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Variation in conformation in a cohort of National Hunt racehorses

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Summary

Reasons for performing the study: **Assessment of conformation is commonly used in the selection of horses for performance purposes. Little information is available on the normal range of conformational traits within the Thoroughbred population.**

Objectives: **To describe variations in conformation in a cohort of racing Thoroughbreds in order to provide a set of baseline standards within which conformational traits can be considered normal.**

Materials and methods: **Ninety-eight conformational parameters were measured in a cohort of 108 National Hunt racehorses using a digital motion analysis system. The measurements consisted of segment lengths, joint angles in 2D and 3D, inclinations, deviations and circumference measurements. The differences between left and right sides were determined to obtain a measure of asymmetry. Conformational parameters were related to each horse's country of origin, preferred race distance and race type.**

Results: **The majority of parameters followed a normal distribution with the biggest relative variation in hoof related measurements and in stifle and coxal angle. All circumference measurements and the majority of the length measurements were significantly correlated with the height of the horse at the withers. No underlying pattern of combinations of conformational parameters was identified. Twenty-five per cent of the parameters showed a significant difference between left and right-sided measurements. A significant difference in girth and intermandibular width was observed between Irish and French horses.**

Conclusions: **Thoroughbreds differ from other breeds, not only with regard to segment lengths but also with regard to joint angles and deviations. Variation in conformational parameters was relatively small and no distinct pattern of combinations of conformational traits identified.**

Clinical relevance: **The variation in conformational measurements in Thoroughbred racehorses establishes a set of baseline measurements of conformational range against which individual horses can be assessed.**

Introduction

It is common practice to select horses for racing and other performance pursuits based on their conformation, but there is little scientifically validated information available on the conformation of the mature Thoroughbred racehorse.

Whereas there is extensive information available on variation in conformation within populations of Standardbreds and Warmbloods, studies in Thoroughbreds have so far concentrated on changes in conformation with growth (Hunt *et al*. 1999; Anderson and McIlwraith 2004) or described the conformation of young animals (Mawdsley *et al*. 1996).

In this study, distribution of conformational parameters in a cohort of National Hunt racehorses was determined in relation to their country of origin, preferred racing distance and type of race.

Thoroughbred racehorses trace their ancestry to 3 foundation stallions and have been subjected to the same selection pressure for 300 years. However, local mares have been used for breeding and different types of horses have been available and favoured in different countries before the stud book was closed (Leicester 1974). We hypothesised that conformational traits such as segment lengths and joint angles follow a normal distribution within narrow ranges, but there will be significant differences in conformation between horses of different countries of origin.

Asymmetry between sides results in asymmetrical loading of anatomical structures. Horses operate within a very narrow safety margin with regard to breaking points of anatomical structures such as bones and tendons (Riemersma and Schamhardt 1985; Riemersma *et al*. 1988; Nunamaker *et al*. 1990). This is supported by a study that showed that symmetrical horses were more successful in racing (Manning and Ockenden 1994). We hypothesised that the differences between left and right sides with regard to conformational measurements would be minimal.

Anecdotally, larger-framed horses have been thought more suitable for jump racing, whereas lighter horses were supposedly better suited for flat racing. We hypothesised that National Hunt store horses are taller at the withers and have a longer neck and back and a bigger chest circumference compared to flat racehorses.

A chase employs higher and more rigid jumps than a hurdle race. In the racing industry it is commonly believed that hurdlers should be shorter and smaller than steeplechasers. We tested whether this can be identified in our cohort.

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Long distance human runners are skinny and lightweight, while sprinters are of stockier build (Martin *et al.* 1990; Spenst *et al.* 1993). This certainly holds true if Thoroughbreds are compared to Arabs bred for long distances (Lopez-Rivero *et al.* 1992). The length of National Hunt races ranges from 16 furlongs (1 furlong is defined as an eighth of a mile, which equates to 201 m) to 32 furlongs (The Grand National at Aintree). In practice, National Hunt racehorses are categorised into '2-mile horses' or '3-mile horses' depending on their preferred distance and we tested for this in our cohort.

The objectives of this study were to determine 1) the distribution of conformational parameters and their intercorrelations, 2) the distribution of conformational parameters in relation to the horse's country of origin, 3) left and right (a) symmetry, 4) the difference in conformation between National Hunt store and flat racehorses, 5) difference in conformation between hurdlers and steeplechasers; and 6) the difference in racehorses used for short and long distance performance.

