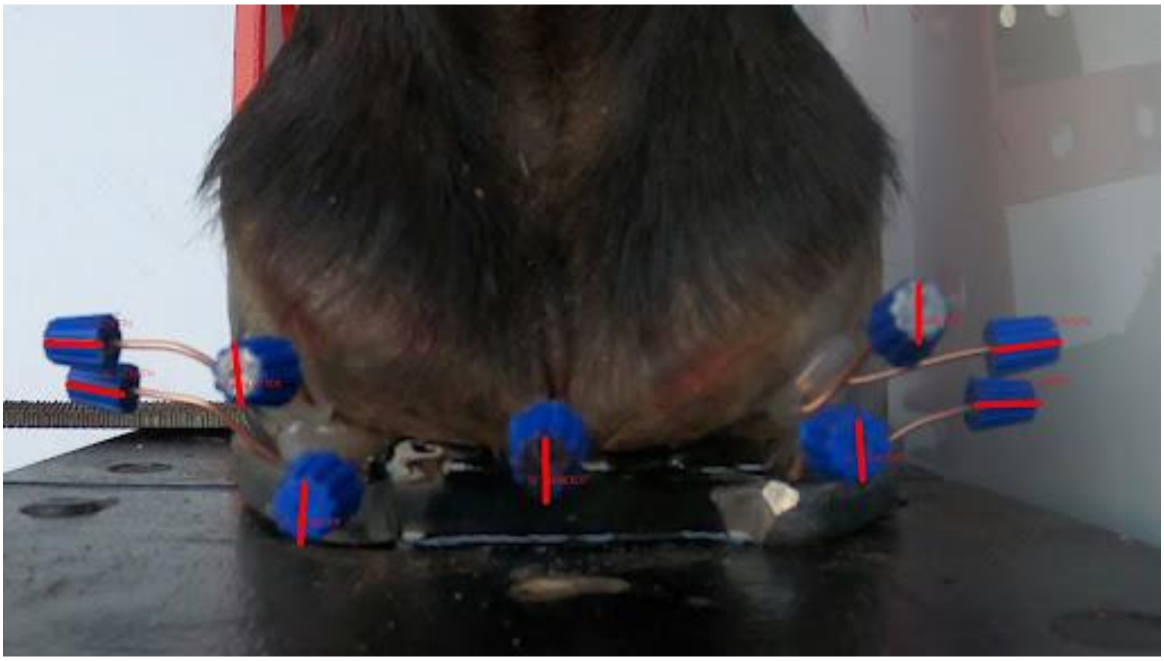

Figure 15. *Visually tagged markers measured through the motion tracker sequences.*

Statistical Tests

Data Formatting

The data from the experiment were formatted in Excel in preparation for statistical analysis. A vector variable was created to characterise the movement of each individual tracker, and to be used as the response variable in the statistical models, as follows: three separate vectors were calculated (V1, V2, V3) using the starting and end point x,y coordinates in millimetres of each tracker and for each pressure cycle using the following equation:

Equation 1:

$$V = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

These vectors were then added (V1 + V2 + V3) to calculate total tracker movement (Vsum) throughout the experiment. This approach was chosen in favour of simply calculating the distance between the tracker starting and end points, since tracker movement was not linear in all cases. Instead, trackers followed a curved pattern, which would result in underestimating total movement if characterised only by starting and end points. Descriptive statistics (min, max, mean, and standard deviation) were calculated for each tracker and can be found in Appendix I.

It was noted during formatting that the left feet included in the experiment had a markedly lower average moisture content than the right feet (8.8% and 15.6%, respectively). This is likely because the experiments on the right feet were conducted on a relatively humid day, whereas conditions were much drier on the day the left feet were handled. This presented the opportunity to estimate the effect of hoof moisture on tracker movement, and the variable was coded as such for inclusion in the statistical models.

ANOVA

Two-way ANOVAs were performed in SAS (SAS Institute Inc, Cary, NC) to assess the effect of all 4 treatments (unshod/ shod, etc…), hoof moisture, and the interaction between these variables on individual tracker movement using the proc mixed procedure. The variable Sample was included as a random effect to control for any variation present due to selection of individual feet for the experiment. This resulted in a total of 9 ANOVA models, one for each tracker. The model assumptions of normality and homogeneity of variances were tested and met for each model. The mixed procedure uses the restricted maximum likelihood method to estimate the variance components.

Multiple Regression

In addition to the two-way ANOVAs, a series of multiple regression analyses was performed to test the overall effects of the following hoof parameters taken from the external foot/limb charts on tracker movement: width:length ratio, heel width, heel length, wall length, wall angle, frog length, sulcus depth, and hoof moisture. For the purposes of the regression, only continuous variables were chosen as predictors. Again, a separate model was run for each tracker, and in these regression models the different treatments were combined into one model and not tested separately. An attempt was made to analyse the trackers separately, but this resulted in loss of overall model significance. The multiple regression models met the assumption of normality and no autocorrelation was present between the independent variables.

Results

Tracker movement

Figures 16 through 18 show a graphical representation of tracker movement during the three cycles of pressure application. Each data point on these graphs is the average of observations for a given tracker and treatment. Since the trackers were located at slightly different (x,y) locations within each raw image, which would make interpretation of the figures challenging, the starting point for each tracker was recalculated to be (0,0) on the x, y plane. The lines represent the actual movement in millimetres of each tracker by treatment across the (x,y) plane under application of three pressure cycles. Figure 16 shows the average movement of trackers 1 through 4, which are located on the right side of the hoof. Figure 18 shows the average movement of trackers 6 through 9, which are located on the left side of the hoof. Figure 17 shows the average movement of tracker 5, note the difference in scale between Figures 16 and 18, and Figure 17. From these figures it is readily visible that tracker 5 shows more movement than the other 8. For an interesting perspective, Figure 19 shows the movement of all 9 trackers simultaneously for a barefoot hoof.

