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The effect of conformation on orthopaedic health and performance in a cohort of National Hunt racehorses: preliminary results

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Keywords: horse; conformation; performance; tendonitis; fracture

Summary

Reasons for performing study: **There is a lack of scientific data and studies on the effect of conformation on performance or on orthopaedic health.**

Objectives: **To investigate the relationship between conformation, injury and performance in racehorses used for racing over fences.**

Methods: **Over 2 years, 108 National Hunt racehorses were followed and their medical and performance data recorded. Conformation was measured in 3D with a computerised motion analysis system. Linear multiple regression models were used to evaluate the effect of conformation on measures of race performance and stepwise forward logistic regression models to assess the effect on risk of injury.**

Results: **An increase in intermandibular width, flexor angle of the shoulder joint and coxal angle (the angle between the ilium and ischium) was demonstrated to have a positive effect on performance. Performance decreased with increasing girth, length of the hind digit and valgus conformation of the metacarpophalangeal joint. The risk of suffering from superficial digital flexor tendon injury increased with increasing metacarpophalangeal joint angle and with carpus valgus conformation. The risk of pelvic fracture increased with valgus conformation of the tarsus and decreased with an increasing coxal angle.**

Conclusion: **Valgus deformation was demonstrated to be detrimental to performance or increased risk of injury, perhaps resulting in higher loads on musculoskeletal structures. The coxal angle was the only parameter to have an effect on both risk of injury and performance. An alignment of the muscles with the axis of the pelvis may be beneficial for force transmission and decrease the bending moment of the muscles on the bones. The statistical power of this study is limited, however it provides preliminary data necessary for the planning of a larger scale study on the effect of conformation on performance and risk of injury.**

Clinical relevance: **Studies of the effects of conformation on performance and risk of injury may aid in identifying individuals likely to perform well on the racecourse and avoid risks of injury.**

Introduction

Horse racing today is a multibillion pound industry with the Thoroughbred racehorse at its centre. Selective breeding for speed has produced a performance horse whose phenotype is homogenous and allows for only small variation within conformational traits (Weller *et al*. 2006a,b). While many anatomical adaptations, such as a light distal limb, are beneficial for high-speed locomotion in the horse, they may compromise the structural stability of the musculoskeletal system therefore causing it to operate within narrow safety margins (Alexander 1981, 1993). Competitive individuals increase speed, which results in an increase in stresses experienced by the components of the musculoskeletal system (Biewener *et al*. 1983; Biewener 1998), and could potentially result in more injuries.

Reports on conformation of the racing Thoroughbred have concerned either the effects on performance (Delahunty *et al*. 1991) or on orthopaedic health (Anderson *et al*. 2005). Delahunty *et al. (*1991) compared intermandibular (IM) width and cannon bone length of 2-year-old racehorses classified as 'winners' and 'nonwinners' and found that 'winners' had wider IM width and longer cannon bones. Anderson *et al*. (2005) identified several conformation parameters associated with the risk of sustaining a fracture and suffering from joint effusion in the racing Thoroughbred.

The aim of the present study was to investigate the relationship between conformation, injury and performance in National Hunt racehorses. We hypothesised that there is a relationship between conformation and performance, between conformation and injury and performance is related to risk of injury.

Materials and methods

A cohort of 108 horses from a single National Hunt racing yard (106 geldings, 2 mares, mean ± age 6.4 ± 1.6 years) was followed from October 1st 2003 to April 30th 2005. Three-dimensional assessment of conformation (Fig 1) was performed at the beginning of the study with a computerised motion analysis system (ProReflex MCU 500, Qualysis)[1] after marking of 28 bony landmarks per side as described by Weller *et al*. (2006a). Lengths and angles were calculated using a custom-written program within the software package Matlab (The

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Mathworks)[2]. Joint angles were calculated in 2D in the x,z plane (resembling a view from the lateral aspect) and in the y,z plane (resembling a view from the cranial aspect). The ratio between the height of the hoof dorsally and the height of the heels was calculated as a measure of collapsed heels (Eliashar *et al*. 2004).

