The Relationship between the Heel Buttress of the Hoof and the Orientation of the Distal Phalanx

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Abstract

The palmar angle of the distal phalanx is a commonly used reference point when looking at lateromedial radiographs for foot balance. There is anecdotal evidence that a lower heel length and angle results in a lower palmar angle, predisposing the horse to an increased risk of lameness in the palmar third of the foot. The solear parietal angle is less commonly referred to, but is consistently more defined than the distal fringe of the pedal bone on lateromedial radiographs.

This study aims to find a correlation between the heel buttress of the hoof capsule and the orientation of the distal phalanx.

External hoof measurements were taken before and after trimming to a standardised protocol and matched to measurements taken from pre and post trimming lateromedial radiographs.

The study of 15 sound warmblood showjumpers showed a significant moderate correlation between the heel angle and the palmar angle (medial $p=0.021$ $r=0.420$, lateral $p=0.010$ $r=0.465$) in the pre-trimmed state, which weakened once trimmed. There was an insignificant weak correlation between the length of the heels and the palmar angle, but a significantly strong correlation between the heel angle and the solear parietal angle (medial $p=0.001$ $r=0.554$, lateral $p=<0.001$ $r=0.603$).

The results of the study show there is a stronger, more significant correlation between the heel angle and the solear angle, than between the heel angle and the palmar angle. There is no correlation between the length of the heels and the palmar angle or the solear parietal angle. The correlations identified that when assessing the hoof capsule a more upright heel buttress angle is an indicator of a positive orientation of the distal phalanx and that the heel length should not be relied upon as a marker for good pedal bone alignment.

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 the permission of the owner.

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Word count; 4963

Abbreviations

°: Degrees of elevation

DP: Distal phalanx

DDFT: Deep digital flexor tendon

DIPJ: Distal interphalangeal joint

NB: Navicular bone

PA: Palmar angle, angle of orientation of the distal fringe of the distal phalanx

PTA: Podotrochlear apparatus, the collective of the navicular bone, collateral sesamoidean ligament and distal sesamoidean impar ligament

SA: Solear parietal angle, angle of the concave solar parietal surface of the distal phalanx

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Introduction

Soundness of the modern sports horse is a growing concern. As the expectations and demands placed upon sports horses increase, so do the demands and expectations placed upon the farrier to maintain soundness. The most common cause of early retirement of performance horses is lameness (Nicolai *et al.*, 2017). In the fore limb, 70% of lameness causes originate from below the knee (Caldwell, 2019), with poor foot conformation believed to be a cause (Dyson *et al.,* 2011). Trimming and shoeing is probably the most important routine procedure for maintaining soundness of the horse (O'Grady and Poupard, 2001). Farriers are in a privileged position to see the horses they trim and shoe on a regular basis, allowing them the opportunity to monitor changes in the hoof before they become a cause for lameness.

Heel Angle

Ideal or 'normal' conformation of the hoof capsule is said to occur when the dorsal wall and the heel angle are parallel (Fig.1a) (Colles and Ware, 2010; Head and Pilsworth, 2002; O'Grady and Poupard, 2003; Stashak *et al.*, 2002). Collapsed or under-run heels are where the horn tubules at the heel have become over-loaded and crushed (Stashak *et al.*, 2002) and the heel angle decreases to ≥5° less than the dorsal hoof wall angle (Fig.1b) (Butler and Butler, 2004). This is different to low heels where the structure of the hoof wall at the heels is strong and the horn tubules are straight, but the heel length is less than the optimal 3:1 ratio (O'Grady and Poupard, 2003). This concept of ideal or normal hoof capsule conformation is questioned by several studies who have found the majority of horses do not meet the parallelism specified above. A study by Powell (2006) examining the front and hind feet of 40 horses, ponies and one donkey, found that only the donkey exhibited parallel heel and toe angles. Hampson *et al.,* (2013) reported mean toe angle 50.4°- 54.8° and mean heel angle 37.9° - 43.7° in feral Australian Brumbies. A cohort of 26 subjects were measured over three trimming cycles with the difference between the toe and heel angles being 10.8° ±1.8° in unshod horses and 15.7° ±0.8° in shod ones (Caldwell *et al.,* 2015). 75 racing Thoroughbreds in New Zealand had mean dorsal hoof wall angles of 55.6° and mean heel angles of 41.5° (Labuschagne *et al.,* 2017).

It is believed that under-run or low heels are an inherited conformational fault (Butler and Butler, 2004), but can also be caused by leaving the toes too long and fitting a shoe which is too small. Furthermore, too long a shoeing interval in predisposed horses could lead to over-loading of the already weaker horn structure at the heel, resulting in heel collapse. (Hunt, 2012).

Fig.1a, *Hoof with desired parallelism of the toe and heel*. Fig.1b *Hoof with toe and heel angles not parallel*.

Distal Phalanx

There is debate over the normal orientation of the distal phalanx (DP) within the hoof capsule. Clinical studies have found a variation in what is deemed normal, as anecdotally it is thought the palmar angle (PA) of DP should be 2-10° elevation (Fig.1c) (Parks, 2003) to allow for descent of the palmar aspect of DP during the loading phase of the limb (O'Grady, 2009).

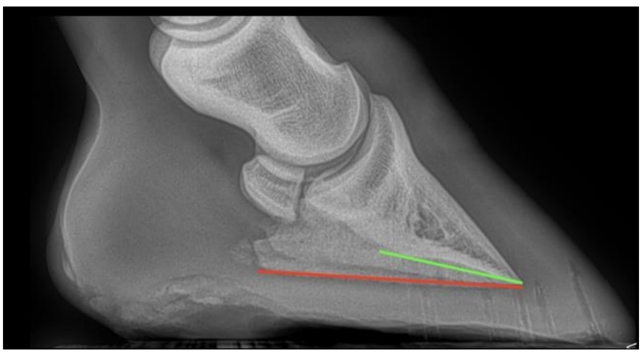


Fig.1c, *Radiograph showing the palmar angle in red and the solear parietal angle in green*

This broad elevation range agrees with the findings of clinical studies, where the PA is 2.5° in Irish Draught cross breds (Eliashar *et al.,* 2004) and between 3.9 and 8° in sound warmblood horses (Kummer *et al.*, 2006; 2009). A study of 300 lame horses had a PA of 5.4-6.4° on the lame (or lamest foot), unfortunately comparative measurements of the sound foot were not taken (Dyson *et al.*, 2011).

