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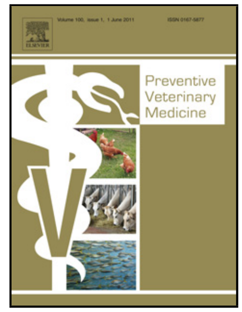

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Risk factors for race-day fatality, distal limb fracture and epistaxis in Thoroughbreds racing on all-weather surfaces in Great Britain (2000 to 2013)

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Abstract

The incidence of race-day injuries in Great Britain (GB) is higher on all-weather (AW) surfaces than on turf. However, to date no studies have focused on identifying risk factors for injury specific to AW racing. Therefore, the objective of the current study was to determine risk factors for fatality, distal limb fracture (DLF) and episodes of epistaxis in flat racing Thoroughbreds racing on AW surfaces in GB. Data included all flat racing starts on AW surfaces (n=258,193) and race-day veterinary events recorded between 2000 and 2013. Information on additional course-level variables was gathered during face-to-face interviews with racecourse clerks. Horse-, race- and course-level risk factors for each outcome were assessed using mixed-effects multivariable logistic regression including horse as a random effect. A classification tree method was used to identify potential interaction terms for inclusion in the models. During the study period, there were 233 fatalities resulting in a fatality incidence of 0.90 per 1000 starts; 245 DLF with a resultant DLF incidence of 0.95 per 1000 starts and 410 episodes of epistaxis resulting in an epistaxis incidence of 1.59 per 1000 starts. Risk factors varied for each outcome, although some factors were similar across models including the going, racing intensity, horse age, age at first race start, horse and trainer performance variables. Generally, older horses and those that had started racing at an older age were at higher risk of an adverse outcome, albeit with an interaction between the two variables in the fatality model. Faster going increased the odds of epistaxis and DLF but not fatality. Increasing race distance increased the odds of fatality but reduced the odds of epistaxis. Epistaxis was associated with type of AW surface (Fibresand versus Polytrack®), but DLF and fatality were not. This study provides further evidence of the association between the risk of race-day injuries and fatalities and current age, age at first start, race distance, going and horse performance. These findings provide the racing industry with information to develop strategies to reduce the occurrence of race-day events on AW surfaces.

Abbreviations:

AW All-weather

BHA British Horseracing Authority

DLF Distal limb fracture

GB Great Britain

IQR Interquartile Range

LRT Likelihood Ratio Test

ROC Receiver Operating Characteristic

Keywords: Risk factors, musculoskeletal injury, fatality, epistaxis, all-weather track

Introduction

Worldwide, all-cause fatality, distal limb fractures (DLF) and exercise-induced epistaxis (i.e. blood at the nostrils) are some of the most common race-day veterinary events experienced by flat racing Thoroughbreds (Johnson et al., 1994; Williams et al., 2001; Parkin et al., 2004; Rosanowski et al., 2016). Previous studies have identified an incidence in flat racing of between 0.76 and 0.90 per 1000 starts for all-cause fatality (McKee, 1995; Wood et al., 2001; Rosanowski et al., 2016) and between 0.30 and 1.25 per 1000 starts for epistaxis (Williams et al., 2001; Rosanowski et al., 2016), while DLF was the most common reason for catastrophic musculoskeletal injury (Rosanowski et al., 2016). As well as the impact that injuries have on horse welfare and safety, it is widely recognised that any injury occurring on race-day negatively affects the public perception of the sport.

Racing surface affects the dynamics of limb loading, hoof acceleration and ground reaction forces (Chateau et al., 2009; Setterbo et al., 2009). Consequently, surface has the potential to affect injury risk. A study of racetracks in Florida identified that horses racing on dirt had a lower risk of fatal musculoskeletal injury than those racing on turf (Hernandez et al., 2001). In contrast, a study in New York found that the risk of musculoskeletal injury was higher on dirt surfaces compared with racing on turf (Mohammed et al., 1991). Additionally, there was evidence that injuries on dirt surfaces tend to occur on surfaces that were rated as good (standard) or fast, based on the condition and speed of the surface. A recent five-year (2009 – 2013) cohort study of all flat racing starts in North America found that horses racing on a dirt surface were at the highest risk of fatality, compared with horses racing on turf or all-weather (AW) surfaces (Georgopoulos and Parkin, 2016). In this study, AW surfaces were associated with the lowest risk of fatality.

Differences in fatality risk on British racecourses have been identified between turf and AW surfaces. Compared to turf surfaces, the likelihood of fatality doubled for horses racing on AW surfaces (Henley et al., 2006), while the risk of epistaxis was 2.5 times higher for horses racing on slow AW surfaces when compared to turf (Newton et al., 2005). The incidence of distal limb injury (Williams et al., 2001) and veterinary events (Rosanowski et al., 2016) was higher in horses racing on AW surfaces compared with those racing on turf surfaces, although in these studies no multivariable analyses were conducted.