The IM width at its widest part, girth behind the elbow and circumferences around the origin and base of the neck, mid-radius, mid-metacarpus, midpastern, mid-tibia, mid-metatarsus and around the front and hind hoof were measured by hand with a flexible tape measure. The middle of each segment was determined by measuring the distance between the markers determining the segment with a tape measure and marking the middle of it with a paper dot. The weight of the horses was recorded at the beginning of the study with a weighbridge. To avoid multicolinearity the correlation between each of the independent variables was calculated and if 2 variables showed a bivariate correlation (r) of 0.7 or more, one of these was omitted (Tabachnik and Fidell 1996). Therefore, for example only the measurements of the left side were used since all conformational parameters showed a strong correlation between left and right sides (with the exception of heel height and pastern circumference), and all parameters that correlated strongly with height at the withers were omitted as well as 3D angles since these correlated strongly with the joint angles viewed from lateral (Weller *et al*. 2006b). Deviations were also not included in the statistical analysis since these were found to have a low repeatability (Weller *et al*. 2006a).

All horses were palpated for signs of musculoskeletal injury at the beginning of the project by an experienced equine clinician (R.W.). Medical records were obtained from the veterinarian in charge and from stable records. Performance data were gained from the Racing Post website (www.racingpost.co.uk): number of starts, life-time earnings, maximum British Horseracing Board Official Rating (OR_{max}), maximum Racing Post Rating (RPR_{max}), maximum top speed rating (TS_{max}) and number of placings.

Statistical analysis

Performance: To investigate the effect of conformation on performance, linear multiple regression was performed for each dependent variable (life-time earnings, number of races placed, OR_{max}, TS_{max} and RPR_{max}). The adjusted r^2 value indicates how much variance in the dependent parameter is explained by the model. The standardised coefficient (B) denotes the contribution of each of the independent parameters to the model after the parameters have been converted to the same scale. The parameter 'injury' was included as independent parameter to the models.

Musculoskeletal injury: The effect of conformational parameters on injury was evaluated by performing a stepwise forward logistic regression. Only diagnoses or palpatory findings with 5 or more cases were included in the statistical analysis. A separate regression model was then built for each condition. To estimate the relative risk of sustaining a musculoskeletal injury the odds ratio was calculated for each independent parameter that contributed significantly to the model. The probability to enter was set at $P = 0.05$ and to remove at $P = 0.10$ for all models.

To control statistically for the possible effect of age and number of starts, these independent parameters were included into the equation as they stood at the endpoint of the study.

To avoid multicolinearity, the correlation between each of the independent variables was calculated and if 2 variables showed a bivariate correlation of 0.7 or more, one of these was omitted (Tabachnik and Fidell 1996). Therefore, only the measurements of the left side were used since all conformational parameters showed a strong correlation between left and right sides (Weller *et al*. 2006b).

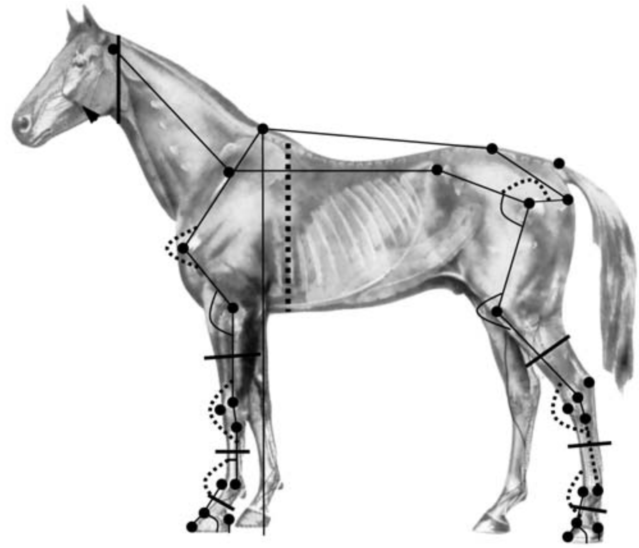

Fig 1: Schematic drawing of a horse with marker positions, segment lengths, joint angles and circumference measurements (bold lines) used in this study. Conformational parameters that contributed significantly to the regression models for performance or musculoskeletal injury are dotted lines (drawing modified after Seiferle 1952).

The relationship between injury and performance was investigated by including the number of races placed as an independent parameter in the regression models. A general parameter 'injury' was created, that contained all injuries and clinical findings. This parameter was added as independent parameter to the performance models. Data analysis was performed using SPSS, version 13[3].

Results

Performance

Outcome: During the study period 4 horses had never raced, 10 horses raced <5 times, 24 horses 5–9 times, 36 horses 10–20 times and 34 horses >20 times. Only horses that had raced were included in the data analysis.

