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Epidemiology of race-day distal limb fracture in flat racing Thoroughbreds in Great Britain (2000 to 2013)

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Keywords: risk factors, trainer, performance, horse, racing, injury

Summary

Background: A key focus of the racing industry is to minimise the number of race-day distal limb fractures (DLF), although no studies have identified risk factors for both fatal and non-fatal DLF.

Objective: To determine risk factors for race-day DLF experienced by Thoroughbred racehorses participating in flat racing in Great Britain (GB).

Study design: Retrospective cohort

Methods: Information was collected from all flat racing starts occurring on GB racecourses between 2000 and 2013, including horse, race, course, trainer and jockey data for each horse start and race-day injury data as reported by on-course veterinarians. Associations between exposure variables and DLF were assessed using mixed effects logistic regression analyses using data from all starts, and turf starts only.

Results: A total of 806,764 starts and 624 DLF were included, of which 548,571 starts and 379 DLF occurred on turf surfaces. In both models, increasing firmness of the going, increasing racing distance and horses in their first year of racing were at a higher risk of DLF, while increasing number of previous race starts were protective. Trainer performance was associated with DLF. Generally, the risk of DLF increased with increasing horse age. Starts in selling or claiming races or Group 1, Group 3 or claiming races were at higher odds of DLF in the all starts and turf models, respectively.

Main limitations: Clinical diagnosis of DLF and all types of DLF considered as one outcome.

Conclusions: This study confirmed previously identified risk factors for DLF including going, race distance and number of horse starts. Novel risk factors were related to trainer and horse performance, and race type. Identification of at risk groups will help inform interventions to reduce DLF occurrence in flat racing horses.

Introduction

Injuries are an inevitable risk in any activity involving high performance athletes undertaking strenuous physical activity. Fracture is one of the most common type of race-day injuries in Thoroughbred racehorses, and the majority of fractures occur in the distal limb [1-4]. Race-day fractures are a concern for a racing industry seeking to maintain racing safety and enhance racehorse welfare. Furthermore, fractures have a financial impact trainers and owners and detract from the public perception of the sport.

Distal limb injuries in racehorses can have career-ending or catastrophic consequences [1; 5-8]. Fractures most commonly occur when there is an imbalance between microdamage and repair due to repeated, cyclic loading [9], which can lead to irreparable damage not only to the bone, but also the structures surrounding the site of fracture [10]. Whilst bone does show functional adaption in response to exercise loads [11], this can lead to an initial weakening of the structures and increased likelihood of fracture [12]. A previous study identified complex relationships between exercise load and fracture risk, with an interaction between the number of loading cycles at a slower pace (canter) compared with faster paced work (gallop) [13]. Bone damage may be subclinical and not evident during training, in which case fracture may occur when bones are placed under the most stress such as during high speed racing conditions [14].

One way to improve the safety of racing is by identifying risk factors for distal limb fractures (DLF), enabling the racing industry to implement effective, evidence-based change. Previous studies of fatality or fatal musculoskeletal injury, including fatal distal limb fracture, in racehorses have identified racing in jump races [15], racing on all-weather or dirt surfaces [16; 17], increasing racing distance [18; 19] and increasing firmness of the racing surface (going) [17; 18] as risk factors. Age has been identified as risk factor in both flat and jump races, with the risk of fatality increased with increasing age at first race for all-cause fatalities [6], fatal musculoskeletal injury [15] and fatality due to fractures of the third metacarpal or third metatarsal bone [20].

While risk factor studies of fatal DLF can inform strategies aimed at reducing the likelihood of catastrophic outcomes, DLF with a fatal outcome are not representative of all DLF occurring on the racecourse, in particular when the decision to euthanise is influenced by factors other than the injury itself. It is therefore important to study both fatal and non-fatal DLF, to provide a more general picture of risk factors for this type of injury. A previous study identified risk factors for DLF on all-weather surfaces [21], but no studies have investigated risk factors for DLF overall, or specifically for turf racing. Therefore, the purpose of the present study was to identify current horse-, race-, course-, trainer- and jockey-level risk factors for race-day DLF in flat racing Thoroughbreds in Great Britain (GB).