Materials and methods

Data collection

Three-dimensional conformation measurements were collected from 108 National Hunt racehorses using a passive motion analysis system (ProReflex MCU 500)[1] as described by Weller *et al.* (2006). In addition, measurements by hand with a tape were obtained as to the intermandibular width, at its widest part, girth behind the elbow and circumferences around the cranial neck, base of the neck, mid-radius, mid-metacarpus, mid-pastern, mid-tibia, mid-metatarsus, mid-pastern and around the front and hind hoof.

The ratio between height of the hoof dorsally and height of the heels was calculated as a measure of collapsed heels (Eliashar *et al.* 2004). Racing data, country of origin, date of birth, preferred distance and type of race were recorded from the Racing Post website (www.racingpost.co.uk) on April 1st 2005. Horses that had started in jump races only were included in the National Hunt store group and all horses that had starts in flat races were included in the flat racehorse group. Categorisation of horses into steeplechasers and hurdlers and 2 mile (3.22 km) versus 3 mile (4.83 km) preferred race distance was based on the horses' last 5 races. Only horses that had raced more than 10 times in the UK were included into this categorisation. While there are many horses that specialise in hurdle races only, it is common practice in National Hunt racing for steeplechasers to start their career in hurdle races before changing to chasing as their career advances. A horse was categorised as a steeplechaser if the majority of its last 5 races were chases and as a hurdler if they were hurdle races. A horse was categorised as a 2-mile horse if the majority of its races were under and as a 3-mile horse if the majority were over 20 furlongs (4.02 km).

Data analysis

The mean, s.d., median, quartiles, skewness and kurtosis were calculated for each conformational parameter to describe the variation of each conformational trait within the study population (Table 1 www.evj.co.uk/suppinfo). To test for normality, the Kolmogorov-Smirnov statistic was performed for each conformation parameter. The relative magnitude of the spread of the length and circumference measurements in the cohort was expressed as coefficient of variation (CoV = s.d./mean). Deviations were excluded from further statistical analysis since their within-subject s.d. was found to be similar to their between-subject s.d. (Weller *et al.* 2006) and hence the repeatability of the measurements judged to be not satisfactory.

A paired *t* test (P = 0.01) was performed to compare front and hindlimbs with regard to length of the dorsal hoof wall, height of the heels, length of the digit and distal interphalangeal (dip) joint angle, hoof angle, height at the withers vs. height at the croup, metacarpophalangeal (mcp) joint vs. metatarsophalangeal (mtp) joint angle, length and circumference of the metacarpus and metatarsus.

The relationship between conformation parameters and height at the withers was evaluated using Pearson product-moment correlation coefficient (r) with the significance level set at P = 0.01. From this, the coefficient of determination (CoD = r^2 x 100) was calculated to get a measure of how much variance is shared by the variables. For interpretation of the strength of the relationship expressed as correlation coefficient the guidelines suggested by Cohen (1988) were followed: r<(-)0.29 = small, (-)0.30<r<(-)0.49 = medium, r>(-)0.5 = large. For independent length measurements (some length measurements contain other length measurements, e.g. horse length includes neck length, so a correlation would be expected), the influence of height at the withers was removed statistically by performing a partial correlation.

To identify groups among intercorrelations of the conformational parameters principal component analysis was performed. This is done by transforming the original dataset into a smaller number of linear combinations (= principal components) in a way that accounts for most of the variability within the dataset with all of the variance of the original variables being used.

To explore the impact of country of origin on conformational traits, a one-way analysis of variance with *post hoc* test was conducted and the effect size (η^2; eta squared) calculated. Interpretation of η^2 followed the guidelines set by Cohen (1988): 0.01 = small effect, 0.06 = moderate effect, 0.14 = large effect.

Left and right sides were compared by conducting a paired-samples *t* test (significance level set at P≤0.01) for each conformational parameter and the effect size was calculated as η^2.

To compare the conformation of National Hunt store vs. flat racehorses, steeplechasers vs. hurdlers and 2-mile vs. 3-mile horses, an independent-samples *t* test was performed. The significance level was set as P≤0.01. Data are presented as mean ± s.d. where relevant.

Results

The cohort in this study comprised 106 geldings and 2 mares. Age was 6.4 ± 1.6 years and a range from 4–11 years. Race histories were: never raced (n = 4), <5 races (n = 19), 5–9 races (n = 35), 10–14 races (n = 25), 15–19 races (n = 22) and >20 races (n = 39).