One group of 'barefoot' podiatrists believe that the PA of the DP should be 0° or horizontal to the floor (Cook, 2012), this is without scientific foundation and is based on observations of wild horse conformations. This has been countered by a study of wild Australian Brumbies where the PA was found to be between 5.7 and 8° depending upon the substrate that the animals lived on (Hampson *et al.*, 2013). This is supported by a study of seven riding school horses over a 16-month period, which were 'barefoot', trimmed to a protocol described by Ovnicek *et al.,* (2003) (which included lowering the height of the heels to the widest part of the frog) and the hoof morphology monitored. The PA of the DP increased from 3.70 to 7.38°, while the angle of the heels remained the same (Clayton *et al*., 2011).

Solear Parietal Angle

The sole angle, or solear parietal angle (SA) (Curtis, 2018) is believed to be more relevant to the health and function of the DP as it is closer to the angle of the flexor surface of the DP than the PA (Dyson *et al.*, 2011; Holroyd *et al.*, 2013). This angle is formed on the mid-sagittal plane of the solear parietal surface of the DP (Dyson *et al.,* 2011) and is visible on latero-medial radiographs. There is limited research data on this angle, but in lame horses varies between 9.6 and 21.4° (Dyson *et al.*, 2011; Holroyd *et al.*, 2013).

Injury

The palmar third of the foot is involved in approximately one third of all forelimb lameness (Turner, 1986; Murray *et al.*, 2006). The navicular bone and its associated structures are most commonly involved, but other structures should not be discounted (Dabareiner and Carter, 2003). The consequences of collapsed heels and a low or negative PA include corns (Dollar and Wheatley, 1898), palmar third foot syndrome (PTFS) (Bathe, 2002), navicular pain (Eliashar *et al.*, 2004), distal interphalangeal joint (DIPJ) pain (O'Grady and Poupard, 2001; Stashak *et al.*, 2002), deep digital flexor tendon (DDFT) injuries (Ferrie and Clements, 2002) and podotrochlear apparatus (PTA) injury (Dyson *et al.*, 2011).

Pressure from the DDFT on the navicular bone may cause palmar surface lesions, which were present in nearly all feet studied by Wright *et al.* (1998). Most researchers agree that biomechanical stress is a major cause of navicular disease or palmar foot pain (Rijkenhuizen, 2006).

It has been shown that a lower PA increases the pressure applied by the DDFT on the navicular bone; increasing PA by 1° can reduce the applied pressure by up to 4% (Eliashar *et al.*, 2004). A study of 1132 horses at a referral centre found that an increased incidence of navicular bone, DDFT and PTA + another injury in showjumpers compared to dressage, eventing and racing; Warmbloods were most frequently injured in all categories (Parkes *et al.*, 2013).

Whilst a flat or negative PA is accepted as being detrimental to a horse's soundness, so too is a PA which is too high. In an *in vitro* study of DIPJ intra-articular pressure, Viitanen *et al.* (2003) found that by increasing the PA of the DP by 5° increased the intra-articular pressure, which over the long term has been linked to osteoarthritis.

Hoof capsule conformation and health are of great importance to the soundness of the horse. When examining lateromedial foot balance radiographs, farriers are frequently asked by veterinary surgeons to shorten the toe and leave the heels longer. Anecdotally this is believed to increase the PA of the DP. However, with some feet allowing the heels to become longer can result in their collapse, as the final weightbearing point moves forward increasing the load on the hoof structures at the heel. If the orientation of the DP within the hoof capsule could be accurately predicted it may be possible to prevent lameness through pre-habilitative trimming and shoeing. Commonly, studies examining the relationship between the hoof capsule and the DP have concentrated on dorsal hoof wall angle, with little attention paid to the palmar aspect of the hoof capsule, which is frequently the area involved in lameness. Studies taking measurements of the heel angle and length often do so from photographs. This results in the inclusion of the heel bulbs in the measurements, and might limit the ability to accurately view the palmar-most weight bearing point of the heel. This may not be a true representation of the actual heel buttress angle.

Aims and hypotheses

This study aims to establish if there is a correlation between the heel buttress and the orientation of the DP within the hoof capsule of a live horse, by measuring the external heel buttress angle and length and measuring the PA and SA of DP from lateromedial radiographs.

It is hypothesised that;

1. There will be a correlation between the heel buttress angle and the palmar angle of the distal phalanx.
2. There will be a correlation between the length of the heel buttress and the palmar angle.
3. There will be a correlation between the heel buttress angle and the solear parietal angle of the distal phalanx.

Materials and methods

Overview

This is an observational study of the front feet of 15 warmblood horses which were conveniently selected and regularly compete in national show jumping competitions. Front shoes were removed and feet cleaned out with a stiff wire brush for exterior hoof measurements of each foot to be taken by the author and recorded by the assisting veterinary surgeon (SH), prior to obtaining the pre-trim lateromedial radiographs. Feet were then trimmed by the author to a standardised protocol, and the exterior hoof measurements and radiographs repeated post-trim. Measurements were taken by the author from the radiographs at a later date using ImageCare V3.1.1.19.

Horses

The project was granted approval by the Royal Veterinary College's Ethics and Welfare Committee. Fifteen Warmblood showjumpers, mean age 7.6 years ±2.2 competing in

1.1m- 1.6m classes were selected from the same yard to provide a consistent type of horse. Each horse was declared sound and in consistent competition work by the owner to fit the remit of this study. This was confirmed by having each subject trotted in a straight line for the attending veterinary surgeon. The radiographs were taken as a routine foot balance procedure and the owner completed and signed a consent form for the use the radiographs solely for the purpose of the study.

Data collection

Data was collected to tie in with the shoeing schedule of each horse, as the horses are competing on a regular basis, they were all shod every five weeks.

External hoof measurements

Shoes were removed and the feet were cleaned with a stiff wire brush to remove excess dirt and any overgrown horny frog at the heel buttress area trimmed to allow accurate measurement of the heel buttresses (Fig. 2a).