Methods

Study design and case definition

A retrospective cohort study was conducted using all Thoroughbred flat racing starts in GB between 1st January 2000 and 31st December 2013. A start was defined as having occurred when a horse that was declared to race had entered the starting stalls prior to racing. One horse could therefore have multiple starts during the study period and the unit of interest was at the start level.

Distal limb fracture (DLF) was defined as an event that resulted in the veterinary diagnosis of a fracture to the distal limb including the carpal, tarsal, second, third or fourth metacarpal or metatarsal bones, proximal pastern, distal pastern, sesamoid or 'fetlock', as recorded by official racecourse veterinarians. A report of a DLF was primarily based on clinical examination and presumptive diagnosis, without further diagnostic investigations. Reports were recorded at the racecourse into the British Horseracing Authority's (BHA) injury database.

Data collection and processing

For each start, horse demographics, race, course, trainer and jockey variables were collated from the Weatherbys racing database (www.weatherbys.co.uk). The racing and injury data were merged into a single custom-designed Structured Query Language (SQL) database, with records matched by horse and race identification numbers.

Additional performance variables were calculated, based on information from previous race starts. For each start, a performance score was created (30 for a win, 20 for a place, 10 for a completed run, 0 for a start but failed to finish) [22], which was then used to calculate an average score based on all race starts and all flat race starts prior to the current start (sum of performance scores in previous starts/number of previous starts). The percentage of wins, placings and failures to finish for each horse, trainer and jockey, both for all previous race starts and previous flat starts only were also calculated. Additionally, for each start, a horse performance index was calculated based on the rank score of the percentage of the field beaten in the race (ranked 1-10, based on deciles) multiplied by the rank score of the total value (purse) offered in the race (ranked 1-10) [23]. The rank of the total race value was calculated for each year, as the purse value increased over the study period. For each horse, the total number of starts prior to the current start, the number of starts in the 15 and 30 days prior to the current start and the percentage of starts made in flat races were calculated.

The number of days since last start (racing intensity) was modelled as a categorical variable with four levels: first start, 1 to 7 days, 8 to 93 days and ≥94 days, based on previous research [6]. A trainer performance variable was created based on the average score of the trainer at the previous start (high = trainers with an average score in the top 25th percentile of average performance score; low = the remaining trainers) and their percentage of horse failures-to-finish at the previous start (high = trainers in the top 50th percentile of percentage of failures to finish, low = the remaining trainers). This resulted in four categories of trainer performance: low average score with low percentage failures, high average score with low percentage failures, low average score with high percentage failures and high average score with high percentage failures (Supplementary Table 1). Age was modelled as current age (in years: 2, 3, 4, 5, 6, 7 and 8+) and variables representing first year racing (yes/no) and age at first start (2, 3, 4+) were also investigated. Sex was categorised in three groups: uncastrated males (stallions, colts and rigs), geldings and females (fillies and mares). The official track rating or condition, called going, was categorised in five levels: 1) hard, firm or fast 2) good to firm or standard to fast, 3) good or standard, 4) good to soft or standard to slow and 5) soft or heavy or slow (see Tables 2 and 3).

Statistical analysis

A mixed effects logistic regression approach was used to determine explanatory variables that were associated with DLF for 1) all starts and 2) starts on turf surfaces only. Exposure variables were screened using univariable logistic regression and those with a likelihood ratio test P-value <0.25 were selected for inclusion in a multivariable model. A preliminary multivariable model was built using a manual backwards method of elimination in which variables were retained in the model if the likelihood ratio test P-value was <0.05. The linearity of continuous variables was assessed and if non-linearity was identified, inclusion of quadrative or fractional polynomial terms was explored as well as categorising the variable based on quartiles, with selection of the most appropriate functional form based on likelihood ratio P-values.

Interaction terms were identified using a classification tree method as described by Camp and Slattery [24]. Briefly, all non-DLF observations were divided into subsets of the same sample size as the DLF set (n=624), and each of these non-DLF sets were combined with the DLF records to assess interaction between risk factors using classification tree analysis. Only risk factors with P<0.25 in univariable analysis were included in the classification tree analyses, and interaction terms identified in greater than 10% of the trees were further assessed in the multivariable mixed effects logistic model.

