An investigation of risk factors associated with injuries to horses undertaking jump racing in Great Britain

Richard John Maurice Reardon
BVetMed(hons) MVM CertES(Orth) Dip ECVS MRCVS

Submitted in fulfilment of the requirements for the Degree of Doctor in Philosophy

Faculty of Veterinary Medicine
College of Medical, Veterinary and Life Sciences
University of Glasgow

July 2013

Abstract

Thoroughbred horse jump racing is popular in Great Britain (GB). Unfortunately it is associated with inherent risk of injury to the horses involved and it has been shown that the risk is significantly higher in jump than in flat racing. As a result, jump racing has been made a priority in racehorse injury investigation by the racing authorities in GB and is the focus of this thesis.

Data about injuries and fatalities collected by veterinary surgeons, from all official race meetings between 2000 and 2009 was made available by the British Horseracing Authority (BHA). Following initial examination of the data, review of the literature and discussion with the BHA, a list of outcomes (injuries and fatality) was defined for further investigation. Multivariable logistic regression modelling was employed to investigate associations between potential risk factors and the outcomes. Model validation techniques were then used for outcomes with the greatest frequencies. In addition, post-mortem (PM) findings from a subset of the available data provided the opportunity to evaluate the accuracy of the information provided.

Outcomes selected for further investigation were: fatality, tendon strain, epistaxis, hind limb fracture, pelvic fracture, and proximal forelimb fracture. Multiple risk factors were identified as being significantly associated with each outcome which can be used to guide legislation or further investigation. Risk factors common to many of the outcomes were: season, surface firmness (going), race distance and previous racing history (especially previous flat start history). Notably in some instances the relationships between these common risk factors and the outcomes varied, such that a risk factor might be associated with increased likelihood of one outcome but a decreased likelihood of another.

Attempts to validate the models with the most frequent outcomes (fatality, superficial digital flexor tendinopathy and epistaxis) against a novel data set (from the year 2010), demonstrated variable calibration and discrimination and relatively poor predictive ability for all of the models. This was thought to be related to the low outcome frequencies and potentially related to risk factors unaccounted for in the models. Evaluation of the accuracy of the recording system for fatal distal limb fractures using PM findings demonstrated good identification of fracture presence, but relatively poor definition of all affected bones.

Frustratingly it was concluded that making policy decisions based on the risk factor models will not be straightforward. Few risk factors had strong associations with all outcomes, not all risk factors are readily modifiable and many potential modifications (such as stopping horses from racing) would have major long term deleterious implications for horses. However, new risk factors for injury were identified providing some additional information about injury aetiology; previously recognised associations (such as firm ground and injury) are supported by the work; and sensible recommendations can be made to the industry, such as: closer monitoring of horses based on their previous racing careers or previous injuries. In addition, further training of racecourse veterinarians and/or provision of diagnostic aids (such as radiography) can be recommended to help with diagnoses made at the racecourses.

Contents

List of Tables

List of Figures

List of Accompanying Material

Published Papers:

1. Reardon RJ, Boden LA, Mellor DJ, Love S, Newton JR, Stirk AJ, Parkin TD (2012). Risk factors for superficial digital flexor tendinopathy in Thoroughbred racehorses in steeplechase starts in the United Kingdom (2001-2009). Vet J. 195 (3) 325-330.

2. Reardon, R.J., Boden, L.A., Mellor, D.J., Love, S., Newton, J.R., Stirk, A.J., Parkin, T.D. (2012). Risk factors for superficial digital flexor tendinopathy in Thoroughbred racehorses in hurdle starts in the UK (2001-2009). Equine Vet J. 2012 Sep; 44(5):564-9.

Acknowledgement

I would like to thank Dr Tim Parkin for his considerable, help support and advice throughout this research. I feel extremely lucky to have had such an enthusiastic, knowledgeable and friendly supervisor.

Mr Anthony Stirk was instrumental in setting up data collection for this research. I would like to thank him for his willingness in sharing his extensive knowledge of the subject, for his enthusiasm in promoting the research and genuine interest in the results that I have produced.

I would also like to thank the following for their help with this thesis:

Dr Lisa Boden for readily sharing her expertise, and smiling when I told her I could get it all done in 6 months.

Professor Sandy Love, for encouraging me to apply for the position and then for providing guidance about horse racing as well as the technicalities of getting a thesis finished.

Professor Dominic Mellor, for providing experienced opinions from a different perspective, which helped considerably at times of blinkered paper submission.