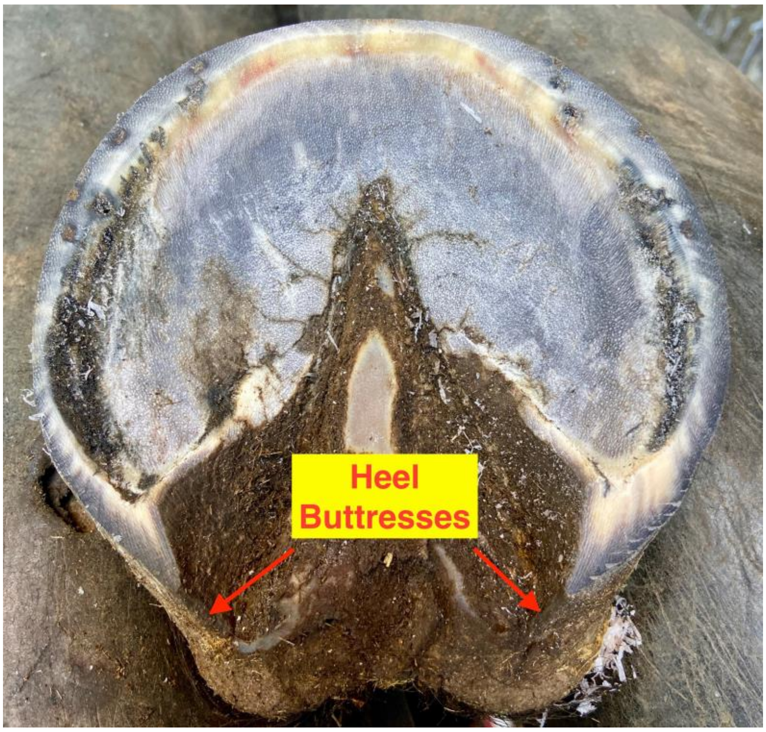


Fig. 2a, *Showing the heel buttresses of the hoof*

Seven hoof measurements were taken (Fig. 2b, 2c, 2d & 2e);

1. hoof width
2. length from toe to lateral heel
3. length from toe to medial heel
4. angle of lateral heel buttress
5. angle of medial heel buttress
6. length of lateral heel buttress
7. length of medial heel buttress

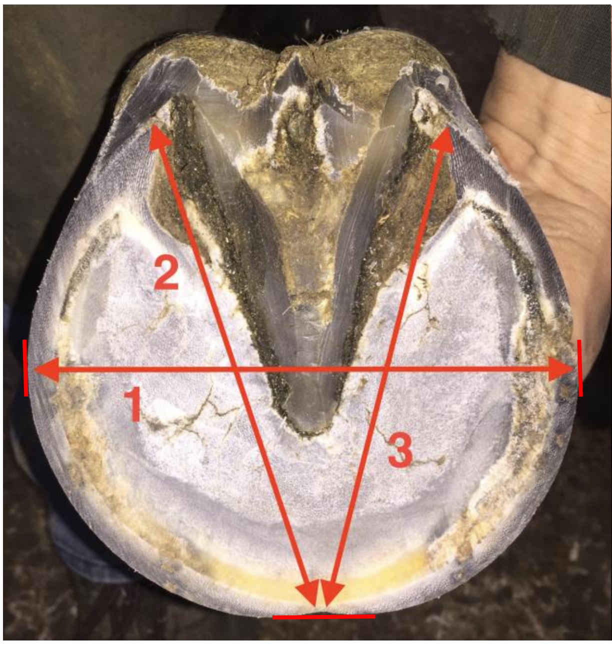


Fig. 2b, *Showing width and length measurements*.

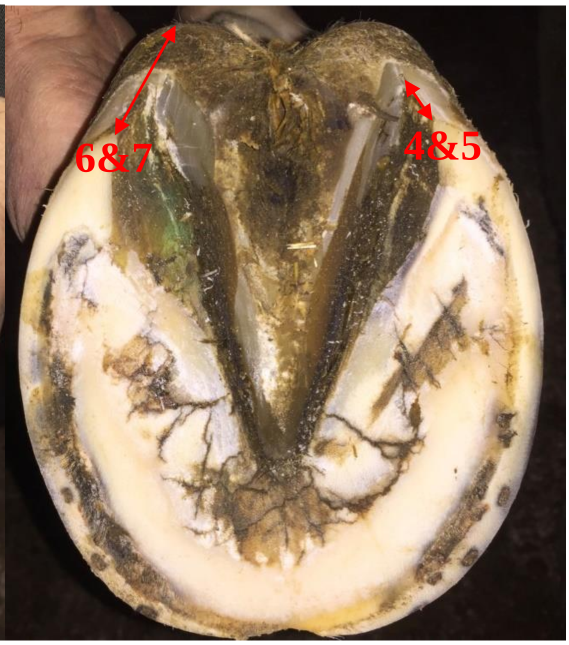


Fig. 2c. *Showing heel angle and length measurements*

Fig. 2d. *Showing heel buttress angle measurements*

Fig. 2e. *Showing measuring the heel buttress angle*

All linear measurements were in millimetres (mm) and taken with a J Blurton 2ft. folding brass ruler [1].

Hoof width was measured at the widest part of the bearing border. Toe to lateral heel and toe to medial heel measurements were defined as the most proximal point of the bearing border to the most palmar point of bearing border on the lateral and medial sides respectively.

Lateral and medial heel buttress angles were measured in degrees (°) using a modified Lumberjack DAR 200 digital angle finder[2](Fig. 3a). One side of the angle finder was shortened by 130mm to allow easy alignment with the heel buttress (Fig. 3b). The longer side of the angle finder was placed on the bearing border of the hoof wall and the shorter side aligned along the heel buttress to give the exterior heel buttress angle.

Fig. 3a Digital angle finder

Fig. 3b Modified angle finder

Heel buttress length was measured from the palmar-most bearing point of lateral and medial heel to the hair line directly above, using Silverline 6'' 150mm Vernier Caliper[3](Fig. 3c).

Fig. 3c Vernier calipers

The measurements were repeated using the same process post-trimming.

Radiographs

Both front feet were placed on 7-centimetre high wooden blocks and lateromedial radiographs were taken by SH. The unit is located 29cm from the subject and the beam is centred on a point midway between the dorsal hoof wall and the heel and 1 centimetre below the coronary band. A BCF Quattro mobile digital radiography unit was used and images uploaded and stored in DICOM format on the practice computer system later that day. Analysis of the images by the author took place at the veterinary practice once all data had been gathered.

Foot trimming

The front feet were trimmed by the author to a standard protocol (Caldwell *et al., 2015)* which was the closest to the author's regular trimming protocol. Where there was excessive growth of the frog, this was removed to form a symmetrical shape. Excess horny sole was exfoliated, only removing what could be easily removed. The horny wall at the toe was trimmed to a point just above the sole. At the heels, the wall was trimmed to maintain strength without leaving excess height. Attention was paid by the author to achieve lateromedial and dorsopalmar balance to the long axis of the limb. The bearing border was then rasped to achieve a flat and level plane. The dorsal wall was dressed with a rasp from toe to heel quarter, sufficient to eliminate any flaring.

Radiographic measurements

Measurements in degrees of the distal fringe of the DP commonly known as the palmar angle (PA) to the horizontal and solear parietal angle (SA) of the DP to the horizontal were taken using ImageCare software[4] at the veterinary practice. To find the PA, a horizontal line was placed on the bearing border of the hoof, and a second straight line was drawn from the proximal most point to the palmar most point of DP along the distal fringe. The distal fringe of DP can be hard to see clearly on some radiographs and where this was the case the measurement was repeated and the mean used.