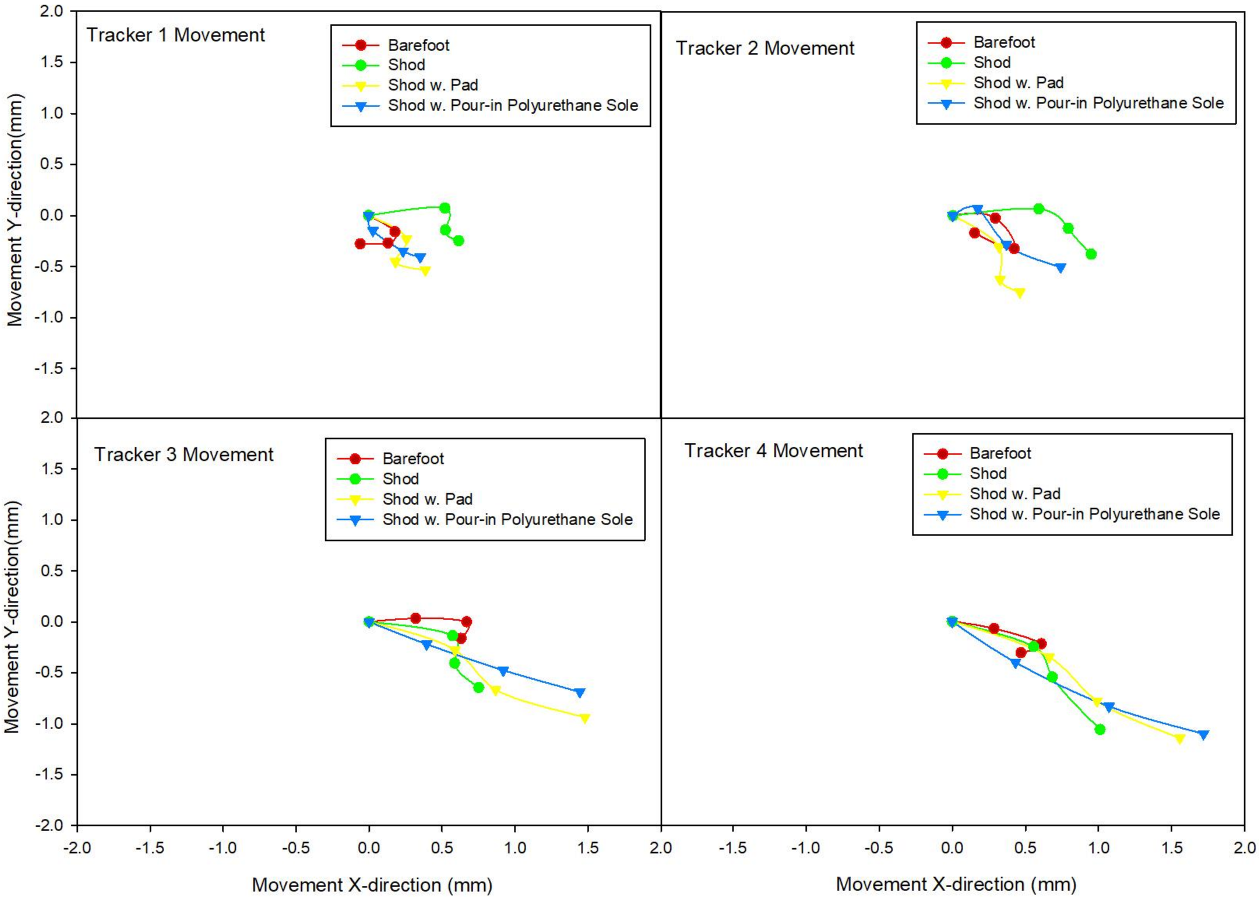

Figure 16*: Movement of trackers 1 through 4.*

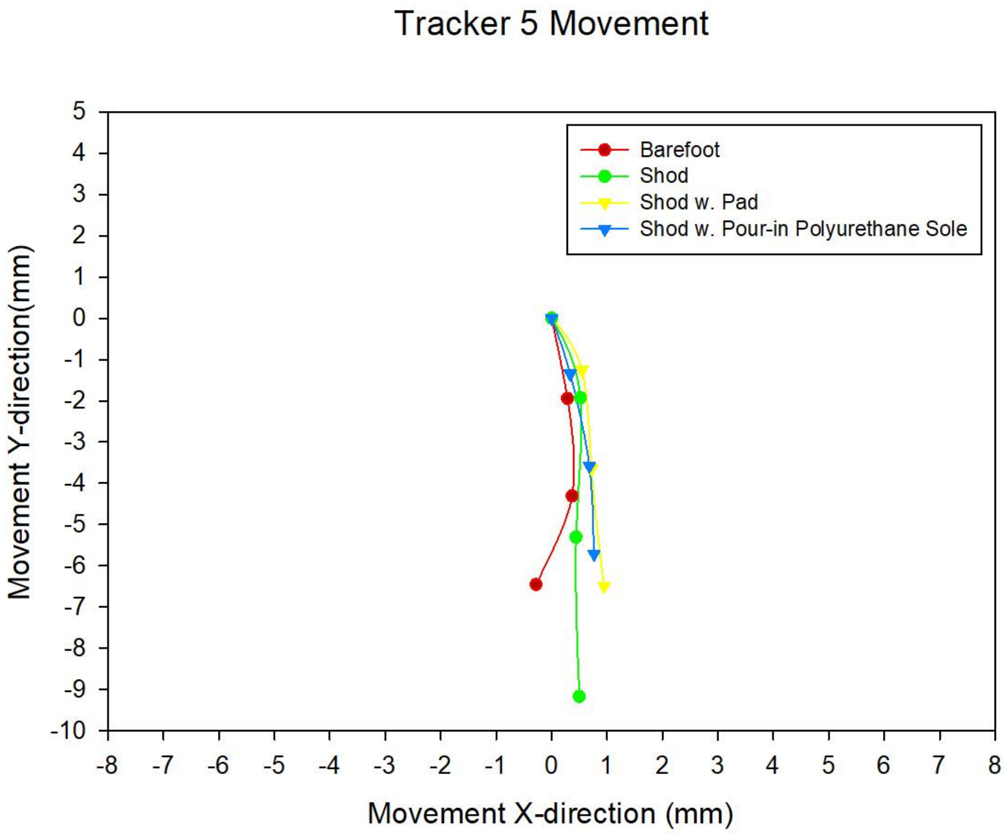

Figure 17: *Movement of tracker 5.*

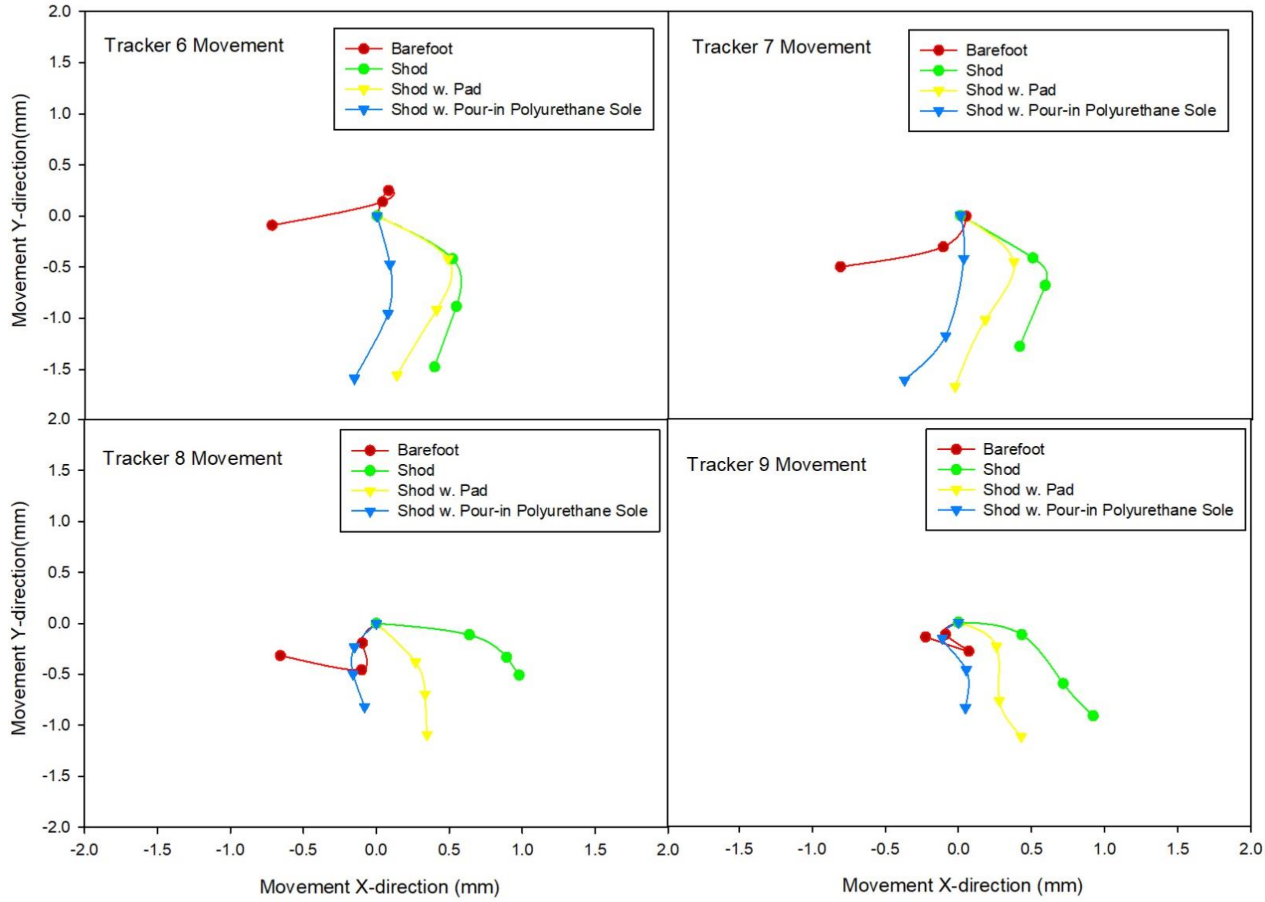

Figure 18: *Movement of trackers 6 through 9.*

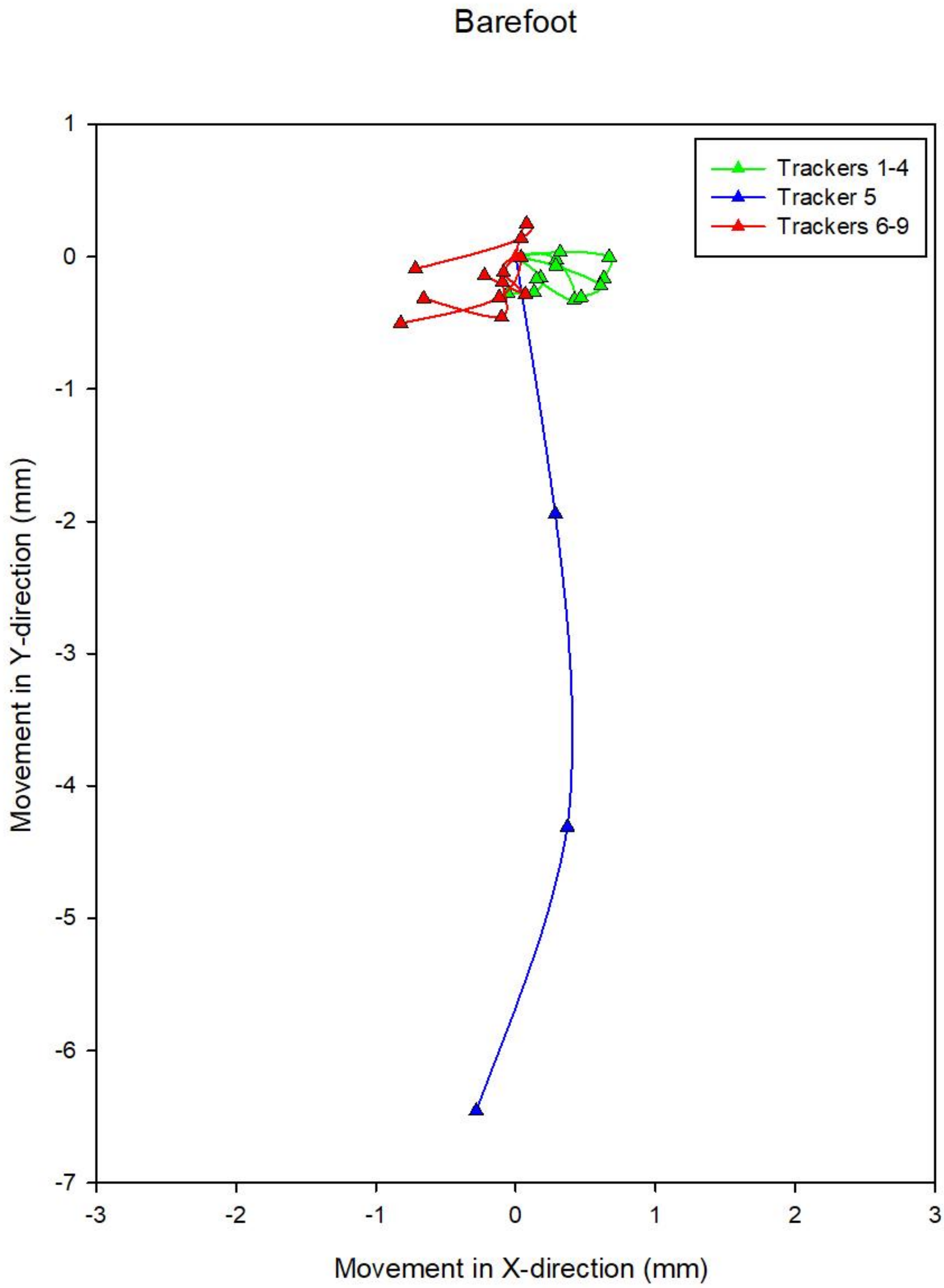

Figure 19: *Movement of trackers 1 through 9, barefoot hoof.*

ANOVA

The results of the ANOVA models showed that the treatments were not a significant predictor of tracker movement ($p>0.05$) for trackers 1 through 4, and 6 through 9 (Figures 20 & 22). However, treatments were a significant predictor of movement for tracker 5 ($p<0.0001$). Figure 21 shows that tracker 5 on feet shod with a regular shoe showed significantly more movement than any of the other treatments, while shod feet with PU showed the least movement, and this difference was significant as well. Tracker 5 on unshod/barefoot feet moved significantly less than shod feet, and significantly more than feet with a shoe + PU. There was no significant difference in movement between unshod/barefoot feet and feet shod with a shoe + FSP.