Racing on AW surfaces has occurred in Great Britain (GB) since the late 1980s. In 2013, there were four racecourses with AW surfaces, with three different synthetic surface types. Despite the apparently increased risk of fatality when racing on an AW surface (Henley et al., 2006), to date no studies have specifically focussed on risk factors for injury in horses starting in races held on these surfaces. The purpose of the present study was to identify horse-, race- and course-level risk factors for race-day fatality, DLF and epistaxis in flat racing Thoroughbreds racing on AW surfaces in GB. Identification of risk factors for these outcomes will enable the racing industry to implement strategies to reduce their occurrence.

Materials and Methods

Study design

A retrospective cohort study was used to collect information regarding all veterinary events occurring on race-days and all race starts on AW surfaces in GB from 1st January 2000 to 31st December 2013. These data were provided by the British Horseracing Authority (BHA) and Weatherbys (www.weatherbys.co.uk) and have been described previously (Rosanowski et al., 2016). Briefly, the population included all Thoroughbreds racing in AW flat races in GB during the study period, with all horses declared to race in at least one race and subsequently entering the starting stalls prior to racing in an AW flat race included in the study. All race-day veterinary events were diagnosed and recorded by official racecourse veterinarians, with additional race start data provided by Weatherbys. The current study includes data from 258,193 starts from the five courses with AW surfaces that were operating in GB during the study period.

Additional information regarding changes in the AW surface, refurbishment of current or previous surfaces and surface maintenance, including seasonal variation, was collected via semi-structured face-to-face interviews with the Clerk of the Course (racecourse clerk), who is responsible for preparing and maintaining the racing surface. The Clerks from four of the five AW courses that were operational during the study period were contacted to participate in the study. A fifth course was operational between 2008 and 2009 and resumed AW racing in 2014 under different ownership and management. The new Clerk of this course did not respond to requests to participate in the study.

Explanatory variables

The unit of interest was a horse start, and one horse could have multiple starts during the study period. For each start, data were collated including horse, trainer, jockey, course and race information. Age variables were current age (in years: 2, 3, 4, 5, 6, 7+) and age at first flat racing start (in years: 2, 3, 4+). In addition, a binary variable of first year racing in flat races (yes/no) was created. Sex was categorised in three categories: stallions and colts, geldings and rigs, and mares and fillies. For each start, a performance score was created (30 for a win, 20 for a second or third place, 10 for a run and 0 for failing to finish) (Reardon et al., 2012). Performance variables were calculated based on information from all starts prior to the current start, including the number of starts, the percentage of wins, placings (first, second or third) or failure to finish for each horse, trainer and jockey, for all flat starts and for AW starts only. An average score variable was calculated using the average of all performance scores for each horse, jockey or trainer prior to the current start. In addition, for each start, an average horse performance index was calculated as described by Compston et al. (2013). Firstly, horses were ranked from 1 to 10 based on the percentage of the field beaten in the race (in deciles). Secondly, races were ranked (1-10) based on the value of the race (purse). The deciles of purse were calculated for each year of the study period. These two ranks were then multiplied and averaged for previous starts. The percentage of flat racing starts attributable to racing on an AW surface was calculated for each horse. The number of days since last start, henceforth called racing intensity, was modelled as a categorical variable (first start, 1 to 7 days, 8 to 93 days and 94 days plus) based on previous research (Wood et al., 2001; Reardon et al., 2012). The number of starts per horse in the previous 15 or 30 days was calculated for each start.

The official track rating or condition, called going, was categorised in three levels: 1) fast and standard to fast, 2) standard and 3) standard to slow and slow. Based on the face-to-face interviews with Clerks of the Course, the variables surface type (Fibresand[1], first generation Polytrack®[2] and second generation Polytrack®), time since last surface change (when a surface was replaced with a new surface type) and time since last refurbishment (when the current surface was added to or renewed) were created. More detailed maintenance records were not kept for most courses. All four courses for which racecourse clerks provided information undertook some refurbishment of the existing surface type over that time. At two of these courses the type of surface was changed during the study period. For the fifth course where no interview was conducted, racing was only held in 2008 and 2009 and all maintenance-related variables were set to missing.

Outcome variables

Three outcome variables were investigated: fatality, DLF and epistaxis (all coded as yes/no). All-cause fatality included events where horses were euthanased due to catastrophic injuries or died suddenly during or after a race (i.e. on race-day). An episode of epistaxis was defined as a veterinary-reported event where blood was observed at the nostrils. Whilst fatality or epistaxis constitute unambiguous outcomes, reports of DLF were primarily based on clinical examination and presumptive diagnosis by the on-course veterinarian, without further diagnostic investigations. Distal limb fracture was defined as fracture(s) of the carpal, tarsal, second, third or fourth metacarpal or metatarsal, proximal pastern, distal pastern and sesamoid or fractures in the fetlock area. The outcome of DLF could be fatal or non-fatal.