Measuring the PA can be challenging, possibly due to the quality of the radiographs, conformation of the horse or the health of the distal fringe of the DP. On all of the radiographs the SA was a consistently clearer and more defined line which ran from the tip of the DP obliquely towards the distal sesamoid, described by Dyson *et al.* (2011) as the solear parietal surface angle of DP. To measure this angle a horizontal line was placed on the bearing border of the hoof capsule and a second straight line drawn from the tip of DP along the solear parietal surface to the most dorsodistal point of the distal sesamoid (Fig. 4).

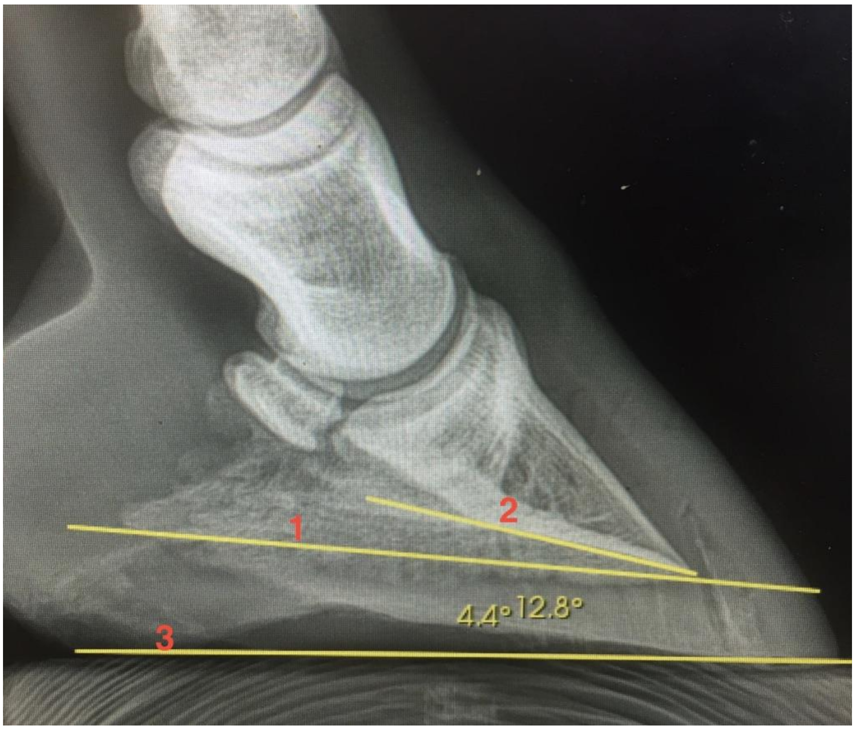


Fig. 4, Lateromedial radiograph showing the palmar angle (1) of 4.4° and solear angle (2) of 12.8° to the horizontal (3)

Data analysis

Normality of the data distribution was tested using histograms and box plots for all data collected from the hoof and radiographs, as well as the age of the subjects. A Wilcoxon signed rank test was performed on the data to determine if there was a difference between the left and right feet. This showed that there was no statistically significant difference between the feet (Tables 1a & b.), so all the data for both front feet was tested for associations collectively.

Where both variables were deemed to be normally distributed, a Pearson correlation test was used. For tests where one or both variables were not normally distributed, a non-parametric Spearman test was used.

All data analyses were performed using SPSS[5] with significance level set at $p<0.05$. Correlation coefficience is defined as weak if $r<0.3$, moderate if $r=0.3$ to 0.5 and strong if $r>0.5$, with a negative correlation defined using a minus sign.

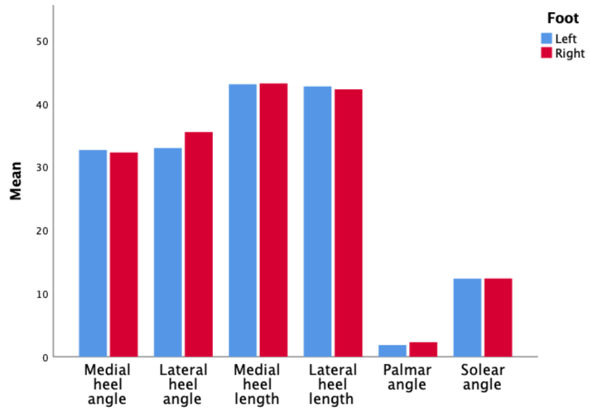
Results

Horses

All horses were at the same yard, all were Warmblood breeding and competing regularly in affiliated show jumping competitions. Of the fifteen horses in the study, 53% (n=8) were geldings, and the remainder mares. The mean age was 7.6 years ±2.2.

Exterior hoof measurements

A Wilcoxon signed rank test showed no statistical difference between the left and right measurements (Fig. 5a & b. Table 1a & b.).



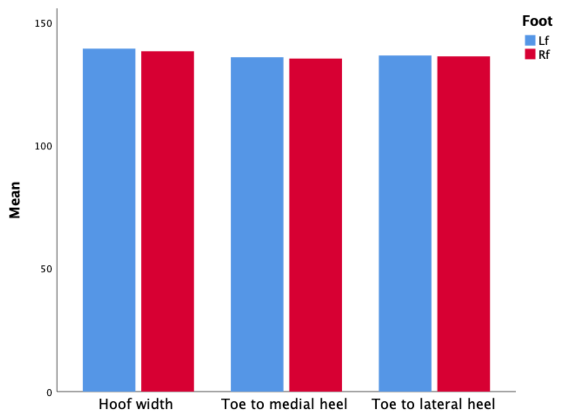


Fig. 5a & b, Bar charts showing no statistically significant difference between left and right feet

Table 1a, Measurements of left and right feet, pre and post-trimming of 15 warmblood show jumpers

Measurement	Pre-trim Mean (±)		Post-trim Mean (±)	
	Left	Right	Left	Right
Hoof Width	141.9mm (±8.5)	139.9mm (±8.5)	137.5mm (±8.5)	136.3mm (±7.9)
Toe to medial heel	135.8mm (±8.6)	135.1mm (±8.9)	135.5mm (±7.7)	135.2mm (±8.0)
Toe to lateral heel	136.5mm (±9.3)	135.8mm (±9.7)	136.3mm (±8.4)	136.3mm (±8.6)
Medial heel angle	31.0° (±8.1)	32.2° (±8.5)	31.6° (±7.7)	32.8° (±7.5)
Lateral heel angle	31.5° (±8.6)	35.9° (±8.5)	34.4° (±7.5)	35.5° (±7.9)
Medial heel length	45.6mm (±10.6)	46.3mm (±10.2)	40.5mm (±7.8)	40.1mm (±8.1)
Lateral heel length	45.5mm (±10.8)	45.5mm (±9.5)	39.9mm (±7.7)	39.3mm (±7.5)
Palmar angle	1.3° (±1.9)	1.7° (±1.6)	2.4° (±1.1)	2.9° (±1.4)
Solear parietal angle	12° (±2.1)	11.9° (±1.9)	12.7° (±1.6)	12.8° (±1.5)