Mean OR_{max} was 106 (± 43, max 173), average RPR_{max} was 96 (± 29, max 177), the average TS_{max} was 116 (± 29, max 177). Performance ratings followed a normal distribution if horses that had no rating were disregarded.

Life-time earnings were £0–£646,240, median £25,721. Data were heavily skewed with only 6 horses earning more than £200,000 and the majority of horses having life-time earnings under £10,000.

Number of races placed was also skewed and ranged 0–39, median 9 races. Life-time earning and number of races placed was log transformed for further analysis. All performance parameters showed a moderate correlation with the total number of starts (r range 0.5–0.6, $P<0.01$) and the age of the horse (r range 0.4–0.5, $P<0.01$). After controlling for the number of starts there was a large correlation between OR_{max}, TS_{max} and RPR_{max} (r range 0.63–0.70, $P<0.01$).

Effect of conformation on performance: The results of the multivariable linear regression models are summarised in Table 1.

All performance parameters increased with the number of starts. An increase in IM width was associated with an increase in life-time earnings and number of races placed and an increase in the lateral coxal angle with an increase in the OR_{max}. The remaining parameters that contributed significantly to any of the performance models were shoulder joint angle (measured as the angle on the extensor side of the joint), metacarpophalangeal (MCP) joint angle as seen from the cranial aspect (measured on the medial side of the joint), girth and length of the hind digit (Fig 1). An increase in these parameters resulted in a decrease in the respective performance parameters (Table 1).

Number of races placed: The following independent parameters contributed significantly to the regression model with 'number of races placed' as the dependent parameter: number of starts, IM width, girth, metacarpophalangeal joint angle as seen from the cranial aspect and shoulder joint angle as seen from the lateral aspect. The adjusted r^2 was 0.55, which changed to 0.65 after adding the significant conformation parameters. The change in r^2 was significant at each step.

Life-time earnings: Independent parameters that contributed significantly to the model with life-time earning as the dependent parameter included: number of starts, IM width, shoulder joint angle as seen from lateral and metacarpophalangeal joint angle as seen from cranial and hind digit length. The adjusted r^2 was 0.40 with number of starts included in the model, adding IM width, digit hind, shoulder and metacarpophalangeal joint angles as seen from cranial resulted in a significant change in r^2 at each step, resulting in an overall r^2 of 0.57.

OR_{max}, TS_{max} and RPR_{max}: The number of starts contributed significantly to the 3 regression models with OR_{max}, TS_{max} and RPR_{max}, respectively, as dependent variables. After taking the effect of number of starts into account the coxal angle as seen from the lateral aspect (defined as the angle between the ilium and ischium measured dorsally) and the length of the hind digit contributed significantly to the TS_{max} model (Fig 1). The coxal angle as seen from the lateral aspect and the metatarsal joint angle as seen from the cranial aspect contributed significantly to the OR_{max} model. No conformational parameter contributed significantly to the RPR_{max} model, however the injury parameter 'forelimb injury' did. For the OR_{max} model the adjusted r^2 changed from 0.36–0.44 when taking the conformational measurements into account, for the TS_{max} model it changed from 0.45–0.49 and for the RPR_{max} from 0.38–0.41.

Musculoskeletal injury

During the study period 14 horses were retired from racing, 7 horses had died, 4 were temporarily retired at the time of the end of the study to be brought back into racing next season and 83 horses were still racing. Out of the 7 dead horses, 3 suffered a sudden death, 3 were subjected to euthanasia on the track (2 thoracolumbar fractures, one humerus fracture) and one was subjected to euthanasia due to re-occurring tendonitis.

Musculoskeletal conditions: These included, superficial digital flexor tendonitis (n = 16), pelvic fractures (n = 7), third metatarsal bone stress fracture (n = 2), upward fixation of the patella (n = 2), fractured thoracolumbar spine (n = 2), one carpal fracture, one humeral fracture and one horse with hoof problems.