[1] http://www.mansfield-sand.co.uk/products/equestrian/fibresand/
[2] http://www.martincollins.com/Surface-Range/Polytrack

Statistical analysis

Mixed effects logistic regression modelling was used to determine explanatory variables that were associated with each of the three outcomes. The linearity of the association was assessed for continuous variables, with continuous variables were categorised into quartiles or deciles and checked for a linear association by comparing models with the variable as categorical verse a model assuming a linear trend based on the likelihood ratio test (LRT). If non-linearity was identified, the variable was categorised based on quartile values unless otherwise stated. Correlations between continuous variables were assessed by calculating pairwise Pearson's correlation coefficients. For pairs of continuous variables with high correlation (P>0.8), only one variable was assessed in the multivariable model. Selection of this variable was based on the LRT P-value and/or Akaike information criterion at the univariable stage. Variables with a LRT P-value <0.25 in univariable analysis were selected for inclusion in a multivariable model. A mixed effects multivariable logistic model including a random effect for horse was built using a manual backwards elimination method. Variables were retained in the final model if the LRT P-value was <0.05.

A classification tree method was used to identify relevant two-way interaction terms between the fixed effect predictors included for assessment in the mixed effects multivariable logistic models (Camp and Slattery, 2002). Specifically, interactions between predictors (both categorical and continuous) were identified if branches from the same node had different predictors further down the tree. Firstly, the data were divided into two parts: non-event starts (N_0) and event starts (N_1), and all non-event starts were randomly divided into K sets of roughly equal sample size ($n_{0,i}$, where i=1,…K), where K was calculated as the nearest integer of $N_0/(N_1*2)$. Secondly, each of these non-event subsets ($n_{0,i}$) was combined with event starts (N_1) to generate a classification tree (Figure 1), resulting in the generation of K classification trees . Thirdly, two-way interactions identified in each tree were tabulated, and interaction terms identified in 10% or more of the classification trees, at any level within that tree, were then assessed in the mixed effects multivariable logistic model. Interaction terms were retained in the model if the likelihood ratio test P-value was <0.05. R version 3.2.2 (R Core Team, 2016) and the package rpart (Therneau and Atkinson, 2007) were used for the classification tree analyses. All other analyses were conducted using Stata 13 (StataCorp, College Station, TX, USA).

The variables jockey, trainer, sire, dam, race or race meeting were each assessed as random effects terms in an intercept-only model and added individually to the final multivariable model without the random effect for horse-level repeated measures. Due to computational constraint, final models are presented accounting for horse-level repeated measures only.

The fitted probability of each outcome was calculated based on the final mixed effects multivariable model. Residuals (observed outcome minus the fitted probability) were calculated to assess model fit. In a well-fitting model, all residuals would be near 0 with negative residuals for non-case starts (observed outcome = 0) and positive residuals for case starts (observed outcome = 1). Cumulative odds for all starts were calculated based on fixed effects in the final mixed effects multivariable logistic model and receiver operating characteristic (ROC) analysis was adopted to assess the predictive ability of the model (Altman et al., 2013).

Results

During the 14-year study period, there were 258,193 starts by 45,423 horses, trained by 1,133 trainers, ridden by 1,735 jockeys, in 25,762 races at 3,791 race meetings held on AW surfaces. Horses were by 1,919 sires out of 23,636 dams. Horses started a median of 5 (Interquartile range (IQR) 2–11) times on AW surfaces (Supplementary Table 1). Two courses changed AW surface type to second generation Polytrack® during the study period. One course originally had fibre sand and the other had first generation Polytrack®. The surface type on the three other AW tracks were fibre sand, first generation Polytrack® and second generation Polytrack®.

Fatality

There were 233 fatalities and the fatality incidence was 0.90 per 1000 starts. The final multivariable model for the outcome of fatality is presented in Table 1. The odds of fatality were higher in horses racing in 2002, when the race was held in August, September or October and if the race was an auction race. If the horse was trained by a trainer with an average performance score in the top 10% of all flat racing trainers, the odds of fatality was one and a half times that of horses trained by trainers with poorer average performance. The odds of fatality increased with increasing horse AW performance index, and an increasing percentage of jockey wins on AW surfaces. Two interaction terms, current age × age at first start (P=0.001) and distance × number of AW horse starts (P=0.04), were retained in the final model. In horses that started racing as a two-year-old, those that were seven or older at the time of the race were at three times the odds of fatality compared to younger (<7 year old) horses. However, horses younger than seven were at nearly twice the odds of fatality if they had started racing at three or older rather than two years of age. There was a negative interaction between racing distance and number of previous starts. That is, the odds of fatality when a horse was racing over longer distances was modified by the number of previous starts, with increasing starts conferring an increased protection. For example, the odds ratios per 100 metre increase in distance were 1.05 (95% CI 1.03–1.08), 1.01 (95% CI 0.97-1.06) and 0.91 (95% CI 0.79-1.05) for horses with 5, 20 or 60 previous starts, respectively (Figure 2). No random effect terms were significant in the univariable or multivariable models (Supplementary Table 2).

The area under the curve for the fatality model was 0.67. The residual values had a median of 0.9989 (IQR 0.9982 to 0.9994) and -0.0007 (IQR -0.0011 to -0.0005) for fatal and non-fatal starts, respectively.

Distal limb fracture

There were 245 DLF and the incidence of DLF was 0.95 per 1000 starts. The multivariable model for the outcome of DLF is presented in Table 2. The odds of DLF increased with increasing firmness of the going, with increasing age at first start and with increasing average horse performance index on AW surfaces. The odds of DLF decreased with increasing AW horse starts, with an increasing percentage of trainer AW wins and with more than 14 runners in the race. Horses racing between 1 and 7 days since their last start were at lower odds of DLF, compared with horses that had started between 8 and 93 days previously. No random effect terms were significant in the final model (Supplementary Table 2).