Distribution of conformation parameters

Figures 1–3 show the mean, maximum and minimum lengths and joint angles (Table 1 www.evj.co.uk/suppinfo). The largest s.d. for length measurements was observed in horse length and segmental hindlimb, the smallest s.d. in hoof and heel measurements. The CoV for circumference measurements was 0.03–0.07, (0.05 ± 0. 002) and for length measurements 0.02–0.28, (0.07 ± 0.006). The biggest relative spread in magnitude was found for the heel measurements (CoV = 0.23 front, 0.28 hind), hoof (CoV = 0.11 fore, 0.08 hind) and pubis measurement (CoV = 0.18). For angles the s.d. was 1.7–10°; the largest s.d. were found for the coxal angle, hip and stifle joint and hoof angles. The majority of the conformational parameters

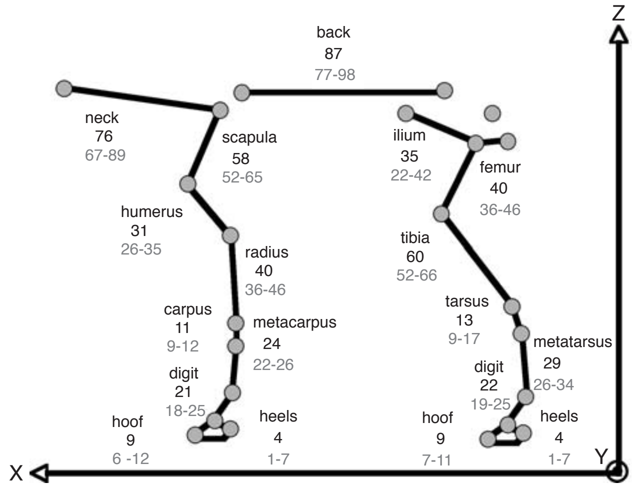

Fig 1: Stick figure of the lateral view of the left side of a horse with the mean values for selected length measurements in black and the maximum and minimum lengths in grey (in cm).

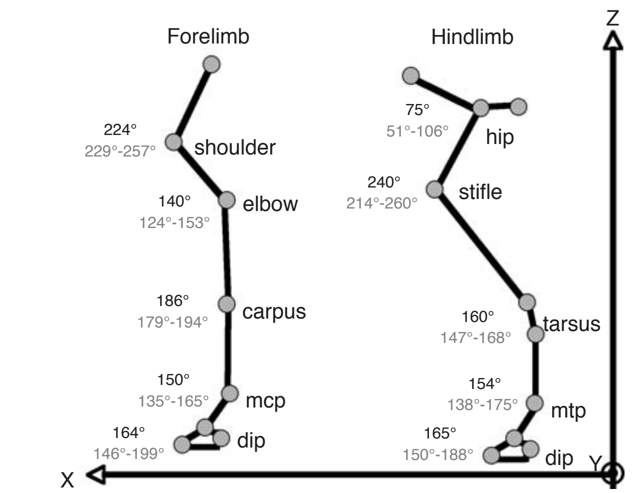

Fig 2: Stick figures of the lateral view of a front leg and hindleg of a horse with the mean lateral joint angles in black and the maximum and minimum angles in grey.

were normally distributed. Significant results of the Kolmogorov-Smirnov tests were largely due to outliers at either end of the distribution, while mean and median were almost identical for all parameters. Statistically significantly skewed distributions were found for the humerus and hoof_fore length measurements, the 3D angles of the carpal, mcp, tarsal and mtp joint. Non-normally distributed 2D angles were the lateral and cranial mcp joint, dip joint front and tarsal angles. Scapula and pelvic inclines and hoof angle fore were not normally distributed. Lateral and cranial deviations of the carpus and mcp joints, lateral deviation of the fore and hindlimb and cranial deviation of the hindlimb and the tarsus were not normally distributed. All circumference measurements were positively skewed with the exception of girth and midpastern hind. The remaining skewed measurements were negatively skewed, except tarsus length, lateral dip joint front, cranial mcp joint angles and hoof angle in front. Extreme outliers (more than 3 times the interquartile range) were found for metacarpal and midpastern hind circumference (this horse suffered from osteoarthritis of the proximal interphalangeal joint), tarsus length, hoof angle fore and hind, tarsal joint and cranial mcp and dip fore angles.