Table 1b, showing no significant difference between left and right feet, significance at <0.05

Left versus right association tested	P value	
	Pre-trim	Post-trim
Hoof width	0.277	0.180
Toe to medial heel	0.394	0.426
Toe to lateral heel	0.304	0.860
Medial heel angle	0.820	0.570
Lateral heel angle	0.363	0.865
Medial heel length	0.513	0.723
Lateral heel length	0.950	0.732
Palmar angle	0.495	0.272
Solear parietal angle	0.977	0.593

Combined left and right hoof measurements

Mean hoof width pre and post trim was 140.4mm ±8.4 and 136.9mm ±8.1.
Mean toe to medial heel measurement was 135.5mm ±8.6 pre-trim and 135.4mm ±7.7 post-trimming.
Pre-trim mean toe to lateral heel measurement was 136.2mm ±9.3, post-trimming this was to 136.3mm ±8.3.
The mean medial heel angle pre and post trim was 31.6° ±8.2 and 33.6° ±7.4.
Pre-trim the lateral heel angle was mean 33.7° ±8.7, post-trim was 35.0° ±7.6.
The mean medial heel length was 45.9mm ±10.3 pre-trimming and post-trim it was mean of 40.3mm ±7.8.
The lateral heel length mean was 45.5mm ±10 pre-trimming and 39.6mm ±7.5 post-trimming.
The mean pre-trim PA was 1.52° ±1.76, this increased post-trim to mean 2.64° ±1.29.
The pre-trim SA mean was 11.95° ±1.98, post-trim increasing to mean 12.76° ±1.51 (Table 2).

Table 2, Showing distribution of data with left and right feet combined

Hoof Measurement (combined left and right front feet)	Pre-trim mean (±)	Post-trim mean (±)
Medial heel angle	31.6° (±8.2) (N)	33.6° (±7.4) (N)
Lateral heel angle	33.7° (±8.7) (NN)	35° (±7.6) (N)
Medial heel length	45.9mm (±10.3) (NN)	40.3mm (±7.8) (N)
Lateral heel length	45.5mm (±10) (NN)	39.6mm (±7.5) (NN)
Medial heel to toe	135.5mm (±8.6) (NN)	135.4mm (±7.7) (NN)
Lateral heel to toe	136.2mm (±9.3) (NN)	136.3mm (±8.3) (NN)
Hoof width	140.4mm (±8.4) (NN)	136.9mm (±8.1) (NN)
Palmar angle	1.52° (±1.76) (N)	2.64° (±1.29) (NN)
Solear parietal angle	11.95° (±1.98) (NN)	12.76° (±1.51) (N)

(N) denotes normally distributed data, (NN) denotes not normally distributed data

Associations between external and radiographic measurements

Table 3 Showing associations tested, significance is at <0.05

Association tested	Pre-trim		Post-trim	
	P value	R value	P value	R value
Medial heel angle – Palmar angle	0.021*	0.420	0.155	0.271
Lateral heel angle – Palmar angle	0.010*	0.465	0.219	0.236
Medial heel length – Palmar angle	0.748	0.061	0.614	0.098
Lateral heel length – Palmar angle	0.990	-0.002	0.542	-0.118
Medial heel angle – Solear parietal angle	0.001*	0.554	0.021*	0.426
Lateral heel angle – Solear parietal angle	<0.001*	0.603	0.002*	0.543
Medial heel length – solear parietal angle	0.354	0.175	0.072	0.339
Lateral heel length – Solear parietal angle	0.558	0.111	0.662	0.085
Solear parietal angle – Palmar angle	0.015*	0.440	0.117	0.297

* denotes significance

Heels, palmar angle

A Pearson test showed there was a moderate correlation (p=0.021 r=0.420) between the medial heel angle and the PA of the DP in the pre-trimmed feet. Post-trimming, a non-parametric Spearman test showed this had become weak and not significant (p=0.155 r=0.271). A slightly stronger correlation between the pre-trimmed lateral heel angle and the palmar angle was found using a Spearman test (p=0.010 r=0.465) (Fig. 6). In the trimmed state this correlation also became weak and not significant (p=0.219 r=0.236).

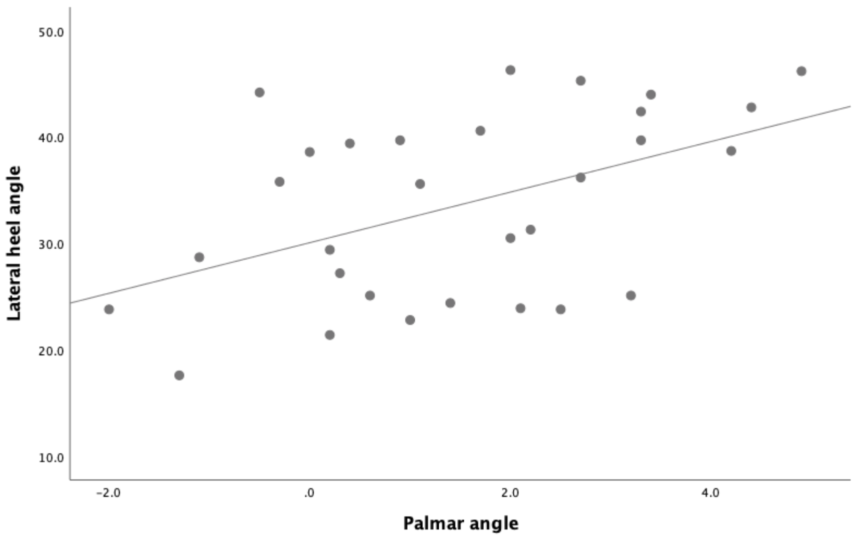


Fig. 6, Scatter graph showing a moderate correlation between the lateral heel angle and palmar angle

Neither medial or lateral heel length showed a significant correlation to the PA in the pre or post trimmed state.

Heels, solear parietal angle

Associations between the heel buttress angle and the SA were significant and strong, the medial heel buttress angle to SA was p=0.001 r=0.554 pre-trimming (Spearman). This weakened slightly post-trimming (p=0.021 r=0.426) (Pearson). The lateral heel buttress angle to SA was slightly stronger and very significant (p=<0.001 r=0.603) (Spearman) in the pre-trim measurements (Fig. 7). Post-trimming the lateral heel to SA correlation remained significant and strong (p=0.002 r=0.543) (Pearson).

