Skeletal forelimb measurements and hoof spread in relation to asymmetry in the bilateral forelimb of horses

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Keywords: horse; conformation; asymmetry; hoof; limb; generalised linear model

Summary

Reasons for performing study: **Research has highlighted a high frequency of skeletal asymmetries in horses. In addition, research into hoof asymmetries has shown that within a bilateral pair, the hoof with the smaller angle is often subjected to greater loading. There has been limited attention paid to understanding compensatory mechanisms for skeletal asymmetries in the horse; the dynamic structure of the hoof could potentially be acting in a compensatory capacity.**

Objectives: **To investigate the relationship between morphometry of forelimb segments and hoof spread and their incidence of asymmetry.**

Methods: **Ten bilateral measurements of the hoof and forelimb were taken from 34 leisure horses. The relationship between hoof spread and forelimb segment measurements were analysed using a generalised linear model (GLM).**

Results: **In relation to left hoof spread, the GLM identified significant negative relationships with left side measurements (third metacarpal length, elbow height), and significant positive relationships with right side measurements (fetlock height, third metacarpal length, elbow height). In relation to right hoof spread, the GLM identified significant negative relationship with left elbow height, and significant positive relationships with right side measurements (fetlock height, point of shoulder). The difference between the number of horses larger to the left or to the right was found to be significant for point of shoulder height ($\chi^2 = 4.8$, P<0.05), and highly significant for heel height ($\chi^2 = 9.53$, P<0.01) and the third metacarpal length ($\chi^2 = 7.26$, P<0.01).**

Conclusions and clinical relevance: **The study demonstrated considerable asymmetry in left-right morphometry of the equine limb. The fact that measurements of hoof spread were significantly associated with limb segment measurements could possibly indicate that an interaction exists. Any asymmetry in hoof spread measurements may suggest unequal loading of the limbs, which in turn may contribute to injuries and reduced performance.**

Introduction

Equine conformation has received considerable research interest in recent years. A horse's athletic capacity and ability to remain injury free are both closely linked to conformation. The effect of asymmetry deserves attention as evidence suggests that a higher degree of asymmetry is negatively correlated with performance in Standardbred trotters (Dalin 1985), Thoroughbred racehorses (Manning and Ockenden 1994) and event horses (McDonald and Dumbell 2008). Human research has identified that leg length asymmetry causes differences in loading and differing compensatory mechanisms (Goel *et al.* 1997; White *et al.* 2004). However, results have been conflicting between studies (Bhave *et al.* 1999; O'Toole *et al.* 2003). The affect of asymmetry on limb loading in horses has not been studied. Related studies have shown that within a bilateral pair, the hoof with the lower angle is often subjected to higher loading (Moleman *et al.* 2006). Nevertheless, it remains unclear whether the higher loading affects the hoof angle, or if actually the hoof angle affects the hoof loading. Because the hoof is a dynamic structure, capable of modifying its conformation to the forces placed on it, this study hypothesised that asymmetry in limb length would bring about changes in hoof shape and size, through asymmetric loading of the limbs. The aim of this study was, therefore, to investigate the relationship between hoof spread and coexisting skeletal asymmetries.

Methods

Measurements

Ten bilateral morphometric measurements of the front limb and hoof were taken from 34 horses. The study group consisted of various breeds and types of horses (140–199 cm height; age 5–25 years) on working livery at Hartpury College, Gloucestershire. Four hoof traits and 6 limb traits were measured to the nearest mm (hoof width bottom, hoof width top, toe height, heel and fetlock height, third metacarpal length, carpal height, elbow height, point of shoulder height, scapular height). Three repeated measurements were taken by the same operator and the mean calculated. The horses were stood squarely to ensure even weight distribution and eliminate potential changes in segment length asymmetries in joint angulations.

Three types of measuring equipment were used: 1) an Invicta metric calliper for hoof width top, hoof width bottom and third metacarpal length; 2) a set ruler with a spirit level for toe height, heel height and fetlock height; and 3) an adapted horse height measure with a spirit level for carpal height, elbow height, point of shoulder height and scapular height.

TABLE 1: Summary statistics for investigated bilateral traits of the left and right forelimbs