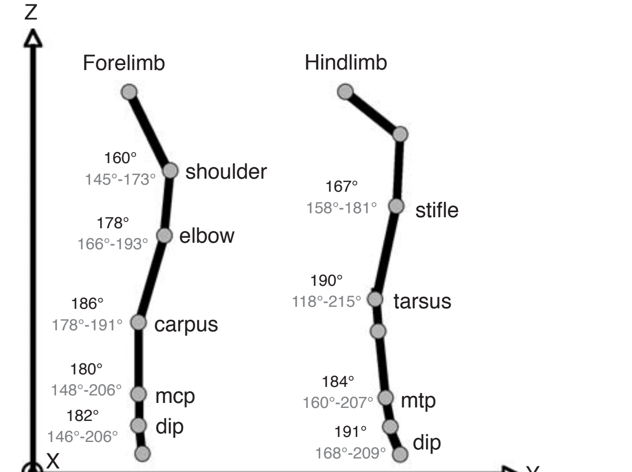

Fig 3: Stick figures of the cranial view of a front leg and hindleg of a horse with the mean cranial joint angles in black and the maximum and minimum angles in grey.

Lengths

The horses' height at withers was 162 ± 3.6 cm (range 154–173 cm). The weight was 501 ± 34 kg, (range 425–588 kg). On average horses were 0.93 cm lower at the withers than at the croup, the maximum individual difference observed was 4.6 cm taller at the croup compared to the withers and 5.4 cm taller at the withers than at the croup. However in the cohort, the height at croup did not differ significantly from the height at withers ($P<0.001$). The length of the horses was 198 ± 8 cm, range 175–224 cm. The mean ratio between length and height was 1.22, range 1.1–1.3.

There was no significant difference between metacarpal and metatarsal length and circumference, nor in the hoof related parameters ($P>0.01$), but there was a significant difference between length of digits ($P<0.001$), dip joint angles ($P = 0.009$).

Ratio between height of hoof dorsally and height of heels was calculated as a measure of collapsed heels (Eliashar *et al*. 2004). Hoof dorsally was 2.5 ± 0.7 x heels in the front limb and 2.5 ± 1.00 x in the hind, minimum ratio was 1.2 in front and 1.3 in hind and maximum ratio 6.1 in front and 8.3 in the hindlimb. Seven horses showed a ratio above 4 in the front limb and 8 showed a ratio above 4 in the hindlimb, suggesting collapsed heels, consistent with the results of the clinical examination in 14 of those horses.

Angles

Carpal angle viewed from cranial was 186 ± 1.8° (range 178–191°), i.e. the majority of horses had a carpus valgus deformation and only 3 horses with a low-grade carpus varus were observed. Angle of the tarsal joint as viewed from caudal was 190 ± 2.85° (range 180–215°), i.e. the majority of horses had a tarsus valgus

TABLE 1: Variation of conformational parameters in a cohort of National Hunt racehorses: mean, s.d., maximum, minimum, skewness and kurtosis. The skewness value indicates the symmetry, the kurtosis value the 'peakedness' of the distribution. Positive skewness values indicate scores clustered at the low values, positive kurtosis values indicate that the distribution is peaked (clustered in the centre). For not-normally distributed conformational parameters (Kolgomorov-Smirnov test P<0.5), the median and the interquartile range are displayed. Lengths in cm, joint angles, inclines and deviations in degrees

Refer to www.evj.co.uk/suppinfo for details.

deformation and none a tarsus varus deformation. Cranial mcp joint angle was 180 ± 6.4° (range 148–206°). Maximal and minimal cranial mcp angles were extreme outliers and if disregarded the range was 165–194°. The distribution for the cranial mcp joint angle was slightly skewed to the left; more horses therefore had valgus than a varus conformation.

Deviation of the front leg from the sagittal plane (resembling a view from cranial) was 180 ± 2.9° (range 167–190°). Deviation of the hind leg from the sagittal plane (resembling a view from caudal) was 180 ± 2.34° (range 173–187°). The alignment of the whole leg is achieved in the individual horse by the combination of joint configurations, but also depends on the length of the segments. In the front leg the cranial elbow joint showed a strong negative correlation with the cranial shoulder and the cranial carpal joint (r = -0.67 and -0.57 respectively) and the cranial mcp joint a weak correlation with the dip joint. In the hind leg the cranial stifle joint was negatively correlated to the cranial coxal joint (r = -0.59), the cranial tarsal joint (r = -0.36) and the cranial mtp joint (r = -0.32), whereas the cranial dip joint was negatively correlated to the cranial mtp joint (r = -0.49) and the tarsus (r = -0.20).