Random effect terms for horse, jockey, trainer, sire, dam, race, race meeting or course were individually added to the final multivariable model. Due to computational constraint, final models are presented with only horse included as a random effect, to account for horse-level repeated measures within the dataset.

Fitted probabilities of DLF were calculated based on the final random effects models. Residual values (observed outcome minus the fitted probability) were calculated to assess model fit; in a well-fitting model, residuals would be near zero. R version 3.3.0 [25] and the package rpart [26] were used for the classification tree model. Stata version 13 [27] was used for the mixed effects logistic regression modelling.

Results

There were a total of 806,764 starts, of which 548,571 were on turf surfaces. Horses had a median of 9 (interquartile range (IQR) 4 to 20; maximum 231) starts, with a median of 8 (IQR 3 to 18; maximum 230) starts on turf. There were 624 DLF and 379 of these occurred on turf surfaces. Table 1 summarises the anatomical location of DLF on turf and all-weather surfaces. The incidence of DLF was 0.77 per 1000 starts and 0.69 per 1000 turf starts. Of the DLF, 310 (49.7%) had a fatal outcome; 183 (48.0%) of these were on turf surfaces.

A summary of the univariable analyses results for the all-starts and turf models is provided in Supplementary Tables 2 and 3. One hundred starts did not have complete information regarding the sex of the horse, leaving 806,664 starts in the multivariable all starts model. In total, 11 variables were retained in the all starts model (Table 2) and nine in the turf model (Table 3). Descriptive statistics of the random effects and their significance are summarised in Table 4. No significant interaction terms were identified among the fixed effects. In both models, the odds of DLF increased as the firmness of the going increased and with increasing race distance. Horses in their first year of racing and horses from trainers with a high average performance score and high percentage of horse failure to finish were at a higher odds of fracture. Generally, older horses were at higher odds of DLF although an increasing number of previous starts decreased the odds of DLF.

In the all starts model, the odds of DLF were higher on all-weather courses, in seller or claiming races (races where horses could be sold at the end of the race [28]), in horses having their first race start, in colts, stallions and rigs, and with increasing percentage of horse prior placings. The random effect of horse was significant in the final model (P=0.04; n=67,510) as was the random effect term for sire (P<0.001; n=2,209), indicating significant variation between horses and between sires in the odds of DLF after adjusting for the fixed effects in the model. The residual values had a median of 0.9983 (IQR 0.9974 to 0.9989) and -0.0002 (IQR -0.0002 to -0.0001) for DLF and non-DLF starts, respectively.

In the turf model, the odds of fracture were higher in May-September compared to October-April and in Group 1, Group 3 or claiming races (where horses can be bought or "claimed" for a specified price [28]). The random effect of horse was significant in the final model (P=0.04; n=62,803) as were the random effects of trainer (P=0.01; n=1,204) and sire (P=0.02; n=2,074). When clustering by trainer was accounted for, the trainer performance with both high average trainer score and high percentage failures changed by 15% to an odds ratio of 1.73 (95% CI 1.21-2.85; P=0.003). The residual values had a median of 0.9977 (IQR 0.9962 to 0.9987) and -0.0002 (IQR -0.0004 to -0.0001) for DLF and non-DLF starts, respectively.

Discussion

This study has identified both previously observed and novel factors associated with DLF in Thoroughbred racehorses. Racing on an all-weather surface, increasing firmness of going, increasing racing distance, older age and racing intensity were risk factors for race-day DLF, while an increasing number of starts was a protective factor. These findings are similar to those from previous studies investigating flat racing fatality [6; 17] and fatal third metacarpal fracture [2; 18]. Newly identified risk factors for DLF in flat racing horses include race type, season, and measures of horse and trainer performance.