The area under the curve for the DLF model was 0.66. The residual values had a median of 0.9981 (IQR 0.9963 to 0.9984) and -0.0004 (IQR -0.0005 to -0.0003) for DLF and non-DLF starts, respectively.

Epistaxis

There were a total of 410 episodes of epistaxis, resulting in an incidence of 1.59 per 1000 starts. A total of 1,507 starts did not have the winning speed recorded and in two of these starts an episode of epistaxis was reported. The multivariable model for the outcome of epistaxis is presented in Table 3. The odds of an epistaxis episode increased with an increasing firmness of the going, with increasing horse age, at increasing winning speeds, if the race was held early in the race-card, and if the horse was a favourite or joint favourite to win the race. Horses racing between 1 and 7 days or more than 94 days since their last start were at lower odds of epistaxis, compared with horses in their first start. The odds of epistaxis decreased with increasing racing distance and was lower if the race was held in May compared to races in other months of the year. Horses that started racing as three-year-olds were at higher odds of an episode of epistaxis than those that started racing at two. Horses starting on a Fibresand surface or on second generation Polytrack® were at higher odds of epistaxis compared with horses starting on first generation Polytrack®. No significant interaction terms were identified.

The random horse effect was significant in the final model (P<0.001; 45,346) (Supplementary Table 2), as were the random effect terms for trainer (P<0.001), jockey (P<0.001), sire (P<0.001) and dam (P<0.001) (when horse random effects were not included). Coefficients or associated confidence intervals were not altered by more than 10% between models where different random effect terms had been used.

The area under the curve for the epistaxis model was 0.72. The residual values had a median of 0.9900 (IQR 0.9781 to 0.9943) and -0.0002 (IQR -0.0003 to -0.0001) for epistaxis and non-epistaxis starts, respectively.

Discussion

In the current study, we examined risk factors for three of the most common veterinary events occurring in AW racing: fatality, DLF and epistaxis. Whilst previous studies have reported differences in the incidence of these outcomes in racehorses in GB (Williams et al., 2001; Rosanowski et al., 2016), none have specifically investigated risk factors for these race-day events in AW racing. The identification of risk factors specific for race-day injury on AW surfaces is pertinent, given that the incidence of these events is higher than on turf (Rosanowski et al., 2016).

Although risk factors varied for each outcome, some factors were consistent across models. In particular, the age that the horse started racing and/or the current age of the horse were associated with all three of the outcomes investigated. For the DLF and epistaxis models, as the age at first start and/or the age of the horse increased, the risk of an adverse outcome increased. In the fatality model, there was an interaction between age and age at first start, with older horses that had started racing as two-year-olds at the highest risk of fatality. Although age has been modelled in different ways in previous studies, increasing age and/or age at first start and/or years racing and/or career length as a risk factor for race-day fatality and injury appears to be a consistent finding. Previous studies of fatal musculoskeletal injuries have identified a higher risk in horses that are four years old or older (Bailey et al., 1997; Bailey et al., 1998) and in horses that started racing as a three- or four-year-old, rather than as two-year-olds (Parkin et al., 2005). In studies of sudden death during racing and race-day fatality, older age has been associated with an increasing risk of death (Lyle et al., 2012; Georgopoulos and Parkin, 2016) and episodes of epistaxis increased with increasing years of racing (Newton et al., 2005) or increasing age (Takahashi et al., 2001). The association between age and fatal or non-fatal fracture can be explained through the accumulation of microdamage in bone, which increases with increasing horse age as an effect of exercise accumulation over time (Turley et al., 2014), and can ultimately lead to failure. Researchers have suggested that the association between age at first start and injury risk may be related to underlying clinical pathology, which may prevent a horse from racing as a two-year-old (Parkin et al., 2005). The effect of a delayed start to racing due to subclinical injury may also be occurring in conjunction with, or separate to, the effect of less accumulated training time and resultant lack of musculoskeletal adaption in horses that did not race at two years of age. Similarly, research in New Zealand has identified that horses that enter training and subsequently race as two-year-olds had longer, more successful racing careers than horses that started as three- or four-year-olds (Tanner et al., 2012).

The going, racing intensity and race distance were identified as risk factors in two out of three models. Increasing firmness of going and first race start were risk factors for both DLF and epistaxis, a finding that is consistent with previous studies of flat racing fatality (Wood et al., 2001; Henley et al., 2006), sudden death in any race type (flat or jumps) (Lyle et al., 2012) and epistaxis (Takahashi et al., 2001) on turf surfaces. While some factors had similar effects across models, other exposure variables provided a protective effect for one outcome but acted as a risk factor another. For example, in the fatality model, longer races represented a higher risk for a fatal event occurring, whereas races over shorter distances were identified as increasing the risk of epistaxis, which is consistent with findings in previous studies for these outcomes (Takahashi et al., 2001; Wood et al., 2001). In the epistaxis model, also after adjusting for race distance and going, faster winning speeds were associated with higher odds of epistaxis. This finding is similar to previous findings for race speed in flat racing horses in GB between 1996 and 1998, although neither race distance nor going were retained in this final model alongside speed (Newton et al., 2005). The risk may be higher in horses competing in faster races due to greater pulmonary vascular pressure associated with peak exertion that does not occur over longer races (Takahashi et al., 2001; Newton et al., 2005) and this factor may be combined with greater loading forces exerted during faster races (Newton et al., 2005).