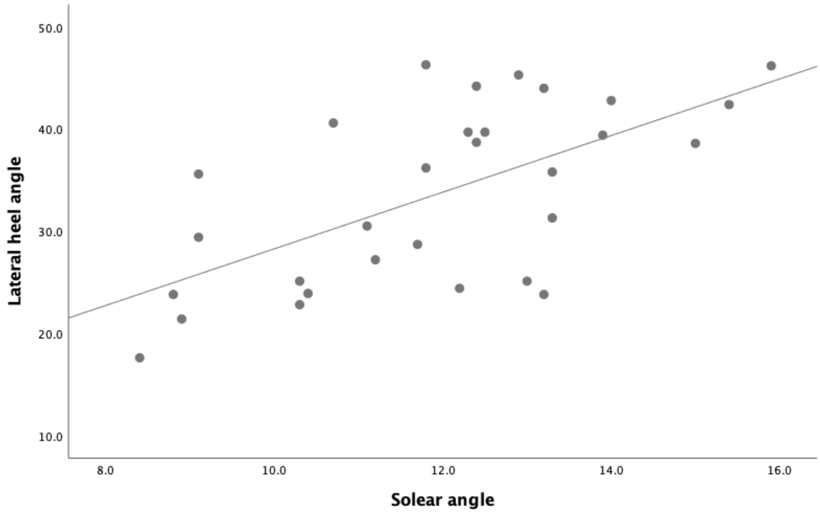


Fig. 7, Scatter plot showing a strong positive correlation between lateral heel angle and solear parietal angle in pre-trimmed state

No significant correlation was found between the medial or lateral heel length and the SA in the pre or post trimmed measurements.

Palmar angle, solear parietal angle

A Spearman test showed a significant moderate correlation (p=0.015 r=0.440) between the solear parietal angle and the palmar angle of the untrimmed feet, this weakened once trimmed (p=0.117 r=0.297).

Heel length, heel angle

There was a significant moderate correlation (p=0.037 r=0.383) (Spearman) between the medial heel angle and the medial heel length prior to trimming, this correlation strengthened further once trimmed (p=0.009 r=0.467) (Pearson). Spearman tests show there wasn't the same correlation between the lateral heel angle and lateral heel length (p=0.128 r=0.284(pre-trim) p=0.109 r=0.299(post trim)).

Hoof width and length, palmar angle

There were insignificant weak negative correlations (p=0.329 r=-0.185) (Spearman) between the width of the feet and the PA before trimming, which strengthened slightly but not significantly once trimmed (p=0.077 r=-0.333) (Spearman).

Testing the measurements from the toe to medial heel and toe to lateral heel using a Spearman test had weak negative correlations to the PA (p=0.421 r=-0.153 toe to medial heel. p=0.427 r=-0.151 toe to lateral heel) before trimming. Once trimmed these weakened further, p=0.550 r=-0.116 for the toe to medial heel and p=0.654 r=-0.087 for the toe to lateral heel.

Hoof width and length, solear parietal angle

The hoof width showed a weak negative correlation to the SA (p=0.323 r=-0.187) (Spearman) before trimming, there was mild strengthening once trimmed (p=0.196 r=-0.247) (Spearman).

The hoof length from toe to medial heel (p=0.613 r=-0.096) and toe to lateral heel (p=0.590 r=-0.102) (Spearman) to SA also showed weak negative correlations prior to trimming, with little change post-trimming (p=0.962 r=-0.009 (toe to medial heel) p=0.565 r=0.111 (toe to lateral heel))(Spearman).

Discussion

The objective of this study was to analyse the relationship between the heel buttress and the distal phalanx, to see if a consistent external marker could potentially be used to accurately predict the orientation of the distal phalanx within the hoof capsule. When the data for both feet was combined there was a significant, but moderate correlation between the pre-trimmed heel angles and the PA, the lateral heel (p=0.010 r=0.465) more so than the medial (p=0.021 r=0.420), which partially supported hypothesis 1., that there would be a correlation, although it is not as strong or significant as author believed it would be.

The level of correlation between the heel buttress angles and the PA may be affected by the amount of foot grown by the horse. Once the feet had been trimmed, the heel buttress angle and the PA increased, but the correlations were lost for both medial and lateral heels. The correlation becomes stronger as the feet become longer and the heel angle decreases and thus the PA decreases. The decrease in heel angle over the shoeing period is believed to be due to the hoof being a truncated, oblique cone (Curtis, 2018), which means the foot grows in a forward diagonal direction rather than vertically downward.

This study showed no correlation between the length of the heels and the palmar angle of the DP and does not support hypothesis 2; this was somewhat unexpected, as anecdotal evidence suggests that length of the heels is an indicator of good foot conformation (Balch, Butler and Collier, 1997; O'Grady and Poupard, 2003). The difference between how the heel length measurement was taken in this study and others may offer an explanation as to why there was no correlation. Other studies have taken measurements of the heel angle from photographs, measuring from the coronary band at the heel to the last visible weight bearing point. The aim of this study was to establish if a farrier/trimmer could take an instant measurement of the hoof capsule to accurately predict the orientation of the DP, rather than to have to take a picture and take measurements from a two-dimensional image.

The most significant correlation observed in this study was between the heel angles and the solear parietal angle, thus supporting hypothesis 3. There was a highly significant correlation pre-trimming (medial $p=0.001$ $r=0.554$, lateral $p=<0.001$ $r=0.603$) and post trimming (medial $p=0.021$ $r=0.426$, lateral $p=0.002$ $r=0.543$), with there being more significance on the lateral heel buttress. This reflects the findings of Dyson *et al.* (2011) who also found a significant correlation between the heel angle and the SA. In the same way the heel angle and PA increased post trimming, so too the SA also increases, although the correlation between the heel angles and SA reduces.

Palmar Angle

In this study, the mean PA of DP was 1.52° ±1.76 in the pre-trimmed feet and 2.64° ±1.29 post-trimming. These results are consistent with both the studies by Eliashar *et al.* (2004)

and Kummer *et al.* (2006). Eliashar *et al. (2004)* showed a mean 2.5° ±2.2 in 31 Irish Draught-cross bred horses. Although the subjects in this study were all warmbloods, the PA had a wide variance, in the pre-trim state it ranged from as low as minus 2° up to 4.9° and post trimming from 0.9° to 5.6°. Kummer *et al.* (2006) found a mean of 4 to 4.7° prior to trimming 40 sound warmblood horses on an 8-10-week shoeing schedule, with a post-trim mean of 5.4 to 6.4°, supporting the increase seen pre and post trimming in the current study. It may therefore be suggested that the trimming of feet to a trimming protocol, as an average, has the effect of increasing the PA.