In both models reported here, age was associated with the DLF risk, which is comparable to similar studies of other outcomes, including fatality, in this population [21; 29]. These results are also similar to those from other studies completed in other populations, although variation in modelling strategies make comparison across studies difficult. Age has been modelled as age at first start and/or current age [2; 6; 17; 30] or as career length [22; 31]. Wood *et al.* [6] identified that horses that started racing younger had a lower risk of racecourse fatality, whilst another study showed that horses in their first year of racing were at increased risk of fatal DLF [2]. Other studies have identified increasing risk of fatality [15; 17] and fracture [30] with increasing age or higher risk of superficial digital flexor tendinopathy (SDFT) with increasing career length [22; 31]. Distal limb fracture in older horses is suggestive of cumulative microdamage, which then leads to failure. The increased microdamage in the third metacarpal condyle of older racehorses, compared to younger racehorses has been described previously [32]. The higher fracture risk in older horses may also partly be due to an age-related change in the bone's adaptive ability, leading to failure [33]. The higher risk of DLF in the first year of racing may be indicative of a failure of bone to adapt to increased exercise loads, or the incorrect timing of a race in relation to bone adaption [12]. It could also be that inexperienced horses are more likely to be injured when racing, e.g. through lack of concentration, stumbling, and bumping into other horses.

Horses from top performing trainers who also had high proportion of horses failing to finish were more likely to have a DLF than horses from trainers with poorer average performance. Training regimens and/or the quality and health of horses trained have previously been hypothesised to play a role in the association between SDFT injury in National Hunt (jumping) racehorses and trainer performance [22]. Training regimens may also play a role in explaining the current finding, and it could be that trainers who employ more intense training strategies are more likely to be successful, but also have more injuries in their horses. Unfortunately, no training data were available for horses in the current study, and it would be difficult to collect these from large retrospective cohorts. Future research will be greatly enhanced by the regular collection of training data, preferably in prospective studies.

Uncastrated male horses were at a higher odds of DLF compared to geldings and females in the all starts model. Similarly, previous studies have identified male horses to be more likely to sustain a fracture [30; 34; 35], SDFT [36], die or be euthanized [19] than their female counterparts. Perkins *et al.* [37] suggested that the lower risk to female horses may reflect the breeding potential of these animals, with fillies and mares being removed from the racing population earlier than males, to protect them from the occurrence of catastrophic injuries that may preclude them from becoming a broodmare. However, the odds of DLF for females and geldings was similar in the current study, even though the racing career of geldings was longer (data not shown). Alternatively, the differing fracture risk between the sexes may be due to differences in bone metabolism as previously identified in two-year-old colts and fillies [38]. Whilst further research may be beneficial to further elucidate potential pathophysiological mechanisms associated with differences in fracture risk between the sexes, this is a non-modifiable risk factor and as such may be difficult to mitigate.

A simple measure of horse performance, based on career placings prior to the current start, was significant in the all starts model, with increasing horse performance increasing the risk of DLF. Although a higher percentage of prior placings indicates success relative to other horses competing in the same races, this measure does not take account of the level of race a horse has been competing at. In contrast, previous studies have identified that horses with a higher rating were at lower risk of fatality and SDFT than horses with no official rating [6; 31]. It is however difficult to compare career placings to official rating, given that the latter is weighted by the quality of the competition. A horse's rating can change after each start depending on type of race and performance of the horse in that race relative to the horse's own previous and expected performance and the performance of similar horses [39; 40]. Rating was not considered as a variable in the current analyses, due to changes in the way in which these data were recorded in 2008. A variable considered to be correlated with official rating is horse performance index [23]. Whilst this variable was investigated in the current study, it was not significant in the final model. It is unclear why a non-weighted performance variable was a risk factor over weighted variables, except that this simple measure removes any account of the quality of the horse. One possibility is that the effect identified here might be a result of horses that do well in lower level races being more likely to incur a DLF, and good horses competing in lower-level races that do not incur a DLF move up into better quality races. In these better quality races, horses are competing on a more even basis (i.e. they are better "matched" on horse ability). Therefore, percentage placings does not play as much of a role, instead the higher risk in better quality horses is represented in the race type variables, with Group 1 and 3 races having a higher risk in the turf model.