Better performing horses, as measured by the average horse performance index in the fatality and DLF models, were identified as being at a higher risk of fracture or fatality. The link between performance and injury or fatality is important, as success in racing is contingent on performance. Previous studies have used official race rating to describe horse performance (Wood et al., 2001; Reardon et al., 2013), which correlates well with the horse performance index used in the current study (Compston et al., 2013). Previous GB studies identified that horses with no official race rating (i.e. lower performance horses) had a higher risk of fatality (Wood et al., 2001) or tendon injury (Reardon et al., 2013) than horses with a high rating, which is in contrast to findings in the current study. This may be due to the previous studies including horses racing on all surface types, rather than specifically on AW surfaces. A variation on official rating or horse performance index as a measure of performance was used in a study of fatality in North American flat racing Thoroughbreds (Georgopoulos and Parkin, 2016). This measure ranked the horse's race odds of winning, relative to the other horses in the race. The authors found that as race odds increased (i.e. higher odds indicated horses less favoured to win), the risk of fatality decreased, a finding that would be comparable to the performance index used in the fatality and DLF models. Similarly, in the epistaxis model, in starts where horse was ranked as favourite or joint favourite to win the race, horses were more likely to experience an episode of epistaxis. This variable has not previously been identified as a risk factor specific to epistaxis, nor for injury or fatality in GB racing.

More successful jockeys were at a lower risk of riding a start where a fatality occurred. Whilst this finding may reflect increased ability of a jockey to win, more experienced jockeys may be more aware of poor performance in their mount and subsequently pull the horse out of the race more rapidly than a less experienced jockey. If the poor performance was due to a subclinical issue, preventing the horse from completing the race may reduce the likelihood of a catastrophic breakdown. Similarly, the risk of DLF decreased with increasing trainer performance. Reardon et al. (2012) found that in horses racing over hurdles there was a reduced risk of tendon injury in horses from high performing trainers. In contrast, the fatality model identified more successful trainers' horses to be at higher odds of death.

This may reflect a proportion of 'make-it or break-it' trainers, i.e. trainers who are overall successful, but at a cost of an increased number of race-day fatalities. Further investigation into training practices may be warranted in light of this finding.

Starts in 2002 and in August, September and October were found to have an increased risk of fatality, compared to starts in other years or months, while starts in May where at a lower odds of an episode of epistaxis, compared to other months. The reason for these findings is unclear, although it is possible that the increased risk in August, September and October may be related to the quality of horse racing on the AW surfaces at the end of summer. During interview, several racecourse Clerks reported a perceived change in horse quality attending AW race meeting in these months. Although a measure of horse performance was included in the model, it could be that the population of horses racing on AW surfaces at this time of year is inherently different from the AW horse population at other times of the year, with more successful horses being targeted towards potentially more profitable races on turf at the end of the season.

Despite investigating course- and surface-related variables for inclusion in the models presented here, no association was found between the risk of fatality and DLF and course or surface variables. Previous studies have identified training surface as a risk factor for race-day fatality (Parkin et al., 2004) and for stress fractures during training (Verheyen et al., 2006; MacKinnon et al., 2015). However, training data are not available for this cohort of horses. In the current study, epistaxis was associated with the type of surface used at the course. This finding may be due to differences in the loading of the forelimbs when racing on AW surfaces, as has been proposed as a reason for epistaxis in jump racing (Newton et al., 2005). The mechanical properties of each surface type, particularly those with and without a wax binder, would have varied and affected the dynamics of limb loading, hoof acceleration and ground reaction forces (Chateau et al., 2009; Setterbo et al., 2009). The mechanical properties of a surface can vary due to the composition of the surface, and also due to the maintenance and refurbishment regimens used on the surface (Peterson and McIlwraith, 2008; Thomason and

Peterson, 2008). Interviews with the Clerks of each course identified a wide variation in the maintenance and management of each of the surfaces in preparation for racing and during race-days. Unfortunately no records were kept of such maintenance activities, and the wide variety of practices did not enable creation of variables to capture this information in a standardised way. Further research regarding the effect of the mechanical properties and maintenance of the surfaces on racehorse injury is warranted.

Classification trees were used to screen the large number of exposure variables relating to each outcome variable. The technique was suitable for this study, as each outcome was binary and classification trees are flexible as they can be applied to mixed exposure variable types (continuous, categorical) with no assumptions regarding distributions (Camp and Slattery, 2002). This study used the successive splitting of the data into increasingly homogeneous subsets to identify interaction terms, two of which were identified in the mixed effects fatality model. Classification trees have previously been used as an alternative to logistic regression analyses in risk factor and interaction studies of human cancer (Camp and Slattery, 2002), malaria (Thang et al., 2008) and as a decision support tool for Bovine Spongiform Encephalopathy in cattle (Saegerman et al., 2004), although in the current study classification trees were used as part of the logistic regression modelling technique. This technique allowed variables to be screened for potential interactions more quickly and thoroughly than only using logistic regression.