Angle of the carpal joint viewed from lateral was 186 ± 3° (range 179 to 194°), i.e. the majority of the horses were thus 'back at the knee'. Lateral angle of the tarsal joint was 160 ± 4° (range 147–168°) with the distribution skewed to the left. Lateral angle of the mcp joint was 150 ± 4.7° (range 135–165°), the lateral angle of the mtp joint was 154 ± 5.3° steeper on average (range 138°–175°). The distributions of both measurements were slightly skewed to the left. The lateral dip joint angle was 164 ± 8.77° (146°–199°) and 165 ± 6.6° (150–188°) for the front and hind legs respectively. This indicates a broken back hoof-pastern axis in the majority of horses.

Correlations

All circumference measurements and the majority of length measurements were significantly correlated with height at the withers. Only positive correlations between conformation parameters and height at the withers were observed. None of the joint angles, inclines or deviations showed a significant correlation with height at the withers. A strong correlation (r>0.5) with height at the withers was observed for croup height, back length, horse length, trunk height, forelimb, segmental forelimb, scapula, radius, croup height, hindlimb, pelvis length, girth, metacarpus circumference and hoof circumference. Moderate correlation (0.30<r<0.49) was observed for the remaining circumference measurements (with the exception of neck and midradius), neck length, metacarpus, pelvis height, croup length, ilium. Length measurements not correlated to height at the withers were humerus, digits and heels front and hind, carpus, tarsus, pubis and intermandibular width.

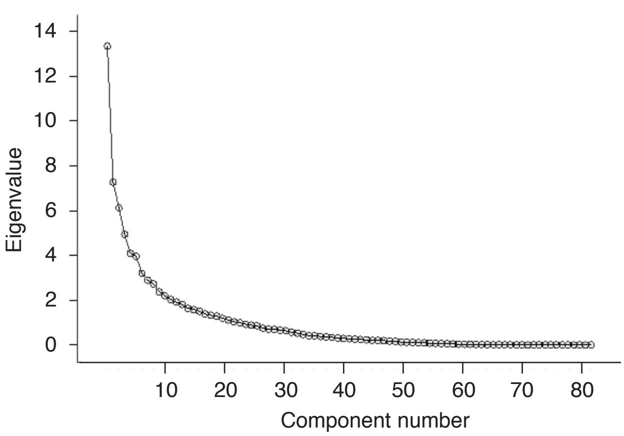

Fig 4: Results of principal component analysis: the scree plot shows the Eigenvalue for each component, which indicates how much variation in the data is accounted for by this component. In this graph there is no clear break between components, but a gradual curve, implying that a horse's conformation is not determined by a few single underlying components, but is the result of the sum of small effects of all the components.

TABLE 2: Conformation parameters that correlate significantly after controlling for height at the withers

Parameters	r	CoD
Lengths		
Radius - trunk height	-0.55	30.25
Humerus - radius	-0.45	20.25
Pelvis length - trunk length	-0.32	10.24
Front digit - hind digit	+0.90	80.10
Trunk length - segmental forelimb	+0.35	12.25
Trunk height - scapula	+0.42	17.64
Metacarpus - metatarsus	+0.32	10.24
Femur - ilium	+0.33	10.89
Front hoof - hind hoof	+0.45	20.25
Angles		
Shoulder - elbow joint	+0.55	30.25
Stifle joint - hip	+0.51	26.01
Elbow - carpal joint	+0.36	12.96
Hip - femur incline	-0.75	56.25
Mcp - dip joint front	-0.46	21.16
Mtp - dip joint hind	-0.47	22.09
Mtp - tarsal joint	-0.39	15.21
Lengths - angles		
Stifle joint - tibia length	+0.67	44.89
Stifle joint - femur length	-0.45	20.25
Mtp joint - femur length	-0.32	10.24

r = Pearson product-moment correlation coefficient; CoD = coefficient of determination.

For conformation parameters that show a significant correlation after controlling for height at the withers see Table 2. All pairs of negatively correlated parameters and some of the positively correlated pairs share one of the markers (e.g. the distal humerus marker is the same as the proximal radius marker), hence these measurements are not independent and their correlations are largely influenced by marker placement.

Three dimensional joint angles and joint angles as viewed from lateral all showed a strong correlation (r>0.88), as did the conformation measurements form the left and right side, with the exception of heel height and pastern circumference.