	Left		Right	
	Mean ± s.d. (mm)	Range (mm)	Mean ± s.d. (mm)	Range (mm)
Hoof width bottom	145.2 ± 16.8	107.0–186.0	144.1 ± 17.0	107.3–181.3
Hoof width top	112.1 ± 11.5	86.0–130.3	112.5 ± 11.2	90.3–136.3
Hoof spread	33.1 ± 8.9	17.0–55.6	31.6 ± 9.7	14.0–56.0
Heel height	34.1 ± 6.7	21.0–50.3	36.7 ± 8.1	15.3–64.3
Toe height	85.4 ± 8.6	68.6–105.3	84.4 ± 8.0	73.0–104.3
Fetlock height	168.2 ± 13.7	139.3–189.3	168.1 ± 15.1	141.6–203.3
3rd Metacarpal length	210.5 ± 31.6	153.3–276.3	212.3 ± 33.0	152.6–278.0
Carpal height	525.3 ± 32.9	424.6–592.6	525.1 ± 30.1	431.3–572.6
Elbow height	956.8 ± 60.5	831.0–1070.6	960.2 ± 60.2	826.0–1073.6
Point of shoulder	1120.8 ± 63.4	948.0–1256.3	1124.2 ± 61.2	951.6–1073.6
Scapular height	1577.4 ± 81.8	1361.0–1758.0	1576.6 ± 80.5	1359.6–1742.6

Data analysis

To investigate intrasubject reliability coefficient of variation was calculated from the raw data. Averages for each bilateral trait ranged from 0–0.73, indicating low variability. Mean ± s.d. and minimum and maximum values were calculated for each trait; hoof spread was calculated by subtracting hoof width top from hoof width bottom. Left and right side values for each trait were compared using a *t* test. To investigate the relationship between hoof spread and skeletal characteristics, a Generalised Linear Model (GLM) was developed using a log-link function in SPSS version 14.0. (Diggle *et al.* 2002; Dobson 2002; Hardin and Hilbe 2003; Elith *et al.* 2006). As goodness-of-fit statistics are not computed for GLM, a corrected quasi-likelihood under Independence model criterion (QICC) value was used to select best-fit model terms using the 'smaller is better' approach evaluated by Zheng and Agresti (2000) and Pan (2001).

GLM output model coefficient values (B) have little relative or absolute interpretive value when a log link function is used to render explanatory variables. The results presented therefore show only the P value of significant terms and the direction of the relationship (- or +). The model was run twice: once with the dependant variable as the spread of the left hoof and once as the spread of the right hoof. For both, the measurements of the limb (fetlock height, third metacarpal length, carpal height, elbow height, point of shoulder height and scapular height) for both the left and right sides were the response variables. The skeletal characteristics were considered to be the explanatory variables as these lengths are fixed once the horse reaches skeletal maturity while the hoof has the ability to change throughout the horse's life in response to the biomechanical forces being placed upon it (Anderson and McIlwraith 2004).

The difference between the left and right sides for each trait was calculated to give an asymmetry index. The asymmetry index was calculated to show the degree of asymmetry (non-directional) and the direction of asymmetry (directional). Calculations of directional-asymmetry gave a resultant sign: negative values indicating larger left side traits and positive values indicating larger right side traits. Left/right frequency could then be determined and a Chi-squared test (χ^2) was performed to identify any significant differences. Non-directional asymmetry was the difference between left and right without the consideration of the resultant sign.

Results

Summary statistics

Table 1 shows the mean, minimum, maximum and standard deviation (mm) for all morphometric measurements.

Generalised model results

In relation to left hoof spread, the GLM identified significant negative relationship with the left side measurements of third metacarpal length, left elbow height, and significant positive relationships with the right side measurements of fetlock height, third metacarpal length, elbow height (Table 2). These results indicated that as hoof spread increased, right fetlock height right increased, left third metacarpal length decreased, right third metacarpal length decreased, left hoof elbow height decreased and right elbow height increased significantly (P>0.05). The heights of the remaining traits were not found to be significant at P>0.05.

In relation to right hoof spread, the GLM identified significant negative relationship with left side elbow height, and significant positive relationships with the right side measurements of fetlock height and point of shoulder (Table 3). As right hoof spread increased, right fetlock height and right point of shoulder increased while left elbow height decreased significantly (P>0.05). The heights of the remaining traits were not found to be significant.

TABLE 2: Significant explanatory variables for left hoof spread where a positive B value indicates an increase in the variable concurrent to left hoof spread and a negative B value indicates a decrease in the variable as left hoof spread increases

Left hoof	B	P
Fetlock height right	+	0.045
Third metacarpal length left	-	0.001
Third metacarpal length right	+	0.001
Elbow height left	-	0.001
Elbow height right	+	0.007

TABLE 3: Significant explanatory variables for right hoof spread where a positive B value indicates an increase in the variable concurrent to right hoof spread and a negative B value indicates a decrease in the variable as right hoof spread increases

Right hoof	B	P
Fetlock height right	+	0.003
Elbow height left	-	0.02
Point of shoulder right	+	0.023

TABLE 4: Summary statistics for asymmetry data, identifying mean, minimum and maximum differences for non-directional data. Directional mean and percentage distribution of left and right for each trait is also shown as well as a percentage value for individuals with no difference between left and right measurements (0%). Heel height, third metacarpal length and point of shoulder showed significance at the level indicated; the remaining traits showed no significance (ns)