This study has identified risk factors for the common veterinary events occurring in horses competing in AW racing. While the rates are higher on AW surfaces than on turf (Rosanowski et al., 2016), overall the incidence of fatality, DLF and epistaxis were low throughout the 14-year study period. This finding is positive for the racing industry, but does create a limitation for the current study in terms of the predictive ability of the current models. The predicted probability from the full models on the 2000 to 2013 data were reasonable for starts where events did not occur. However, due to the low incidence of events in the current study and the low predicted probability for event starts, the models are unlikely to be useful for predicting the occurrence of future outcomes. This is supported by the moderate areas under the ROC curves identified. Further work is needed to enable better identification of individuals at risk of an adverse outcome during racing. Nonetheless, this study provides further evidence of the association between the risk of race-day injuries and fatalities and current age, age at first start, race distance, going and horse performance. Further, the models have identified the impact the jockeys and trainers may have on the risk of events, and that while the incidence of events is higher on AW surfaces than on turf, the type of AW surface does not appear to be directly associated with the risk of fatality or DLF. These findings will provide the racing industry with information to develop strategies to further reduce the occurrence of race-day events on AW surfaces. This may include closer inspection of horses with attributes that may put them at higher risk of injury and/or longitudinal monitoring of trainer and jockey performance to identify trends that could trigger timely intervention. However, it must be acknowledged that interventions strategies should not be solely based on the results of risk factor analysis. Instead, strategies also need to consider measures of impact, which are related to prevalence of exposure in the population.

Ethical animal research

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

Conflict of interest

The authors report no conflict of interest.

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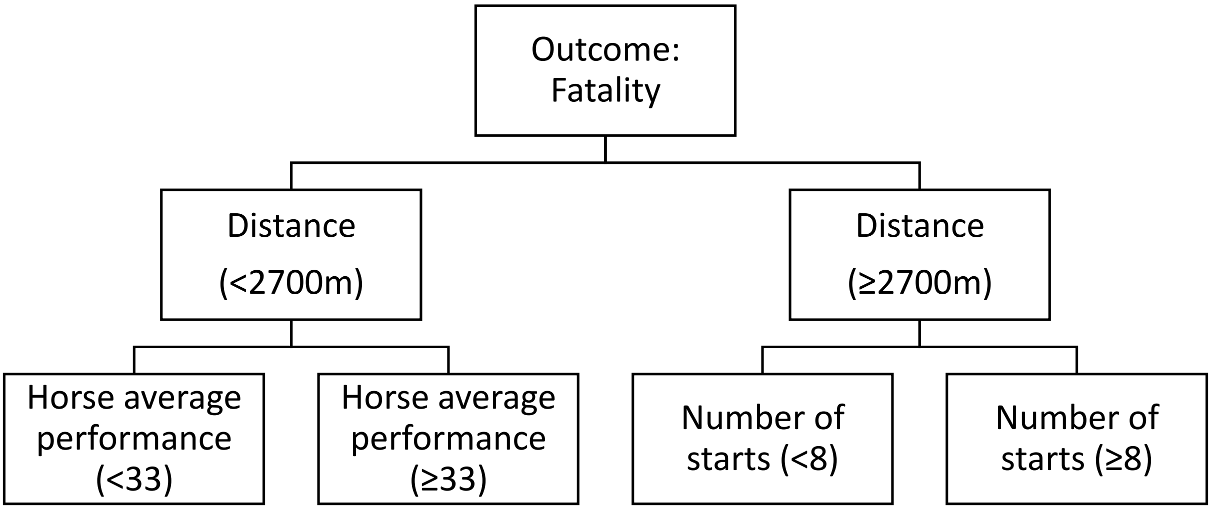

Figure 1: An example of a classification tree analysis for all-weather fatality, including the explanatory variables of distance (in metres), horse performance and the number of starts. An interaction Is identified when the effect at the lower 'branch' of the tree (horse average performance or number of starts) on the outcome (fatality) depends on a higher branch (i.e. race distance). In each classification tree analysis, each time the tree branches, an interaction is identified. In this example, two interaction terms were identified (distance x horse average performance and distance x number of starts). Interactions identified in 10% of classification tree analyses were tested in the mixed effect logistic regression model.