Results of principal component analysis

Principal component analysis revealed the presence of 23 components with Eigenvalues exceeding one, explaining 83% of the variance. An inspection of the screeplot (Fig 4) revealed no clear break in the curve, but a gradual curve with the middle of the bend at component 10, explaining 60% of the variance at this level. Component 1 was mainly loaded by length and circumference measurements (the only length measurements not contributing to component 1 were carpus, tarsus, metatarsus, humerus and heel hind). Component 2 was mainly loaded by proximal joint angles (shoulder, elbow, carpus, hip, stifle and tarsus).

The results of the principal component analysis indicate that the variation in horses cannot be explained by a few underlying components, but is due to complex interaction of all conformational parameters.

Left and right asymmetry

The following segment lengths showed asymmetry between left and right sides (P<0.01): radius, heel front, ilium, pubis, tibia and heel hind. Significantly different 3D angles were elbow, dip joint front and hind, hoof fore, and coxal angles. Lateral 2D angles that differed significantly between left and right were dip joint fore and hind, and hoof angle fore. Cranial 2D angles that differed between left and right were carpus, mcp joint, mtp joint and hoof angle fore. Significantly different inclines were found for the scapula, humerus and croup. Significantly different circumference measurements were found for left and right mid metacarpus and mid pastern hind.

A large effect size ($\eta^2>0.14$) was observed for heel front, dip joint front and hind in 3D and 2D as seen from the lateral aspect, mcp and mtp joint as seen from the cranial aspect, croup incline and height. A moderate effect size ($0.06<\eta^2<0.13$) was seen in the rest of the asymmetrical parameters.

Impact of country of origin on conformation

The majority of horses in the study cohort were bred in Ireland (n = 54 horses), followed by UK (n = 28) and France (n = 18). There were also 4 horses from the USA, and one each from Italy, New Zealand, Japan and Germany, which were not included in the statistical analysis due to the small group sizes.

A significant difference was found between Irish and French bred horses with regard to intermandibular width (P = 0.003, 99% confidence interval 0.92–5.43) and girth (P = 0.007, 99% confidence interval 0.32–1.41). The effect was moderate for girth ($\eta^2 = 0.06$) and large for intermandibular width ($\eta^2 = 0.08$). The French bred horses had a lower girth measurement on average compared to the Irish horses (186 compared to 189 cm) and a smaller intermandibular width (11.5 compared to 12.5 cm). While there were no significant differences between British horses and Irish or French horses, in all parameters the mean differences between British and Irish horses were smaller than those between British and French bred horses.

National Hunt store vs. flat racehorses

Within the study cohort 4 horses did not race between October 2003 and April 2004, one horse started in flat races only, 63 horses started in jump races only and 40 horses started in both flat races and jump races. The majority of horses that started in both jump and flat races had started their career in flat racing and moved on to jump racing; 4 of the horses however were dual-purpose horses alternating between jump and flat racing.

A significant difference between flat racehorses and National Hunt store horses was found for neck length, forelimb length, pelvis length, tibia circumference, front and hind hoof circumference. National Hunt store horses had the bigger average values for all of these measurements compared to the flat horses. The effect size was large for front and hind hoof and moderate for the rest of the significant conformation parameters. P values, confidence intervals and η^2 for each conformation parameter and group are in Table 3.

TABLE 3: Conformation parameters for which there was a significant difference between National Hunt store and flat racehorses

Conformation parameter	P value	99% confidence intervals (cm) lower	upper	η^2
Hoof circumference_fore	0.00	1.38	2.97	0.24
Tibia circumference	0.01	0.22	1.47	0.07
Hoof circumference hind	0.00	1.27	2.81	0.22
Neck length	0.01	0.78	4.63	0.08
Horse length	0.00	2.12	8.55	0.10
Forelimb length	0.01	0.52	3.19	0.07
Digit length_fore	0.01	0.17	1.16	0.07
Pelvis length	0.00	0.52	2.80	0.08

Hurdlers vs. Steeplechasers

Fifty-six horses within the cohort had 10 or more starts in jump races with 13 classified as hurdlers and 43 as steeplechasers. None of the conformation parameters differed significantly ($P\leq0.01$) between the 2 groups.

Influence of preferred distance: 2-mile vs. 3-mile horses

Of the 56 horses that had raced more than 10 times, 25 were classified as 3-mile horses and 14 as 2-mile horses. None of the conformation parameters showed a significant difference between the 2 groups.