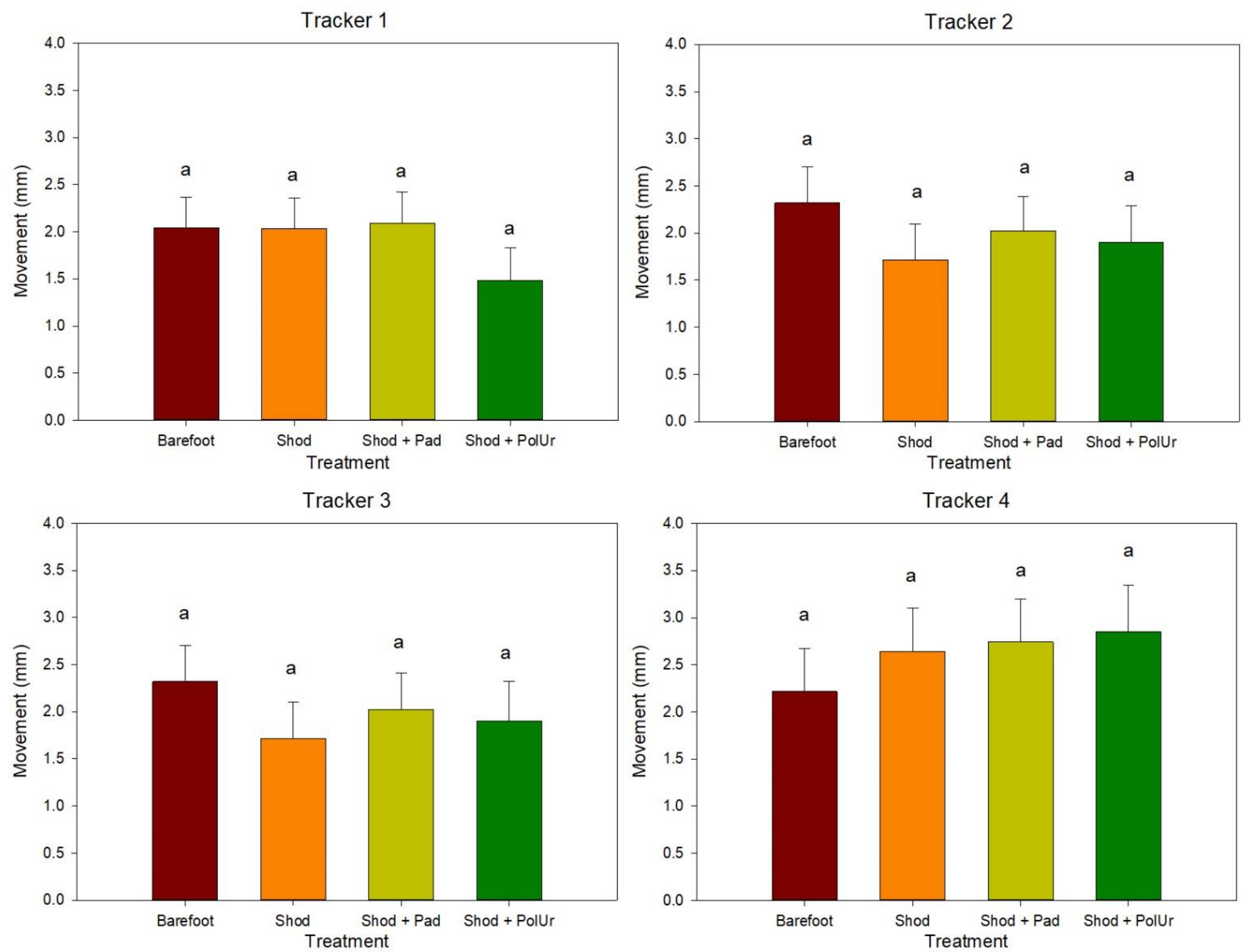

Figure 20: *Least squares means, the effect of treatment on movement of trackers 1 through 4. Bars with the same letter are not significantly different from one another.*

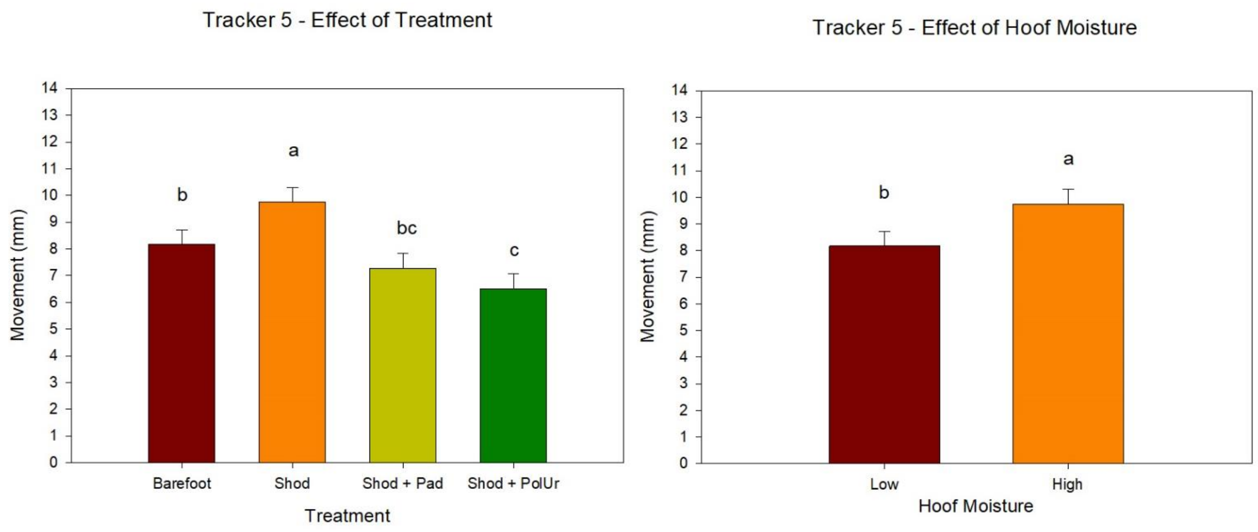

Figure 21: *Least squares means, the effect of Treatment and hoof moisture on tracker 5 movement. Bars with the same letter are not significantly different from one another.*