Superficial digital flexor tendonitis (SDF tendonitis) as diagnosed from ultrasonographic examination occurred in 16 horses, 7 in the first season and 9 in the second season. Three

TABLE 1: Results of multivariable linear regression models evaluating the effect of conformation on performance. Parameters that contribute significantly to the respective models. The standardised coefficient B denotes the contribution of the individual parameters to the models

Dependent parameter	Independent parameter	Unstandardised coefficients	95% Confidence interval		Standardised coefficients B	P value
Number of placings	(Constant)	9.64	5.49	13.79		<0.001
	Jumpstarts	0.03	0.02	0.03	0.69	<0.001
	Girth	-0.01	-0.03	0.00	-0.16	0.05
	IM width	0.06	0.02	0.11	0.20	0.01
	Mcpjoint_cran	-0.01	-0.02	0.00	-0.18	0.01
	Shoulderjoint_lat	-0.01	-0.03	0.00	-0.17	0.02
Life-time earnings	(Constant)	21.93	14.09	29.77		<0.001
	Jumpstarts	0.04	0.02	0.05	0.03	<0.001
	IM width	0.14	0.05	0.23	0.26	<0.001
	Digit hind	-0.01	-0.02	0.00	-0.23	0.01
	Shoulderjoint_lat	-0.04	-0.06	-0.01	-0.25	<0.001
	Mcpjoint_cran	-0.02	-0.04	0.00	-0.16	0.04
TS_{max}	(Constant)	574.57	194.32	954.83		<0.001
	Jumpstarts	2.26	1.48	3.03	0.60	<0.001
	Digit hind	-0.78	-1.31	-0.21	-0.22	0.01
	Shoulderjoint_lat	-1.47	-2.90	-0.04	-0.17	0.04
OR_{max}	(Constant)	258.00	-52.82	568.82		0.10
	Jumpstarts	2.34	1.51	3.18	0.61	<0.001
	Mtpjoint_cran	-1.76	-3.15	-0.37	-0.22	0.01
	Coxal angle_lat	0.60	0.01	1.20	0.17	0.05
RPR_{max}	(Constant)	78.31	54.89	101.74		<0.001
	Jumpstarts	1.65	1.01	2.29	0.57	<0.001
	Injury	-12.48	-24.05	-0.91	-0.19	0.03

OR_{max} = maximum British Horseracing Board Official Rating, RPR_{max} = the maximum Racing Post Rating, TS_{max} = maximum top speed rating.

TABLE 2: Results of multivariate logistic regression models evaluating the effect of conformation on musculoskeletal injury, age in years and joint angles in degrees

Dependent parameter	Independent parameter	Coefficient	P value	Odds ratio	95% Confidence interval	
Tendonitis	Age	0.49	0.06	1.63	1.04	2.70
	Mcpjoint_lat	0.47	0.01	1.60	1.14	2.25
	Carpaljoint_cran	0.66	0.03	1.94	1.06	3.54
Pelvic fracture	Coxal angle_lat	-0.08	0.03	0.92	0.86	0.99
	Tarsaljoint_cran	0.22	0.05	1.25	1.01	1.56
Digital tendon sheath effusion hind	Tarsaljoint_cran	0.14	0.03	1.15	1.01	1.32

horses that suffered from tendon injury in the first season of the study were brought back into training the next season and were re-injured. Out of the 16 horses diagnosed with SDF tendonitis, 6 returned to racing, 6 horses were retired (including all 3 horses that had suffered a re-injury), 3 were still recovering at the end of the study and one was subjected to euthanasia. Two of the horses had bilateral lesions, in 8 horses the left leg was injured and in 6 horses the right leg.

Seven horses were diagnosed with a pelvic fracture based on scintigraphic findings. Three of these horses were retired from racing, 3 were back in racing and one horse was still recovering at the end of the study. One horse was retired during this study due to undiagnosed forelimb lameness.

Clinical findings: Palpation conducted at the beginning of the study included digital tendon sheath effusions in the hindlimb (26 horses, 17 bilateral, 6 left, 3 right) and forelimb (2 horses, 1 left, 1 right), exostoses on the dorsal aspect of the metatarsal bones (7 horses, 2 bilateral, 3 left, 2 right), exotoses over the second metacarpal bone in both limbs (1 horse, bilateral), joint effusions in the MCP joint (4 horses, 1 bilateral, 2 left, 1 right) and the metatarsophalangeal (MTP) joint (2 horses, both left) and the tarsocrural joint (6 horses, 3 left, 3 right), firm swellings on the dorsal aspect of the distal intertarsal and tarsometatarsal joints (3 horses, all bilateral) and around the proximal interphalangeal joint in the hindlimb (4 horses, 3 bilateral, 1 left) and forelimb (4 horses, 4 bilateral) and bowed tendons (defined as a convex contour of the palmar metacarpus) (4 horses, 3 left, 1 right).