A positive PA is believed to be more beneficial to long term soundness of competition horses, as it reduces compression of the palmar third of the hoof capsule thus reducing the chances of lameness (Holroyd *et al.,* 2013).

Solear Parital Angle

The SA was a mean 11.95° ±1.98 in the pre-trim measurements and mean of 12.76° ±1.51 post trimming. Dyson *et al.* (2011) observed a of mean 15.64° ±3.45 in non-weight bearing radiographs, while Holroyd *et al.* (2013) recorded a SA of between 9.6 and 21.4° in various groups of horses with different soft tissue lesions within the hoof. While both of these studies had a large subject count, they were looking at horses which were lame for an undisclosed amount of time, which may have produced significantly differing results to the study.

Given the significance of the correlations between the heel buttress angle and the SA further studies may be warranted to investigate this further with the aim of establishing what the ideal SA, or range of SA, is for a sound horse.

Heel Angle

The mean measured heel buttress angle was 31.6° ±8.2 medial and 33.7° ±8.7 lateral in the pre-trimmed state, with a mean of 33.6° ±7.4 medial and 35° ±7.6 post trimming. The means observed in this study were therefore notably less than those observed by Dyson *et al.* (2011); the mean of 43.5° ±6.3 in 25 non-lame horses and 44.7° ±6.5 in 300 lame horses studied. Lower also than those observed by Labuschagne *et al.,* (2017); 41.5° ±1.4 found in 75 thoroughbred racehorses, and also than the 48.7 ° ±7.1 observed in 96 showjumpers and dressage horses in New Zealand (Dijkstra *et al.,* 2016). Measurements were taken from digital photographs, where the heel angle is defined as the palmar most point of the coronary band to the last visible weight bearing point, as opposed to measuring the heel buttress, which may offer an explanation into the difference in results. Kane *et al.* (1998) recorded a mean heel angle of 38.8-41.6°, the lower angles were found in racehorses which had suffered condylar fracture, with the higher angles from a control group. The variation in recorded measurements could be as a result of the use of different measurement points, equipment or operator (Moleman *et al.,* 2005).

Although dorsal hoof wall angle measurements were not taken as part of this study, it is assumed that the heel angles were not maintaining the parallelism seen as being desirable by many authors (Balch, Butler and Collier, 1997; Butler and Butler, 2004; O'Grady and Poupard, 2003; Stashak *et al.*, 2002). This idealism has been questioned by others to the point where a lower heel angle is seen as normal (Caldwell *et al.,* 2015; Dyson *et al.,* 2011; Eliashar *et al.,* 2004; Kane *et al.,* 1998; Labuschagne *et al.,* 2017).

Heel Length

The length of the heels was measured from the palmar-most weight bearing point of the hoof wall as it reflects inward to form the bars of the hoof, to the hair line directly above and in line with the heel buttress. This was the most accurate and repeatable method (Reilly *et al*., 1998), as attempts to simply measure the length of the heel buttress proved to be inconsistent due to the junction of the frog and heel bulbs. The combined left and right pre-trim mean for the medial heel length was 45.9mm ±10.3 and 45.5mm ±10 for the lateral heel. Post trimming, the medial heel length was 40.3mm ±7.8 and 39.6mm ±7.5 for the lateral heel. The difference in the medial and lateral heels, pre and post trim, may be due to correction of mediolateral balance during the trim, as the hoof growth can be compressed on the medial side (Curtis, 2018). It is difficult to compare the heel lengths in this study to others, as they are predominately taken from photographs and a vertical elevation of the heel bulb is measured.

Hoof Width and Length

Other measurements taken during the study, were of the hoof length (toe to lateral heel, toe to medial heel) and the hoof width. These were tested against the PA and SA to determine if there was a correlation, with only very weak negative correlations found. The main need for these measurements was to determine if there were any distortions or asymmetry between the left and right feet. A Wilcoxon signed rank test concluded that there were no statistical differences between the left and right feet, although the mean measurements showed that the right foot was 2mm narrower pre-trimming and the heel angles were more upright. The disparity between the left and right feet pre-trimming was reduced in the post-trimming measurements, where possible medial/lateral and dorso/palmar hoof imbalances are corrected. Previous studies have observed an asymmetry between front feet (Curtis 2018; Dyson *et al.,* 2011; Labuschagne *et al.,* 2017), with up to 70% of horses having a significant difference between them (Kummer *et al.,* 2006). There is evidence to suggest that this may be the cause of a shortening of the competitive life of some horses (Dijkstra *et al.,* 2016; Ducro *et al.,* 2009).

Study Limitations

The relatively small number of subjects in this study may limit the impact of the findings, this was a study specifically of sound horses in work. Previous studies of much larger subject numbers have found more correlations, but have predominantly been of lame horses. Warmblood showjumpers were the predominant injured subjects in a study of 1132 lame horses at a referral centre (Parkes *et al.* 2013), so to study a group which were without injury provides valuable data. Despite this study being limited to one breed, there are many varieties of warmblood, the subjects were of a varying size with feet measuring from 124mm to 150mm wide.

Further studies could gather data from the dorsal hoof wall and to observe other breed types.

Conclusion

The findings of this study have shown that there is a correlation between the heel angle and the palmar angle of the distal phalanx in the pre-trim state, but this is lost post-trimming. The correlation between the heel angle and SA is stronger pre and post trimming than that of the heel angle and PA. Once the feet have been trimmed the heel angle generally increases, as does the PA and the SA. Regular trimming of the feet to readjust heel angle will maintain a positive orientation of P3 within the hoof capsule.

Heel length does not correlate to the PA, so to allow the heels to become longer in length in order to increase the PA is counter-productive.

When dealing with a flat or negative PA it is worth noting the angle of the heel buttresses. Hooves with low heel buttress angles are more likely to have a lower PA and SA, which could be detrimental to the soundness of the animal. Careful trimming of the feet and application of an appropriate shoeing package may be beneficial in improving the heel buttress angle over a period of time, which should in turn improve the orientation of P3.

Equipment list

1, Jim Blurton 2-foot folding brass ruler, Jim Blurton Tools, Rosehill, Kingswood, Forden, Welshpool

2, Lumberjack DAR 200 digital angle finder, Toolsave Limited, Unit C, Manders Ind. Est., Old Heath Road, Wolverhampton

3, Silverline 6'' 150mm Vernier Caliper Tool, Silverline Tools,
Boundary Way, Yeovil, Somerset

4, Medecom Image-Care V3.1.1.9, 9 bis, rue de Kerbrat, 29470 Plougastel Daoulas, France

5, IBM SPSS statistics version 25

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Appendix

The relationship between the heel buttress angle and length and the orientation of the distal phalanx.