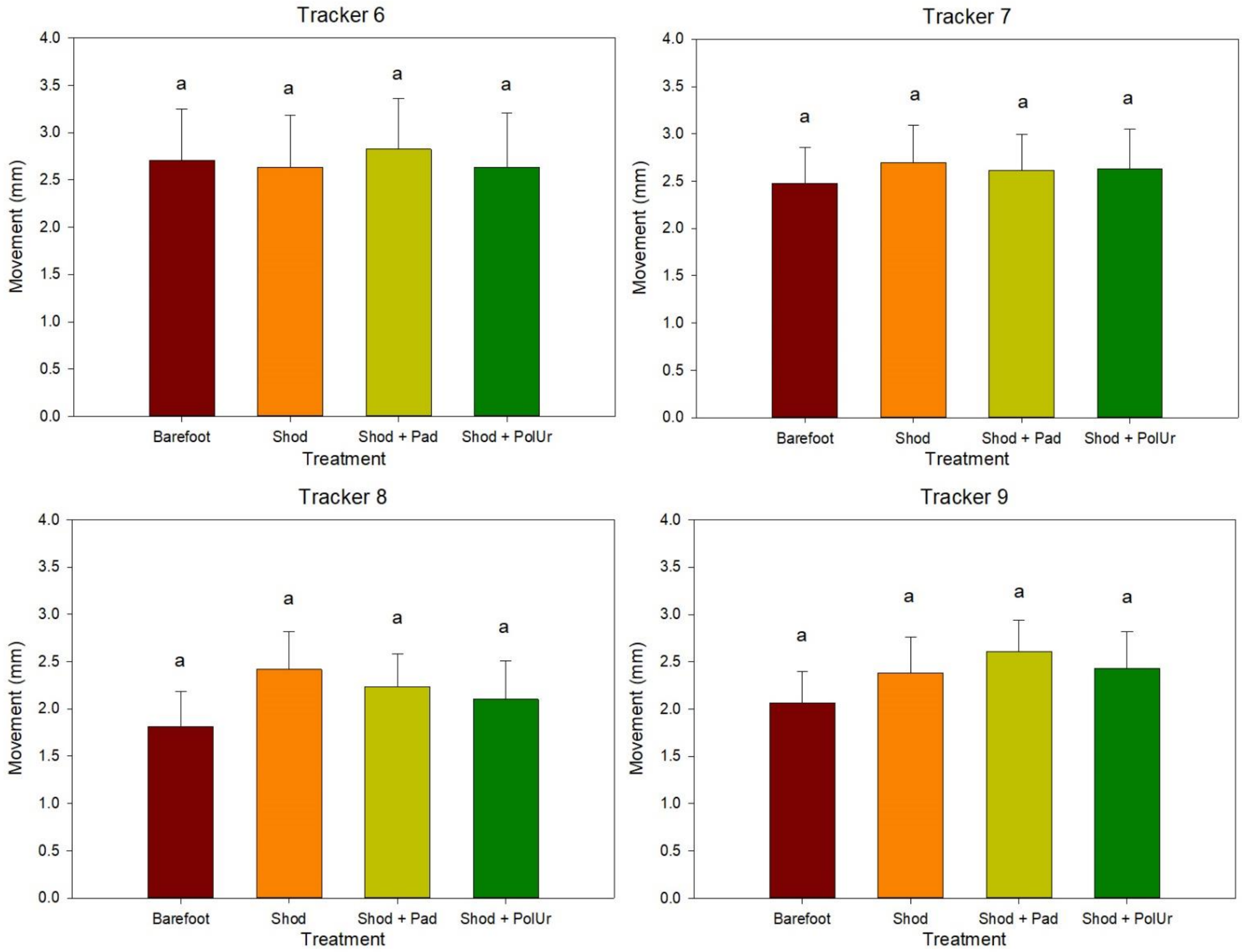

Figure 22: *Least squares means, the effect of treatment on movement of trackers 6 through 9. Bars with the same letter are not significantly different from one another.*

Hoof moisture had a significant effect on tracker movement ($p<0.05$) for all trackers, with the exception of trackers 6 and 7. Here, an interesting observation can be made: for the lateral and medial trackers (1 through 4, and 8 and 9) an increase in hoof moisture results in a significant decrease in tracker movement (Figures 23 & 24). For tracker 5, however, this effect is reversed. An increase in hoof moisture results in a significant increase in movement of tracker 5, located on the frog of the hoof (Figure 21).