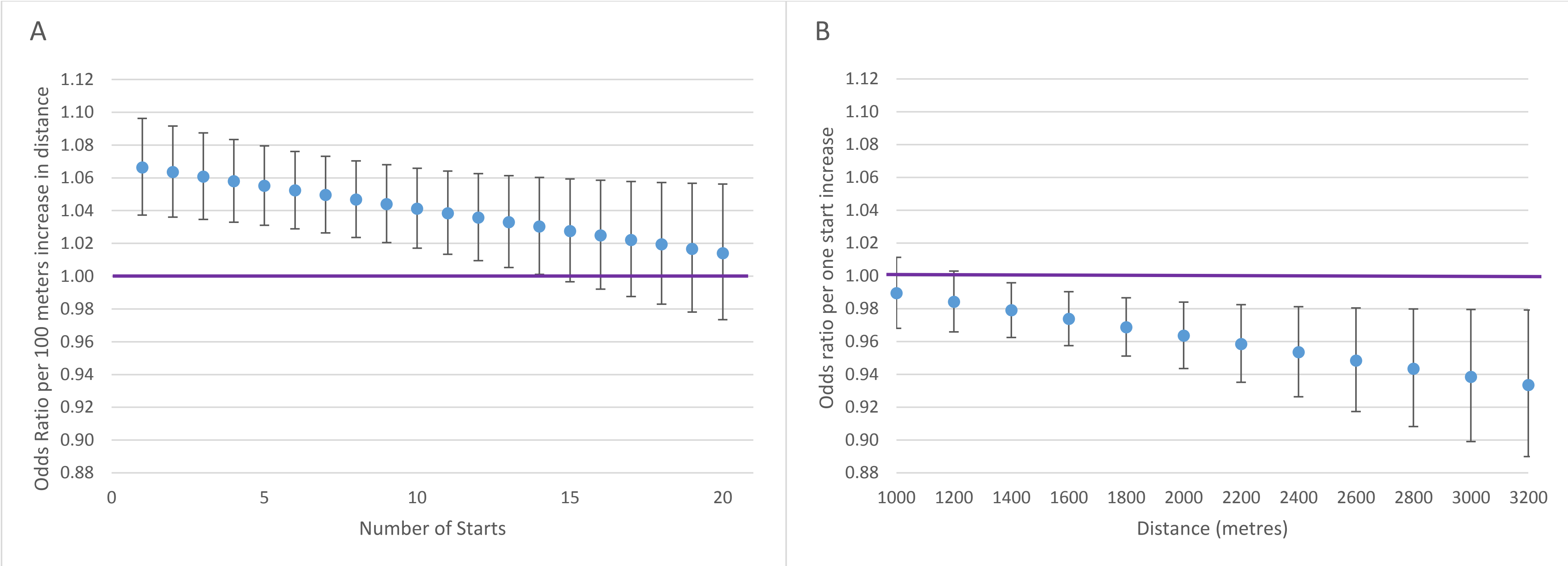

Figure 2: Graphical representation of the interaction between horse starts and distance included in the logistic regression model with the outcome of fatality. (A) odds ratio per 100 meters increase in distance at varying starts and (B) odds ratio per one start at varying distance. Odd ratio for per 100 metres increase in distance for a horse with K starts can be calculated as EXP(100*0.000668+100*K*-2.7×10^{-5}); odds ratio for per one horse start increase at race distance D can be calculated as EXP(1*0.015841+1*D*-2.7×10^{-5}).

Table 1: Multivariable mixed effects logistic regression results including a random effect for horse for the risk factors for all-weather surface fatality in British flat racing Thoroughbreds, 2000 to 2013.

Variable	**Category**	**No. of Cases**	**No. of Starts**	**Incidence (/1000 starts)**	**Odds Ratio (95% Confidence interval)**	**Wald test P value**	**Likelihood ratio test P Value**
Year	Not 2002	208	244,711	0.85	Reference		0.001
	2002	25	13,482	1.85	2.26 (1.49 - 3.44)	<0.001	
Month	Nov to Jul	172	208,239	0.83	Reference		0.01
	Aug, Sep, Oct	61	49,954	1.22	1.50 (1.12 - 2.03)	0.01	
Distance (per 100 metres)					1.07 (1.04 - 1.10)	<0.001	<0.001
Number of AW horse starts					1.02 (0.97 - 1.06)	0.48	0.48
Distance x no. of AW horse starts[a]					0.997 (0.995 – 1.00)	0.05	0.04
Auction race	No	211	241,401	0.87	Reference		0.02
	Yes	22	16,792	1.31	1.77 (1.11 - 2.81)	0.02	
Average AW horse performance index					1.02 (1.01 - 1.03)	0.004	0.01
Percentage of AW jockey prior wins					0.96 (0.94 - 0.99)	0.02	0.02
Trainer in the top performing 10% [b]	No	194	229,903	0.84	Reference		0.02
	Yes	39	28,290	1.38	1.55 (1.08 - 2.23)	0.02	

Current age and age at first start (years) interaction	Start at 2, currently 2 to 6	116	171,816	0.68	Reference		<0.001
	Start at 2, currently 7+	37	24,566	1.51	2.95 (1.95 – 4.47)	<0.001	
	Start at 3+, currently 2 to 6	70	51,313	1.36	1.76 (1.29 – 2.38)	<0.001	
	Start at 3+, currently 7+	10	10,498	0.95	1.60 (0.82 – 3.12)	0.17	
Random effect (horse n=45,423)							0.47

[a] Odds ratio per 100 metres increase in distance for a horse with K starts can be calculated as EXP(100*0.000668+100*K*-2.7×10^{-5}); odds ratio for per 1 horse start increase at race distance D can be calculated as EXP(1*0.015841+1*D*-2.7×10^{-5}). Please see Figure 2.

[b] of flat racing trainers. Based on average trainer performance score for all flat racing starts for that trainer.