An indirect measure of horse quality retained in both models was race type. Horses entering seller or claiming races are for sale at the end of the race [28], while Group 1 races are international-level championship races and Group 3 races are the highest national-level races. No Group 1 races were held on all-weather surfaces during the study period. In both models, claiming races were a risk factor for DLF. In the all starts model, selling races also increased the likelihood of DLF, while in the turf model selling, Group 1 and Group 3 races increased the likelihood of DLF. It is unclear why these race types had higher odds of DLF, although it is of note that horses competing in Group races would be considered as some of the highest performing horses in the racing population, whereas horses in seller or claiming races would be at the other end of this spectrum. The association between the risk of injury and starting in a seller or claiming race has previously been noted [22]. The authors theorised that the possible reason for horses being entered in these race types was previous poor performance, associated with sub-clinical injury. However, this theory would not support the finding of higher DLF odds in Group races, which attract top-performing horses. It may be that horses performing in Group races are more likely to attempt to perform at the limits of their physical capability, resulting in injury, particularly for horses with no or few prior starts at the Group-level. However, from the data available in the current study it was not possible to assess horse capability at the level they were competing at.

An increasing number of race starts was protective for DLF, a factor that has previously been identified in studies investigating flat racing fatality [6; 17]. An alternative approach is to determine the number of starts in specified time periods [22; 31]. More starts in the previous three months was protective for tendon injury in steeplechase horses [31], while having no starts, or eight or more starts in the previous three months were risk factors for tendon injury in hurdles horses [22]. In the current study, racing intensity (the time since last start) was also significant in the final model, similar to previous studies [6]. While the importance of standardised measures of training intensity have previously been defined [41], these recommendations have not been extended to race-day measures.

Although the residual values indicated adequate model prediction of non-DLF starts, because the incidence of DLF was low, the predictive ability of the model for DLF starts was also low. As such, the current models are unlikely to be useful for predicting starts that will result in DLF and further work is needed to enable better identification of individuals at risk of an adverse outcome.

In the current analyses, a catch-all definition DLF was used, which did not differentiate specific fracture types. The categorisation of fractures was based on the clinical signs identified during examination by race-day veterinarians and, given the limited diagnostic facilities on British racecourses, it is likely that some fractures were misclassified. Reardon *et al.* [42] identified that when race-day veterinary reports of DLF were compared to subsequent post mortem examinations, race-day veterinarians correctly identified the majority of horses with fracture, although the correct reporting of at least one of the affected bones was less accurate. In some cases, multiple bones were fractured with only one fracture site reported. In addition, a minority (6%) of horses euthanased with veterinary-reported DLF did not have a fracture; instead, many of these horses had suspensory ligament rupture or sesamoidean ligament damage. The current study utilised the same data recording methods as this previous study [42], so similar misclassifications of fracture types could be expected which may justify a broader case definition of DLF at the expense of identifying risk factors for specific fracture types.

Conclusions

This study confirmed previously identified risk factors for DLF including going, race distance and number of previous horse starts. Novel risk factors were related to trainer and horse performance, and race type. Further, significant variation between horses, between sires and between trainers in the odds of DLF were identified. This study has helped to identify “at risk” groups, which will help inform interventions to reduce DLF occurrence in flat racing horses, enhancing horse welfare and safety.

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Conflict of interest

The authors report no conflict of interest.

Ethical animal research

Consent to use and store the data included in this study was obtained from the British Horseracing Authority. The project was ethically reviewed and approved by the Clinical Research Ethical Review Board of the Royal Veterinary College, approval number URN 2015 1362.

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Tables

Table 1: Race-day distal limb fractures (DLF) occurring in flat racing Thoroughbreds in Great Britain (2000-2013) described by anatomical location and racing surfaces.

Fracture location	All weather (n=245)[a]		Turf (n=379)[a]	
	Number	% of DLF	Number	% of DLF
Third metacarpal	76	31.0	129	34.0
First phalanx	54	22.0	123	32.5
Carpus	59	24.1	57	15.0
Third metatarsal	19	7.8	34	9.0
Proximal sesamoid – both	17	6.9	13	3.4
- **lateral**	4	1.6	8	2.1
- **medial**	7	2.9	5	1.3
- **unspecified**	3	1.2	5	1.3
Second or third phalanx	5	2.0	4	1.1
Tarsus	3	1.2	3	0.8
Second or fourth metacarpal	1	0.4	2	0.5
Second or fourth metatarsal	1	0.4	1	0.3
'Fetlock'[b]	0	0	1	0.3