	Mean diff	Min diff	Max diff	Directional mean	% Left	% Right	0%	P
Hoof width bottom	4.28	0.00	28.00	-1.14	50.00	44.12	5.88	ns
Hoof width top	2.72	0.33	23.67	0.40	47.06	52.94	0.00	ns
Hoof spread	6.01	0.00	6.00	-1.54	58.82	35.29	5.88	ns
Heel height	4.57	0.33	14.00	2.59	23.53	76.47	0.00	<0.01
Toe height	3.18	0.33	10.00	-1.04	64.71	35.29	0.00	ns
Fetlock height	5.98	0.00	28.33	-0.08	47.06	47.06	5.88	ns
Third metacarpal length	3.14	0.00	12.33	1.80	23.53	67.65	8.82	<0.01
Carpal height	9.53	0.00	22.00	-0.20	36.67	60.00	3.33	ns
Elbow height	10.22	1.00	36.00	3.40	43.33	56.67	0.00	ns
Point of shoulder	12.12	0.67	38.00	3.41	30.00	70.00	0.00	<0.05
Scapular height	10.16	0.00	37.00	-0.78	46.67	50.00	3.33	ns

Asymmetry

A high frequency of asymmetry was found. In the 358 pairs of measurements taken only 11 instances demonstrated no difference between the left and right measurements. As demonstrated in Table 4, point of shoulder height showed the greatest absolute asymmetry with an asymmetry index mean of 12.12 mm (range 0.67–38 mm) while hoof width top showed the smallest amount of absolute asymmetry with a mean of 2.72 mm (range 0.33–23.67 mm). Table 4 also shows the distribution of each trait and whether this difference between left or right was significant. All 3 significant traits showed a directional bias to the right.

The difference between the number of horses larger to the left or to the right was found to be significant for point of shoulder height ($\chi^2 = 4.8$, d.f. = 1, $P<0.05$), and highly significant for heel height ($\chi^2 = 9.53$, d.f. = 1, $P<0.01$) and third metacarpal length ($\chi^2 = 7.26$, d.f. = 1, $P<0.01$).

Discussion

This study is the first report in which the relationships between skeletal and hoof measurements in the forelimb have been examined. The significant relationship identified between measurements of hoof spread and skeletal limb measurements is of interest because of the implications on health and performance.

For both third metacarpal length and elbow height, hoof spread increased as measurements on the left decreased and measurements on the right increased, suggesting that a shorter limb will demonstrate greater hoof spread. Previous studies have shown that the hoof with the lower angle is the hoof subjected to the highest load (Moleman *et al.* 2006). Hoof angle was not measured in this study as hoof spread was used as the main parameter. Visual observations during the current study suggest that low hoof angles tend to be associated with increased spread of the hoof wall. More upright hooves, with a higher angle tended, to show less spread and be more ‘boxy’; further research is required to confirm these observational findings. If low hoof angle is associated with increased hoof spread this would then suggest that the hoof with the largest spread would be subjected to the highest loading. These findings indicate that the shorter limb will be subjected to higher loading, potentially through increased concussive forces. Further data analysis is required to confirm whether these limbs are actually shorter, or whether other segments within the limb are compensating for the differences.

The relationship involving the right hoof appeared less clear with hoof spread increasing as right fetlock height increased, left elbow height decreased and right point of shoulder height increased. Findings did not support those for the left hoof, as the longer limb showed greater spread. The underlying cause of the differences between the left and right hoof are unclear, the relationship between skeletal and hoof measurements is likely to be complicated. A total of 59% of horses showed more hoof spread to the left which may also have skewed the results.

Interestingly, it was noted at the time that the horses who had the most difficulty in standing square often had greater asymmetry compared to those who naturally stood more evenly. This observation supports findings by van Heel *et al.* (2006) who found that foals who developed a preference to protract the same limb whilst grazing developed more asymmetric feet than foals who did not develop a preference.

Interpreting the causal effects between significant morphometric relationships needs to be approached with some degree of caution. However, the key advantage of generalised linear modelling over bivariate approaches (e.g. correlation and regression), is that it allows covariance between explanatory variables to be controlled for in a single analysis. For morphometric studies this is necessary, because of the potential causal associations between structural and asymmetry measurements. Other factors that may also have a confounding affect (e.g. an individual’s motor pattern, pain, shoeing history, level of training and rider), were beyond the scope of the present study but are worthy of future investigation.

Asymmetry is obviously present in horses. Understanding the effect of asymmetry on soundness and movement is vital in keeping individuals healthy. Today’s equine athletes work very close to the limit in terms of the capability of some structures, and any deviations from the perfect conformation can contribute to the breakdown of these structures. As yet the long-term effects of asymmetry are unknown, as is the amount of asymmetry needed to cause pathology.

Acknowledgements

The authors would like to thank all the yard staff in the Hartpury College Equine Centre for their assistance.

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