Table 2: Multivariable mixed effects logistic regression results including a random effect for horse for the risk factors for all-weather surface distal limb fracture in British flat racing Thoroughbreds, 2000 to 2013.

Variable	Category	o. of ases	No. of Starts	Incidence (/1000 starts)	Odds ratio (95% Confidence interval)	Wald test P value	Likelihood ratio test P value
Going	Standard to fast or fast		3,247	2.77	3.13 (1.28 - 7.61)	0.01	0.03
	Standard	25	241,714	0.93	1.08 (0.59 - 1.99)	0.8	
	Standard to slow or slow	1	13,232	0.83	Reference		
Number of runners	Fewer than 14	25	224,043	1	Reference		0.02
	14 or more	0	34,150	0.59	0.59 (0.37 - 0.93)	0.02	
Age at first start (years)	2	52	196,382	0.77	Reference		<0.001
	3	7	52,941	1.45	1.86 (1.40 - 2.47)	<0.001	
	4+	6	8,870	1.8	2.29 (1.34 - 3.92)	0.002	
Number of AW horse starts					0.97 (0.95 - 0.99)	0.004	0.003
Average AW horse performance index					1.02 (1.01 - 1.03)	<0.001	<0.001

Trainer AW percentage wins	<6.86	3	64,784	1.13	Reference		0.01
	6.86 to 9.1	5	64,344	0.7	0.61 (0.42 - 0.90)	0.01	
	9.11 to 12.25	7	64,518	0.73	0.57 (0.39 - 0.83)	0.004	
	12.26+	0	64,547	1.24	0.88 (0.63 - 1.23)	0.45	
Racing intensity	First start	8	14,366	1.25	Reference		0.02
	1 to 7 days	7	30,725	0.55	0.51 (0.26 - 1.03)	0.06	
	8 to 93 days	94	186,387	1.04	0.86 (0.51 - 1.44)	0.56	
	94 days plus	6	26,715	0.6	0.48 (0.24 - 0.96)	0.04	
Random effect (horse n=45,423)							0.12

Table 3: Multivariable logistic regression results including a random effect for horse for the risk factors for all-weather surface epistaxis in British flat racing Thoroughbreds, 2000 to 2013.

Variable	**Category**	**No. of Cases**	**No. of Starts**	**Incidence (/1000 starts)**	**OR (95% CI)**	**Wald test P value**	**Likelihood ratio test P value**
Going	Fast	6	3,213	1.87	2.55 (0.94 – 6.95)	0.67	0.01
	Standard	388	240,334	1.61	2.12 (1.22 – 3.69)	0.01	
	Slow	14	13,139	1.07	Reference		
Sequence	Early	141	71,883	1.96	Reference		0.01
	Middle	123	70,485	1.75	0.60 (0.47 - 0.76)	<0.001	
	Late	144	114,318	1.26	0.95 (0.74 - 1.22)	0.7	
Winning speed (seconds per furlong)	<12.4	118	64,875	1.82	Reference		0.01
	12.4 to 12.8	129	78,272	1.65	0.79 (0.59 - 1.06)	0.12	
	12.9 to 13.4	79	56,573	1.4	0.57 (0.39 - 0.84)	0.004	
	13.5 to 16	82	56,966	1.44	0.55 (0.36 - 0.82)	0.004	
Distance (per 100metres)					0.96 (0.93 - 0.99)	0.003	0.002
Current age (years)	2	15	35,619	0.42	Reference		<0.001
	3	62	73,279	0.85	2.40 (1.33 - 4.32)	<0.001	
	4	120	54,416	2.21	6.85 (3.86 - 12.16)	<0.001	
	5	81	35,498	2.28	7.67 (4.24 - 13.88)	<0.001	
	6	44	23,023	1.91	6.46 (3.43 - 12.15)	<0.001	

	7+	86	34,851	2.47	9.77 (5.32 - 17.94)	<0.001	
Age at first start (years)	2	273	195,237	1.4	Reference		0.002
	3	119	52,620	2.26	1.65 (1.26 - 2.16)	<0.001	
	4+	16	8,829	1.81	1.03 (0.57 - 1.84)	0.92	
Racing intensity	First start	13	14,305	0.91	Reference		0.01
	1 to 7 days	40	30,499	1.31	0.77 (0.39 - 1.50)	0.44	
	8 to 93 days	319	185,334	1.72	1.24 (0.69 - 2.24)	0.47	
	94 + days	36	26,548	1.36	0.88 (0.45 - 1.73)	0.72	
Favourite or joint favourite	No	344	228,518	1.51	Reference		0.002
	Yes	64	28,168	2.27	1.6 (1.21 - 2.13)	0.001	
Month	Not May	399	245,899	1.62	Reference		0.01
	May	9	10,787	0.83	0.44 (0.22 - 0.86)	0.02	
Surface type	First generation Polytrack®	117	106,908	1.09	Reference		<0.001
	Second generation Polytrack®	127	77,700	1.63	1.85 (1.33 - 2.58)	<0.001	
	Fibresand	164	72,078	2.28	2.66 (1.96 - 3.60)	<0.001	
Random effect (horse n=45,364)							<0.001