Discussion

The variation in conformational traits was smaller (CoV = 0.4 ± 0.5) than reported previously in a cohort of young flat racehorses (Mawdsley *et al.* 1996). Although comparability of the studies is limited due to the different evaluation systems used, 2 possible explanations can be suggested. Different growth rates in adolescent horses may account for the greater variation shown in Mawdsley's study on horses age 2 and 3 years. Alternatively, it could be suggested that horses at the extremes of the normal range do not continue to race.

In this study, mean deviation of front and hindleg from the sagittal plane was 0° with s.d. below 3°. These results differ from findings in Standardbred trotters, in which most horses show an outward rotation of the frontlimb and from Standardbred trotters, Warmbloods and Thoroughbreds in which the majority of horses were found to have an outward deviation of the hindlimb (Magnusson 1985; Holmström *et al.* 1990; Mawdsley *et al.* 1996). This could be due to the fact that deviation measurements vary with the stance of the horse and are influenced by the choice of marker location as well as operator error during marker placement (Weller *et al.* 2006). However, it might also reflect the fact that all horses in this study were over 5-years-old and had already started their racing career. It is possible that a straight limb is a prerequisite to withstand the rigorous demands of training and racing and that horses that are not able to cope had already been selected out. The combination of joint configurations and segment lengths to achieve a straight limb are endless and complex, with the only limitations being the maximum and minimum cranial angle each joint can adopt.

The average horse showed a *carpus valgus* deformation of 5°. Correction of *carpus valgus* is a common surgical procedure performed in foals and it aims to create a straight carpus (Parente 2003). The results of this study suggest that a *carpus valgus* of 5° is normal and does not seem to stop horses pursuing a racing career, it may however impair their racing performance. Most horses were 'back at the knee' to some degree. This should therefore be considered 'normal' for the racehorse rather than a serious conformational fault, predisposing these horses to lameness.

The differences observed in hind pastern circumferences may be due to early unilateral osteoarthritis in the proximal interphalangeal joint (high ring bone). Eight horses in the cohort had palpable new bone formation, all but one bilaterally, leading to similar circumference measurements between left and right. In 5 of these horses degenerative joint disease was diagnosed based on radiographic finding.

The findings of others (Magnusson 1985; Anderson *et al.* 2005) that all long bone measurements are moderately correlated with height at the withers was consistent with the findings in this study, with 2 exceptions. Metacarpal and metatarsal length did not show a significant correlation with wither height at all in this study.

The Thoroughbreds in this study were longer than the trotters in which the body lengths equalled the height at the withers (Magnusson 1985). There was no significant difference between hoof angle and length between front and hind, as stated in most of the commonly used anatomical textbooks (Dyce *et al*. 1987). This finding may be influenced by the farriery technique; a radiological study would be needed to investigate this further.

The results of the principal component analysis showed that a horse's conformation cannot be described by a few components only, but is the sum of all conformational traits without distinct patterns of correlations. While one or more parameters might be out of the norm, this does not appear to compromise the ability of the horse to remain in racing.

Twenty-seven conformational traits showed a significant difference between left and right, of which 6 were hoof and heel measurements. These particular differences could be caused by asymmetrical loading and/or farriery. Asymmetry of segment lengths are commonly seen in man (Krawiec *et al*. 2003) and have been reported in horses (Manning and Ockenden 1994; Watson *et al*. 2003). Differences in joint angles and deviations might more reflect the asymmetrical stance of the horse than true asymmetry, due to the stance dependency of those measurements.

British, Irish and French horses did not show significant differences in the majority of conformational parameters with the exception of girth and intermandibular width. With the advent of easy air and sea travel, breeding of Thoroughbreds is an international industry and mares are sent to different countries to be mated and stallions are shipped worldwide. Differences in girth and intermandibular width might reflect the preference of French breeders for more elegant horses.

National Hunt horses were larger framed horses than flat racehorses, which may be the effect of the widespread opinion that bigger horses are more successful in jump racing.

Contrary to popular belief, no significant difference was found between steeplechasers and hurdlers and 2-mile and 3-mile horses. The categorisation of the horses was based on the number of starts in each category. The choice of race for each horse lies with the trainer and must, therefore, be influenced by factors beyond the horse's conformation.

In conclusion, tables showing the normal range of values for a wide range of conformational parameters have been produced. Some conformational parameters were more variable than others though the horses in the cohort were very similar in their appearance. However no distinct patterns of combinations of conformational parameters were identified.

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Manufacturer's address

[1]Qualisys Medical AB, Gothenburg, Sweden.