[a] Six horses racing on turf and four horses racing on all-weather track had fractures in multiple locations in one DLF event

[b] Specific bone(s) affected not recorded

Table 2: Multivariable logistic regression results for the risk factors for distal limb fractures in British flat racing Thoroughbreds racing on turf and all-weather surfaces (2000 to 2013). Model includes a random effect for horse (n=67,510, P=0.04)

Variables	Level	No. of Cases	No. of Starts	Incidence per 1000 starts	Odds Ratio (OR)	95% Confidence Interval (OR)	Wald P-value	Likelihood ratio P-value
Surface	Turf	379	548,498	0.69	1			<0.001
	All-weather	245	258,166	0.95	1.62	1.3, 2.03	<0.001	
Going	Firm, hard or fast	24	29,293	0.82	1.41	0.91, 2.20	0.13	<0.001
	Good to firm or Good to fast	186	220,343	0.84	1.31	1.04, 1.65	0.02	
	Good or Standard	331	394,186	0.84	1			
	Good to soft or Good to slow	45	84,357	0.53	0.78	0.56, 1.09	0.15	
	Soft, heavy or Slow	38	78,483	0.48	0.71	0.50, 1.02	0.07	
Distance per 100 metres					1.05	1.03, 1.06	<0.001	<0.001
Race type	Not a seller or claiming race	543	733,197	0.74	1			<0.001
	Seller race	38	38,332	0.99	1.56	1.11, 2.19	0.01	
	Claiming race	43	35,135	1.22	1.89	1.37, 2.60	<0.001	
Sex	Colt, stallion or rig	157	147,587	1.06	1			0.04
	Filly or mare	197	268,295	0.73	0.77	0.62, 0.96	0.02	
	Gelding	270	390,782	0.69	0.77	0.61, 0.97	0.03	
Current age (years)	2	149	155,365	0.96	1			<0.001
	3	203	254,893	0.80	1.26	0.96, 1.64	0.10	
	4	85	154,070	0.55	1.26	0.87, 1.83	0.23	
	5	75	94,063	0.80	2.18	1.45, 3.27	<0.001	
	6	38	60,647	0.63	2.02	1.25, 3.26	0.004	

	7	39	39,571	0.99	3.56	2.17, 5.85	<0.001	
	8+	35	48,055	0.73	2.94	1.73, 4.99	<0.001	
First year racing	No	369	583,459	0.63	1			<0.001
	Yes	255	223,205	1.14	2.2	1.70, 2.84	<0.001	
Number of days since last start	First start	65	64,524	1.01	1			0.002
	1 to 7 days	37	83,009	0.45	0.62	0.40, 0.96	0.03	
	8 to 93 days	483	580,517	0.83	0.98	0.73, 1.33	0.91	
	94 days plus	39	78,614	0.50	0.62	0.4,0 0.95	0.03	
Number of previous horse starts on flat					0.98	0.97, 0.99	<0.001	<0.001
Horse prior place %					1.01	1.002, 1.01	0.001	0.002
Trainer performance	Low average score, low percentage failures	176	296,491	0.59	1			
	Low average score, high percentage failures	226	311,258	0.73	1.25	1.02	1.52	0.03
	High average score, low percentage failures	98	116,873	0.84	1.23	0.95	1.59	0.12
	High average score, high percentage failure	123	82,040	1.5	2.09	1.63	2.68	<0.001

* For 100 starts, the sex of the horse was unknown (n=806,664)

Table 3: Multivariable logistic regression results for the risk factors for distal limb fractures in British flat racing Thoroughbreds racing on turf surfaces (2000 to 2013). Model includes a random effect for horse (n=62,859, P=0.04)