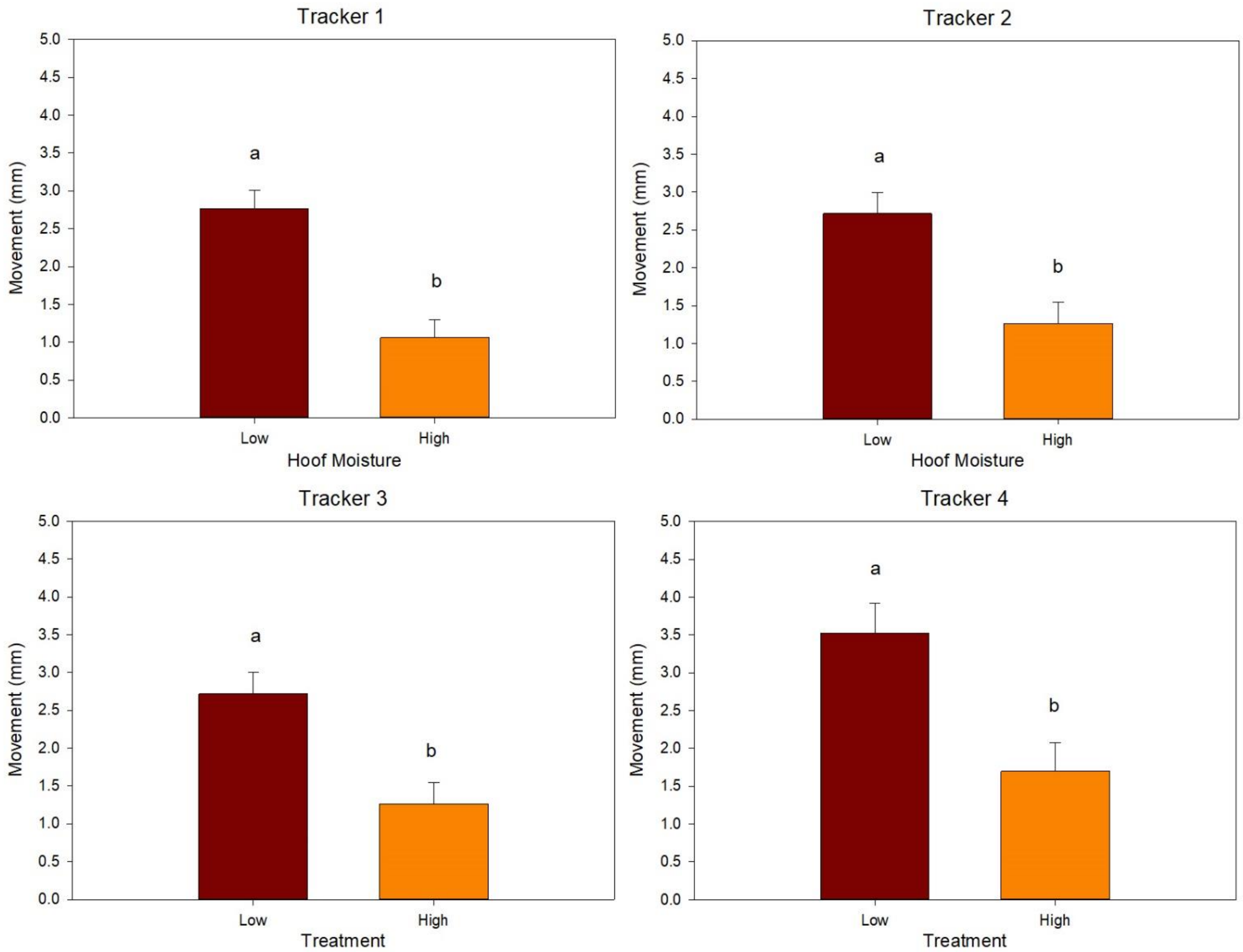

Figure 23: *Least squares means, the effect of hoof moisture on the movement of trackers 1 through 4. Bars with the same letter are not significantly different from one another.*

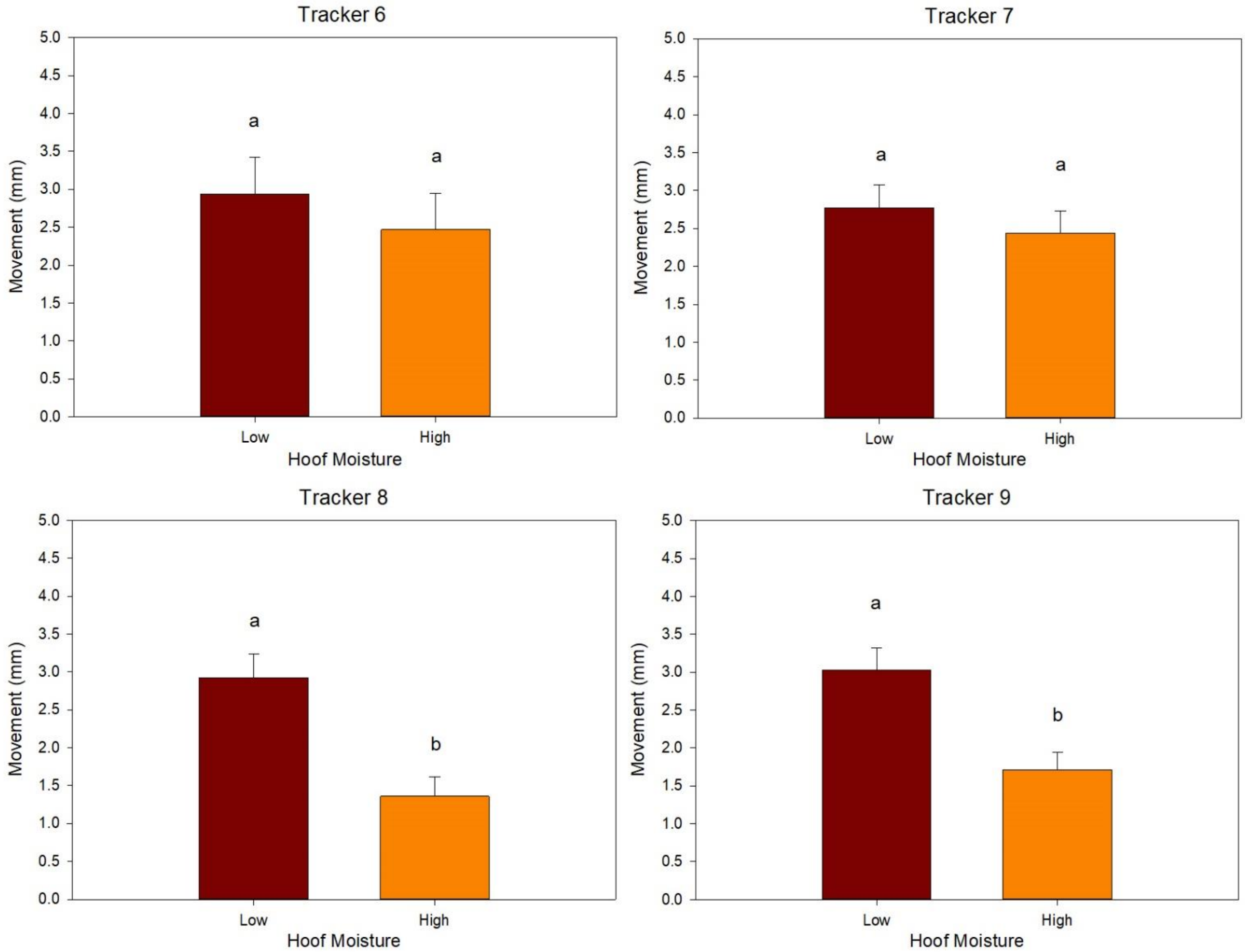

Figure 24: *Least squares means, the effect of hoof moisture on the movement of trackers 6 through 9. Bars with the same letter are not significantly different from one another.*

Multiple regression

The results of the multiple regression analyses are shown in tables 2 through 9, see Appendix II. The results of tracker 7 are omitted since this model did not attain overall significance ($p=0.480$). All models were significant at $p<0.05$, with the exception of the model for tracker 9, which was significant at $p<0.1$ ($p=0.072$). Similarly to the ANOVA models, hoof moisture has a significant effect on tracker movement ($p<0.05$) for all trackers except 6. The effects are in agreement with the ANOVA results in that for trackers located on the lateral and medial sides of the foot, a one unit increase in hoof moisture leads to a significant decrease in tracker movement (negative coefficient), whereas for tracker 5, the effect is opposite: a one unit increase in hoof moisture leads to a 0.274 increase in the movement of tracker 5 (p=0.001). Then, sulcus depth has a significant effect on movement for several trackers, although the effect is absent for trackers 7, 8, and 9. Adjusted R-square values for trackers 1 through 4 were between 0.24 and 0.33, indicating that the measured variables accounted for 24% to 33% of the variation in the response variable. The adjusted R-square value for tracker 5 was 0.12, possibly due to the absence of treatment as a predictor which according to the ANOVA has a significant effect on movement of this tracker. Finally, adjusted R-square values for trackers 6, 8, and 9 are 0.23, 0.16, and 0.10, respectively.