Fifteen horses were found to have collapsed heels on inspection, in 5 horses all 4 hooves were affected, in 3 horses the forelimbs and in 7 horses the hindlimbs. All but one of these horses had a ratio between the height of the dorsal hoof and the height of the heel greater than 4 based on motion analysis measurements.

Effect of conformation on musculoskeletal injury

The results of the multivariable logistic regression models are summarised in Table 2.

Tendonitis: Odds of suffering from superficial flexor tendonitis increased with increasing age (odds ratio 1.63 per year increase in age, 95% confidence interval [CI] = 1.04–2.70), metacarpophalangeal joint angle as seen from the lateral aspect (odds ratio 1.60 per degree increase in joint angle, 95% CI = 1.14–2.25) and each degree of carpus valgus (odds ratio 1.94 per degree increase in joint angle, 95% CI = 1.06–3.54).

Pelvic fracture: With each degree of increase in the lateral coxal angle the relative risk of a pelvic fracture decreased by 0.92 (95% CI = 0.86–0.99) and with each degree of increase in tarsus valgus the risk increased by 1.25 (95% CI = 1.01–1.56).

Effusion of the digital tendon sheath in the hindlimb: Odds of showing signs of digital tendon sheath effusion in the hindlimb increased with an increase in tarsus valgus (odds ratio 1.15 per degree increase in joint angle, 95% CI = 1.01–1.32).

None of the independent parameters contributed significantly to the regression models with 'tarsocrural joint effusion', 'exostosis on the dorsal aspect of the third metatarsal bone' and 'injury' as dependent parameters. Performance, factored in as the number of races in which the horse was placed, did not contribute significantly to any of the injury related logistic regression models.

The 2 horses that suffered from an intermittent upward fixation of the patella had a very steep lateral stifle angle (more than 1.5 s.d. from the cohort mean) compared to the other horses in the cohort. The 2 horses that were diagnosed with stress fractures of the third metatarsal bone had extremely short hind digits (more than 4 s.d. from the cohort mean) and both were found to have exostoses on the dorsal aspect of the third metatarsal bone on clinical examination at the beginning of the study.

Discussion

Performance

Despite the widespread anecdotal evidence that a relationship between conformation and performance exists, there is a lack of scientific data and studies on conformation of the racing Thoroughbred. Previous studies on which factors influence performance of a racehorse have concentrated on the cardiovascular system (Young *et al.* 2005) or the effect of training (Perkins *et al.* 2004) and there is only one study reported on the relationship between conformation and performance by comparing 'winners' to 'nonwinners' (Delahunty *et al.* 1991). Performance is difficult to quantify and the performance parameters available do not simply reflect the performance potential of the horse, but are influenced by other factors. Official Rating, Top Speed rating and Racing Post Rating are not calculated objectively, but incorporate the handicap. Lifetime earnings and number of races placed are influenced by the choice of trainer and owner in which race the horse competed and, hence, by tactical considerations. Since none of the performance measures are ideal, we created 5 different statistical models each with one of the 5 different performance measures as outcome parameter. This approach has the risk of identifying some conformational parameters as significant by chance, but has the advantage of observing consistencies across the different performance measures.

A wide intermandibular (IM) width, large flexor shoulder angle and large lateral coxal angle seemed to be beneficial for jump racing. The importance of a wide IM width conforms to findings in a study on 'winners' versus 'nonwinners' in flat racehorses (Delahunty *et al.* 1991). It has been suggested that there is an indirect correlation between IM width and hereditary laryngeal neuropathy with an incremental decrease in the severity of recurrent laryngeal neuropathy as IM width increases (Cook 1988). In other equine disciplines (show jumpers and dressage horses) elite horses had a more sloping shoulder (Holmström *et al*. 1990), and a more sloping shoulder has been showed to correlate with an increase in stride length in walk (Henninges 1933). Here a smaller flexor angle of the shoulder was associated with a decrease in performance. However comparison of our data with previous studies is difficult due to different population of horses examined and the different measurement techniques used. A large lateral coxal angle has been demonstrated to be beneficial for performance in this study. This might correspond to a larger area for the gluteal musculature, which generate much of the motor power for locomotion in the hindlimb (Payne *et al*. 2005). The lateral coxal angle was the only parameter that contributed to both, performance models and injury models. An increase in this angle reduced the risk of a pelvic fracture. This may be due to a decrease in the bending moment of the muscles acting on the ilium. The flatter the angle the more the muscles fibres are in alignment with the bone and act along the long axis of the bone and the smaller the bending moment.