The aim of this study is to establish if by taking external measurements of the hoof capsule we can accurately predict the positioning of the distal phalanx in sound horses.

Data collection: This will be performed on location at your premises using horses which are due to be shod as part of their usual shoeing regime.

Personnel: *Phillip Martin*; lead investigator and farrier responsible for taking measurements, trimming and shoeing feet.
Sally Hodgson; veterinary surgeon responsible for taking radiographs and over-seeing welfare of the subjects during data collection.
Veterinary assistant (TBC), responsible for assisting Sally Hodgson whilst taking radiographs.
Horse holder; to be provided by you, this is to be someone who is competent of handling fit competition horses whist the radiographs are taken.

Equipment: For taking the external measurements of the horses' feet a brass ruler, a digital angle finder and a pair of Vernier callipers will be used. The usual farrier tools (hoof knives, cutters and rasp) will be used for trimming the feet.
A BCF Quattro mobile radiography unit will be used for the onsite radiographs, with a focal distance of 39cm. Image Care software will be used to take measurements from the radiographs at a later date.

Protocol:

- All horses will be walked and trotted in a straight line prior to commencement of the data collection for Phillip Martin and Sally Hodgson to verify their soundness and suitability for the study.
- Each horse will in turn have its shoes removed and external hoof measurements taken.
- Pre-trim radiographs will be taken.
- Feet will be trimmed to a standard protocol used daily.
- External hoof measurements taken.
- Post-trim radiographs will be taken using the same protocol used for the pre-trim.
- Shoes will be applied as part of the standard shoeing regime.

Total time commitment for each horse will be approximately 1 hour.

General consent for study participation

- I have read and understood the above description of the experiments and agree to participate.
- I understand that at any point during the study I can withdraw from the study.
- Owner's/animal's details will not be included in presentations/publications and these data will be kept in a locked filing cabinet only accessible to the lead researcher.
- I agree that any data collected (except video) can be used for research/presentation purposes.

Date_________ Print name and signature____________________________________

Thank you very much for your participation in this study.
Kind regards.

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Table of data gathered

horse id	pre/post	left_m_h_a	right_m-h_a	left_l_h_a	right_l_h_a	left_m_h_l	right_m_h_l	left_l_h_l	right_l_h_l	left_p_a	right_p_a	left_s_a	right_s_a	left_h_w	right_h_w	left_h_len_lat	right_h_len_lat	left_h_len_med	right_h_len_med
1	pre	33.5	39.6	38.6	42.8	36	43	31	43	0	4.4	15	14	134	130	130	131	128	134
1	post	28.4	35.5	38.9	37.9	35	40	34	38	0.9	5.6	14.4	12.8	133	130	132	134	130	133
2	pre	15.5	28.6	17.6	29.4	33	38	32	39	-1.3	0.2	8.4	9.1	142	135	132	134	130	131
2	post	21.3	24.6	23.9	32.1	31	35	31	35	1	1.4	10	10.7	140	130	131	134	131	130
3	pre	27.6	34.3	23.8	42.4	43	47	49	40	2.5	3.3	13.2	15.4	124	126	130	133	133	130
3	post	38.9	35.9	47.1	43.3	37	42	34	35	4.6	4	14.1	15.7	122	124	132	134	132	131
4	pre	27.6	23.4	23.8	27.2	43	45	49	46	-2	0.3	8.8	11.2	143	144	140	140	145	141
4	post	28.4	30.4	29.7	26.2	39	41	41	39	1.5	2.3	11.7	13.7	139	139	139	143	140	140
5	pre	36.4	29.6	45.3	35.6	59	51	60	49	2.7	1.1	12.9	9.1	145	140	153	155	152	147
5	post	39.1	33.2	39.1	42.7	46	45	44	40	3.6	3	14.8	13.6	139	135	151	151	147	146
6	pre	24.4	39.3	25.1	39.7	32	33	32	33	3.2	3.3	10.3	12.5	147	147	125	125	127	124
6	post	32.7	37	26.6	35.4	31	30	32	30	3.7	4.7	10.4	13.8	147	143	126	125	128	125
7	pre	31	36	30.5	44	59	60	59	60	2	3.4	11.1	13.2	147	145	143	142	141	142
7	post	34.6	34.7	27	38.2	50	50	50	49	2.6	4.4	12.4	13.8	140	138	140	142	139	140
8	pre	35.5	30	39.8	33.2	48	45	48	42	0.6	0.9	13	12.3	147	147	125	125	127	124
8	post	28	33.6	35	31	45	45	45	41	1.5	1.2	13	12.5	147	143	126	125	128	125
9	pre	38	46.3	40.6	46.3	49	51	49	51	1.7	2	10.7	11.8	131	129	130	126	130	126
9	post	42.6	41	42.3	45	42	43	44	43	2.1	2.5	11.4	12.1	127	125	132	131	131	130
10	pre	34.4	15.2	36.2	21.4	44	40	41	40	2.7	0.2	11.8	8.9	150	155	151	149	149	150
10	post	30.1	18	35.8	20.7	43	34	40	38	2.5	1	12.3	10.8	148	150	151	148	150	148
11	pre	30	19.7	31.3	24.4	42	41	42	42	2.2	1.4	13.3	12.2	143	144	129	124	129	124
11	post	31.4	22.5	31.4	30.3	39	36	34	37	3.5	2.8	14.1	14	137	140	129	124	124	124
12	pre	23.9	28.2	23.9	22.8	48	50	44	53	2.1	1	10.4	10.3	143	140	135	130	128	135
12	post	28.2	22.3	28.3	21.3	37	37	39	42	2.7	2.5	10.5	10.8	138	138	132	131	132	136
13	pre	51.1	29.7	46.2	38.7	49	40	49	37	4.9	4.2	15.9	12.4	126	135	135	135	135	132
13	post	51.8	38.2	43.9	38.3	45	34	42	30	2.5	4.1	13.7	11.8	123	133	137	138	137	135
14	pre	33	40.7	28.7	44.2	46	50	48	50	-1.1	-0.5	11.7	12.4	140	132	140	140	140	140
14	post	34.9	39.7	32.5	41.1	41	44	43	46	1.9		14.4		134	129	138	138	138	138
15	pre	34.4	33.4	35.8	39.4	69	72	65	66	-0.3	0.4	13.3	13.9	152	150	150	148	144	147
15	post	39.5	42.1	42.3	44.2	60	61	59	57	1	1.5	13.3	13.4	148	148	149	147	146	147