Discussion

It was hypothesised that the palmar-caudal hoof area may show capsular movement which varies with the barefoot/shoeing treatments described, trimmed and shod to the national standard of competence for farriery (Lantra 2010).

Key findings

ANOVA models showed that the shoeing treatments were not a significant predictor of tracker movement (p>0.05) for trackers 1 through 4, and 6 through 9. However, the treatments were a significant predictor of movement for tracker 5 (p<0.0001) in all the shoeing treatments and markedly so, unshod vs shod + FSP & PU showed similar tracker terminations characteristics thus implying to the author that with the application of this shoeing system it can to a degree mimic the solar aspect of the barefoot upon loading. In contrast, Shod + PU material only showed an earlier tracker descent termination implying premature load resistant forces were in play which to the belief of the author supports theories noted by (Weishaupt et al., 2017) (Grady, and Poupard, 2003) (Willemen et al .,1999) (Eliashar 2007).

Contrary to all previous treatments, the shod example alone clearly shows a much later tracker descent termination characteristic implying no load resistant force to the frog in a standard open heeled shoe treatment and relates to, that in the domesticated shod horse, friction occurs between the expanding heel and the shoe, inducing greater wear at the heel (Eliasha, 2007), (Weishaupt, 2017).

Hoof moisture had a significant effect on tracker movement 1 through 5 and 8 and 9 ($p<0.05$). The regression confirmed the findings of the ANOVA that tracker 5 movement increased with hoof moisture, while other trackers movement decreased with increasing hoof moisture. Regression results confirmed that for lateral and medial heel trackers, an increase in hoof moisture leads to a significant decrease in tracker movement (negative coefficient), whereas for tracker 5, the effect is opposite: a one unit increase in hoof moisture leads to a 0.274 increase in the movement of tracker 5 ($p=0.001$). It has been speculated by the author if the difference in hydration between the first and second day experiments could account for the added movement in tracker 5 on one of two processes. There are several possible explanations for this effect. First, it is possible that the increased hydration makes the frog more pliable compared to the rest of the hoof capsule, thus allowing more motion. Second, the increase in hydration could allow the horn tubules to have an increased ability to withstand compressive forces before they distort. The answers to these questions are beyond the scope of the current study but are possible explanations to open an avenue for future research.

Sulcus depth also had a significant effect with hoof moisture with movement of several trackers, except for trackers 7, 8, and 9. This could indicate minor asymmetry in pressure application during the experiment with effect to switching sides between left and right forelimb loading in the press, even with manual limb pre-treatment tests. These parameters had varied significance and were not robust across the models. The study was conducted in 3 seven second timed forced compressions of the limbs rather than recorded by actual visual digital/dial force in pounds, this was purely because the force press used was a 25-ton press, and although displayed a force dial, it showed no pounds pressure upon limb compressions which may have been because the press was so powerful. It may be advantageous to set the compressions poundage during the limb cycles, but since this was not possible with the available equipment, timed cycles were adopted instead.

Conclusion

In conclusion, whilst most authors would agree that various shoeing treatments including ones pertained to this study can affect the hoof mechanism and its physiology, the limitation constraints to the early evolving raw data of this experiment suggested that the lateral view tracker values were not reliable enough for cohesive comprehensive results due to the trackers appearing clustered and inconsistent in the images, leading to missing data where trackers overlapped/obscured one another. However, the palmar-caudal views were able to sequence all the trackers values in all the four unshod and shod treatments. ANOVA results suggested there was marginal tracker movement for trackers 1 through 4, and 6 through 9, whilst tracker 5 showed consistent, appreciable movement throughout the experiment. This movement was significantly affected by treatment as well as hoof moisture content. Seven of the nine trackers had significant decreasing tracker movement effects whilst tracker 5 had increased movement with increased hoof moisture. The characterisation of this reversed effect would be a relevant topic of future research, which could confirm the mechanisms at play.

Both *in vitro* and i*n vivo* experiments can have their limitations. On a critical evaluation to the culmination of this experiment, the assumptive HPA evaluations and the hypothesised assumptions to standing load, walk, trot and canter as described in these methods of the experiment and including the overall failure of the raw motion visual lateral tracker readings, can be argued.

Armed now with the knowledge gained from this experiment, the use of 4 cameras may have been more beneficial to capture the tracker movement/foot position, laterally, medially, palmar/caudal and from above with possible use of a force press recording weight upon the limbs in real time. This, as well, would be a consideration for any future research to be conducted using similar experimental design.

Manufacturers addresses

1, Animal removal & cremations, Conboys Enterprises 7001 Greenwich Pike, Lexington, 40511, Lexington USA.

2, Khan Forge, 502 East La Palma Avenue, Anaheim, CA, 92807, USA.

3, 3rd Millenium Ltd, Unit 6 G, Peel Hall Business Village, Peel Road, Westby, Lancs, FY4 5JX, UK.

4, Royal Kerckhaert, Rapenburg 76, 4581, AE, Vogelwaarde, Netherlands.

5, Vettec Inc, 1717 West Collins Avenue, Orange, CA, 92867, USA.

6, Castle Plastics, 11 Francis Street, Leominster, MA, 01453, USA.

7, GoPro, 3025 Clearview Way, San Mateo, C.A, USA.

8, Home Depot, 2455, Ferry Road, Atlanta,GA, 30339, USA.

9, General tool & Instruments, 75 Seaview Drive, Secaucus, NJ, 07094, USA.

10, The Hillman Group Inc, 10590 Hamilton Avenue, Cincinnati, OH, 45231, USA.

11, Walmart Inc, Bentonville, AR, 72716, USA.

12, Ingersoll-rand Air compressors - Model P1.51V-A9, Ingersoll-rand Company, Davidson, North Carolina, 28036, USA.

13, Python Software, High Level Programming, Python.Org.

14, Microsoft Excell, www.microsoft.com.

15, SAS 9.4, SAS Institute Inc, Cary, NC, USA.

16, Sigmaplot 12.5, Systat Software, San Jose, CA, USA.