References

Anderson, T.M. and McIlwraith, C.W. (2004) Longitudinal development of equine conformation from weanling to age 3 years in the Thoroughbred. *Equine vet. J.* **36**, 563-570.

Anderson, T.M., McIlwraith, C.W. and Douay, P. (2005) The role of conformation in musculoskeletal problems in the racing Thoroughbred. *Equine vet. J.* **36**, 571-575.

Cohen, J.W. (1988) *Statistical Power Analysis for the Behavioural Sciences*. 2nd edn., Hillsdale, New York. pp 51-52.

Dyce, K.M., Sack, W.O. and Wensing, C.J.G. (1987) The forelimb of the horse. In: *Textbook of Veterinary Anatomy*, W.B. Saunders Co., Philadelphia. pp 542-575.

Eliashar, E., McGuigan, M.P. and Wilson, A.M. (2004) Relationship of foot conformation and force applied to the navicular bone of sound horses at the trot. *Equine vet. J.* **36**, 431-435.

Holmström, M., Magnusson, L.-E. and Philipsson, J. (1990) Variation in conformation of Swedish Warmblood horses and conformational characteristics of elite sport horses. *Equine vet. J.* **22**, 186-193.

Hunt, W.F., Thomas, V.G. and Stiefel, W. (1999) Analysis of video-recorded images to determine linear and angular dimensions in the growing horse. *Equine vet. J.* **31**, 402-410.

Krawiec, C.J., Denegar, C.R., Hertel, J., Salvaterra, G.F. and Buckley, W.E. (2003) Static innominate asymmetry and leg length discrepancy in asymptomatic collegiate athletes. *Manual Therapy* **8**, 207-213.

Leicester, C. (1974). *Bloodstock Breeding*, J.A. Allen & Co., London. pp 17-28.

Lopez-Rivero, J.L., Serrano, A.L., Diz, A.M. and Galisteo, A.M. (1992) Variability of muscle fibre composition and fibre size in the horse gluteus medius: an enzyme-histochemical and morphometric study. *J. Anat.* **181**, 1-10.

Magnusson, L.-E. (1985) *Studies on the Conformation and Related Traits of Standardbred Trotters in Sweden*. PhD thesis, Swedish University of Agricultural Sciences, Skara.

Manning, J.T. and Ockenden, L. (1994) Fluctuating asymmetry in racehorses. *Nature* **370**, 185-186

Martin, A.D., Spenst, L.F., Drinkwater, D.T. and Clarys, J.P. (1990) Anthropometric estimation of muscle mass in men. *Med. Sci. Sports Exerc.* **22**, 729-733.

Mawdsley, A., Kelly, E.P., Smith, F.H. and Brophy, P.O. (1996) Linear assessment of the Thoroughbred horse: an approach to conformation evaluation. *Equine vet. J.* **28**, 461-467.

Nunamaker, D.M., Butterweck, D.M. and Provost, M.T. (1990) Fatigue fractures in thoroughbred racehorses: relationship with age, peak bone strain, and training. *J. orthop. Res.* **8**, 604-11.

Parente, E.J. (2003) Angular limb deformities. In: *Diagnosis and Management of Lameness in the Horse*, Eds: S.J. Dyson and M.W. Ross, W.B. Saunders Co., Philadelphia. pp 557-558.

Riemersma, D.J. and Schamhardt, H.C. (1985) *In vitro* mechanical properties of equine tendons in relation to cross-sectional area and collagen content. *Res. vet. Sci.* **39**, 263-70.

Riemersma D.J., Schamhardt, H.C., Hartman, W. and Lammertink, J.L. (1988) Kinetics and kinematics of the equine hindlimb: *in vivo* tendon loads and force plate measurement in ponies. *Am. J. vet. Res.* **49**, 1344-52

Spenst, L.F., Martin, A.D. and Drinkwater, D.T. (1993) Muscle mass of competitive male athletes. *J. Sports Sci.* **11**, 3-8.

Watson, K.M., Stitson, D.J. and Davies, H.M.S. (2003) Third metacarpal bone length and skeletal asymmetry in the Thoroughbred racehorse. *Equine vet. J.* **35**, 712-714.

Weller, R., Pfau, T., Babbage, D., Brittin, E., May, S.A. and Wilson, A.M. (2006) Reliability of conformational measurements in the horse using a three-dimensional motion analysis system, *Equine vet. J.* **38**, 610-615.

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