A large girth, valgus formation of the metacarpophalangeal joint and a long hind digit were detrimental for jump racing performance. A large girth corresponds to a big body mass and an increase in mass increases peak limb force and energy cost of locomotion (Heglund and Taylor 1988). Valgus deformations and an increase in the digit length move the ground reaction force vector away from the sagittal plane and the long axis of the leg at the level of the metacarpo-/metatarsophalangeal joint. It will be useful to consider these factors in dynamic studies that are currently being undertaken to investigate the effect of conformation on locomotion.

Injury

The incidence of tendon injuries and pelvic fractures in this study was lower than the incidence previously reported from other National Hunt racing yards (Ely *et al*. 2004). This may be due to differences in study period and starting date of the studies. The present study started in October 2003, 2 months after horses have been brought back into training and a number of horses were withdrawn due to musculoskeletal injury within the first few weeks of training.

The number of starts had no significant influence on injury rate in this study. The rate of injury has been shown to be related to the frequency of racing in Japanese flat racing (Takahashi *et al*. 2004) but, in this study, only the total number of starts was considered with no consideration of the time-intervals between races. It must be considered that races are only a small part of the overall ‘mileage’ covered by a horse and training data were not included here, although it has been shown to affect the frequency of injury (Estberg *et al*. 1996).

The risk of suffering from superficial digital flexor tendonitis increased with age. This corresponds to the findings of epidemiological studies (Bailey *et al*. 1997; Perkins *et al*. 2005) and is explained by changes in the microstructure and composition of tendons with age (Bailey *et al*. 1997; Smith *et al*. 2002).

A more upright fetlock related to an increased risk of tendonitis of the superficial digital flexor tendon. This is in contrast to popular belief, where a sloping pastern (and hence a more acute metacarpophalangeal joint angle) is believed to predispose to tendonitis (Eastman 2004).

Lateral deviations of the carpal and tarsal joint as viewed from the cranial/caudal aspect were associated with an increased risk of tendonitis and pelvic fracture, respectively. This may be due to the fact that the forces acting on the musculoskeletal system during locomotion are not evenly distributed across the limb in the lateromedial direction. A lateral deviation of the tarsus was also associated with an effusion in the digital tendon sheath, which may again be associated with asymmetrical loading of the tendon sheath.

While the presence of any signs of injury compromised performance, there was no evidence of performance having an effect on the risk of injury. This might be due to the fact that only horses that can withstand the demands of training proceed to racing, while those that cannot, leave the yard in the first few months of the training calendar. A previous study into the wastage in Thoroughbred racing reported that 6.2% of horses that were trained never raced, due to lack of ability and unsoundness (Jeffcott *et al*. 1982).

The use of conformational parameters as predictors for performance or risk of injury in individual horses is limited by the repeatability of the measurement technique (Weller *et al*. 2006a). Sources of variability are the identification of anatomical landmarks (with the more proximal landmarks being more difficult to identify repeatably) and the change in measurement with the stance of the limb. Even if the horse is perceived to be standing square and equally weightbearing on all 4 limbs, slight shifts in weight result in change in joint angles.

The horses in the studied cohort were all from a single racing yard, hence constituting a nonrandom sample. This had the advantage that potential trainer effects were minimised, but results may not apply to the whole population of NH racehorses. However while many trainers hold strong beliefs about which conformational parameters are desirable when buying horses, there are other parameters, such as pedigree and former racing performance, that also have a strong influence on choice of horse. Also, many horses are not chosen by the trainer, but selected by the owners or bloodstock agents or brought in from another racing yard.

With the small number of clinical cases observed in this study in relation to the number of horses in the cohort, the statistical power is limited. This study however provides information about the frequency of musculoskeletal disease in jump racehorses and also about the range of conformational parameters observed (Weller *et al*. 2006b). Together with information about the precision of the measurement technique, these data can be combined to calculate the sample size necessary to achieve adequate accuracy in a larger study.

In conclusion, this study has identified certain conformational parameters that were associated with performance and injury risk. These results may aid in identifying individuals that are likely to perform well on the racecourse while at the same time being maximally resistant to injury.

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[2]TheMathWorks, Inc., Natrick, Massachusetts, USA.
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