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Appendix I

Descriptive statistics for trackers 1 through 9

Tracker 1	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.000	7.035	2.068	1.758
Shod	0.000	7.576	1.988	1.895
Shoe + Pad	0.000	6.492	2.087	1.769
Shoe + Polyurethane	0.000	3.541	1.374	1.108

Tracker 2	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.000	8.118	2.320	2.067
Shod	0.000	6.919	1.739	1.716
Shoe + Pad	0.000	5.825	2.093	1.616
Shoe + Polyurethane	0.279	4.479	1.842	1.392

Tracker 3	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.566	7.902	2.329	1.860
Shod	0.489	8.500	2.302	1.993
Shoe + Pad	0.000	9.752	2.542	2.313
Shoe + Polyurethane	0.616	5.404	2.387	1.483

Tracker 4	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.407	7.690	2.215	1.939
Shod	0.478	9.389	2.574	2.134
Shoe + Pad	0.000	7.972	2.742	2.522
Shoe + Polyurethane	0.517	7.154	2.641	1.915

Tracker 5	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	3.402	18.054	8.178	3.093
Shod	6.659	12.115	9.811	1.819

Shoe + Pad	2.563	11.684	7.277	2.322
Shoe + Polyurethane	3.371	9.198	6.430	1.820

Tracker 6	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.000	10.709	2.709	2.644
Shod	0.379	7.190	2.648	1.851
Shoe + Pad	0.759	8.646	2.825	2.070
Shoe + Polyurethane	0.806	7.721	2.483	1.655

Tracker 7	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.555	6.456	2.477	1.725
Shod	0.000	8.186	2.705	1.889
Shoe + Pad	0.904	7.033	2.602	1.580
Shoe + Polyurethane	0.334	5.512	2.607	1.517

Tracker 8	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.000	4.888	1.818	1.498
Shod	0.000	7.604	1.962	2.191
Shoe + Pad	0.000	6.217	2.196	1.626
Shoe + Polyurethane	0.000	5.586	1.888	1.586

Tracker 9	*Min*	*Max*	*Mean*	*St. Dev.*
Barefoot	0.000	4.746	2.105	1.232
Shod	0.626	6.113	2.043	1.488
Shoe + Pad	0.000	6.726	2.477	1.630
Shoe + Polyurethane	0.000	7.401	2.111	1.914

Appendix II

Regression tables for trackers 1 through 6, and 8 and 9. Tracker movement in mm is the dependent variable.

Table 2: Tracker 1

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	2.303	4.017	0.57	0.568
Heel Width	-0.046	0.029	-1.61	0.112
Heel Length	0.241	0.092	2.62	0.011**
Wall Length	0.040	0.047	0.85	0.400
Wall Angle	0.063	0.087	0.72	0.472
Frog Length	0.031	0.057	0.55	0.586
Sulcas Depth	-0.212	0.083	-2.55	0.013**
Hoof Moisture	-0.191	0.047	-4.08	0.0001**

* indicates significance at p<0.1

** indicates significance at p<0.05

Table 3: Tracker 2

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	2.873	4.383	0.66	0.515
Heel Width	-0.028	0.032	-0.87	0.386
Heel Length	0.224	0.101	2.21	0.030**
Wall Length	0.039	0.055	0.71	0.483
Wall Angle	0.092	0.101	0.92	0.363
Frog Length	0.028	0.063	0.44	0.664
Sulcas Depth	-0.276	0.089	-3.09	0.003**
Hoof Moisture	-0.180	0.054	-3.34	0.001**

* indicates significance at p<0.1

** indicates significance at p<0.05

Table 4: Tracker 3

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	3.933	4.794	0.82	0.415
Heel Width	-0.018	0.035	-0.51	0.611
Heel Length	0.214	0.113	1.89	0.062*
Wall Length	0.029	0.056	0.51	0.614
Wall Angle	0.199	0.106	1.88	0.064*

Frog Length	0.075	0.070	1.08	0.285
Sulcas Depth	-0.262	0.100	-2.62	0.011**
Hoof Moisture	-0.163	0.056	-2.9	0.005**

* indicates significance at p<0.1
** indicates significance at p<0.05

Table 5: Tracker 4

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	-1.721	4.980	-0.35	0.731
Heel Width	-0.074	0.036	-2.03	0.046**
Heel Length	0.067	0.118	0.57	0.571
Wall Length	0.122	0.058	2.09	0.040**
Wall Angle	0.138	0.110	1.26	0.212
Frog Length	0.154	0.072	2.13	0.037**
Sulcas Depth	-0.386	0.104	-3.71	0.0004**
Hoof Moisture	-0.140	0.059	-2.39	0.0120**

* indicates significance at p<0.1
** indicates significance at p<0.05

Table 6: Tracker 5

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	0.574	6.993	0.08	0.935
Heel Width	-0.026	0.051	-0.5	0.619
Heel Length	0.094	0.165	0.57	0.571
Wall Length	0.085	0.082	1.04	0.303
Wall Angle	0.304	0.154	1.98	0.052*
Frog Length	0.117	0.102	1.15	0.253
Sulcas Depth	-0.280	0.146	-1.92	0.059*
Hoof Moisture	0.274	0.082	3.33	0.001**

* indicates significance at p<0.1
** indicates significance at p<0.05

Table 7: Tracker 6

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	-13.74	5.190	-2.65	0.010**
Heel Width	-0.025	0.038	-0.66	0.512
Heel Length	0.090	0.123	0.74	0.464
Wall Length	0.128	0.061	2.1	0.039**
Wall Angle	0.060	0.114	0.52	0.603
Frog Length	0.050	0.075	0.66	0.509
Sulcas Depth	-0.382	0.108	-3.53	0.001**

Hoof Moisture	0.016	0.061	0.26	0.794

* indicates significance at p<0.1
** indicates significance at p<0.05

Table 8: Tracker 8

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	-2.417	5.126	-0.47	0.639
Heel Width	-0.015	0.038	-0.39	0.698
Heel Length	0.228	0.122	1.86	0.067*
Wall Length	-0.005	0.058	-0.09	0.926
Wall Angle	0.024	0.102	0.24	0.811
Frog Length	0.043	0.070	0.62	0.536
Sulcas Depth	-0.174	0.110	-1.58	0.119
Hoof Moisture	-0.151	0.058	-2.62	0.011**

* indicates significance at p<0.1
** indicates significance at p<0.05

Table 9: Tracker 9

Variables	*Coefficient*	*Standard Error*	*t*	*P*
Width:Length	0.809	4.993	0.16	0.872
Heel Width	-0.051	0.040	-1.27	0.208
Heel Length	0.236	0.116	2.03	0.047**
Wall Length	-0.052	0.056	-0.93	0.357
Wall Angle	0.023	0.096	0.24	0.815
Frog Length	0.012	0.070	0.17	0.863
Sulcas Depth	-0.088	0.104	-0.85	0.397
Hoof Moisture	-0.142	0.056	-2.52	0.014**

* indicates significance at p<0.1
** indicates significance at p<0.05