Variable	Level	No. of Cases	No. of Starts	Incidence per 1000 starts	Odds Ratio (OR)	95% Confidence Interval (OR)	Wald P-value	Likelihood Ratio P-value
Going	Hard or firm	23	29,002	0.79	1.27	0.8, 2.00	0.31	0.003
	Good to firm	178	217,424	0.82	1.17	0.92, 1.49	0.20	
	Good	106	152,511	0.70	1			
	Good to soft	40	76,665	0.52	0.74	0.52, 1.07	0.11	
	Soft or heavy	32	72,969	0.44	0.64	0.43, 0.95	0.03	
Flat season	Off (October to April)	15	55,576	0.27	1			<0.001
	On (May to September)	364	492,995	0.74	2.31	1.37, 3.90	0.002	
Distance (per 100 meters)					1.06	1.03, 1.06	<0.001	<0.001
Race type	Not a Group or claiming race	339	519,314	0.65	1			<0.001
	Group 1	12	4,605	2.61	3.08	1.68, 5.64	<0.001	
	Group 3	11	7,816	1.41	1.92	1.04, 3.55	0.04	
	Claiming race	17	16,836	1.01	1.84	1.12, 3.02	0.02	
Current age (years)	2	111	119,631	0.93	1			<0.001
	3	135	181,290	0.74	1.12	0.81, 1.56	0.49	
	4	36	99,277	0.36	0.78	0.47, 1.29	0.34	
	5	35	58,347	0.6	1.55	0.91, 2.63	0.11	
	6	21	37,453	0.56	1.7	0.91, 3.17	0.09	
	7	23	24,205	0.95	3.28	1.74, 6.18	<0.001	
	8+	18	28,368	0.63	2.43	1.21, 4.87	0.01	

First year racing	No	200	382,791	0.52	1			<0.001
	Yes	179	165,780	1.08	2.45	1.77, 3.38	<0.001	
Number of previous horse starts on the flat					0.98	0.97, 0.99	0.001	0.001
Trainer performance[a]	Low average score, low percentage failures	101	198,784	0.51	1			<0.001
	Low average score, high percentage failures	117	194,124	0.60	1.25	0.95, 1.64	0.11	
	High average score, low percentage failures	76	92,352	0.82	1.37	1.01, 1.88	0.04	
	High average score, high percentage failures	85	63,311	1.34	2.11	1.56, 2.87	<0.001	

[a] When trainer was included as a random effect (instead of horse), the trainer performance with both high average trainer score and high percentage failures changed by 15% to an odds ratio of 1.73 (95% CI 1.21-2.85; P=0.003). No other odds ratios within the model changed more than 5%.

Table 4: Number of clusters, descriptive statistics and significance of random effect terms in the multivariable logistic regression model of risk factors for distal limb fracture (DLF) in all-starts and turf starts in British flat racing Thoroughbreds, 2000 to 2013.

Random effect	Number of clusters	Clusters with DLF cases	Median number of cases (IQR; maximum) [a]	Random effect multivariable P-value
All starts model				
- Horse	67,510	616 (0.9%)[b]	1 (1 – 1; 2)	0.04
- Trainer	1346	271(20.1%)	2 (1 – 2.5; 32)	0.08
- Jockey	2625	215 (8.2%)	2 (1 – 4; 17)	0.39
- Course	37	37 (100%)	11 (8 – 15; 94)	0.44
- Race meeting	11,412	613 (5.4%)	1 (1 – 1; 2)	0.49
- Race	77,336	624 (0.8%)	1 (1 – 1; 1)	0.49
- Sire	2209	338 (15.35%)	1 (1 -2; 15)	<0.001
- Dam	29,299	609 (2.1%)	1 (1 – 1; 2)	0.08
Turf starts model				
- Horse	62,859	371 (0.6%)[b]	1 (1 -1; 2)	0.04
- Trainer	1218	188 (15.4%)	1 (1 -2; 28)	0.01
- Jockey	2400	165 (6.9%)	1 (1 -3; 11)	0.47
- Course	35	35 (100%)	11 (8 – 14.5; 24)	0.44
- Race meeting	7876	375 (4.8%)	1 (1-1; 2)	0.49
- Race	51,574	379 (0.7%)	1 (1-1; 1)	0.49
- Sire	2085	248 (11.9%)	1 (1 -2; 10)	0.02
- Dam	27,825	373 (1.3%)	1 (1-1; 2)	0.14

[a] For clusters with cases of DLF; [b] 8 horses had multiple DLF.