Professor Paddy Dixon for help with final corrections and proof reading – hugely appreciated help in getting over the final hurdle.

Dr Richard Newton for help with paper reviews and for sharing his experience from the field.

Dr Matt Denwood for his exceptional help with the intricacies of “R”, almost always at the last minute, but always with a (outward) smile.

The PhD students who shared an office with me, for their advice about being a good post-graduate student, especially their critique of my posters and presentations.

The staff of Weatherbys and BHA for their help and support with provision of data and advice about its interpretation.

The Horserace Betting Levy Board for funding the research, including the post-mortem work and Tim Parkin's position between 1999 and 2005.

I would like to thank my wonderful parents and in-laws for their support over the three years taken to produce this work. I think they must be wondering when I'll stop finding a new thing to worry about – "just off to work on my PhD". Finally I would like to thank my darling wife Kyla for her support over three relatively tough years – she has been amazing.

Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, that this thesis is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Signature ___ ____

Printed Name ____Richard Reardon____

Definitions/Abbreviations

GB = Great Britain

BHA = British Horseracing Authority

PM = Post Mortem

BC = Before Christ

NHF = National Hunt Flat

USA = United States of America

MSI = Musculoskeletal Injury

PSB = Proximal Sesamoid Bone

SDF = Superficial Digital Flexor

EIPH = Exercise Induced Pulmonary Haemorrhage

US = United States

NH = National Hunt

VO = Veterinary Officer

AIC = Akaike Information Criterion

km = Kilometres

SDFT = Superficial Digital Flexor Tendon

OR = Odds Ratio

C.I. = Confidence Interval

rho = Residual Intraclass Correlation Coefficient

ROC = Receiver Operator Curve

lbs = Pounds

POFB = Proportion of Field Beaten

FL = Forelimbs

HL = Hind limbs

PhD = Doctor in Philosophy

MCPJ = Metacarpophalangeal joint

HLF = Hind Limb Fracture

PF = Proximal Forelimb

PAF = Population Attributable Fraction

1 Review of the Literature

1.1 Introduction

1.1.1 Horseracing Background

Reports of horses being raced competitively go back as far as 6000 years, whilst ridden horse racing was part of the Olympics as long ago as 648 BC. The Thoroughbred breed originated much later, in the late 17th and early 18th century and now predominates in the most common types of racing. To this day horseracing has genuine global appeal and is watched in almost every nation of the world. The industry associated with this sport is responsible for the employment of an enormous number of people, as well as for the care of a significant number of horses. In the year 2010, 354,123 horses ran in officially regulated races in 51 different countries[1] and considering that many horses are bred and trained for racing, without ultimately running a race (Wilsher et al., 2006) the actual number of horses associated with racing is likely to be considerably higher. Significant amounts of money are associated with the sport; world-wide in 2010, a prize fund of just over £3 billion pounds was awarded, whilst gambling associated with horse racing was estimated to be worth approximately £69 billion[1]. Three types of horseracing predominate: flat racing; racing over jumps; and harness racing, the latter of which usually involving the Standardbred breed, the popularity of each varying with geographical location. Based on reports from international racing authorities; world-wide in 2010 there were 154,340 flat races (involving 230,041 horses); 7,919 jump races (involving 19,184 horses); and 133,972 harness races (involving 104,898 horses)[1].

Jump racing is a unique mainstay of British racing. In 2010, 48% (9,212/19,242) of the racehorse population in Great Britain (GB) took part in this form of racing[1]. Worldwide 41% (7,840/19,178) of racehorses undertaking solely jump racing, competed in GB with Ireland (25%) and France (21%) being the only other countries with significant numbers of jump racehorses[1]. In GB two major types of jump racing predominate: “hurdle” and “steeplechase” racing: Hurdle racing involves jumping timber obstacles (hurdles) whilst steeplechase racing involves jumping a variety of obstacles, which can include: Plain fences (larger than hurdles); Water jumps where horses clear a fence with water on the landing side; and/or open ditches, which are fences with ditches on the take-off side. Despite the declining financial situation and recent recession in GB, over the ten years

[1] http://www.ifhaonline.org/home.asp

from 2000 the number of jump races increased by nearly 10% showing that racing still continues to be a popular sport.

1.1.2 Injuries

Unfortunately, there is an inherent risk of injury to horses involved in racing. However, there is a risk of injury for participants in all sports, for example, overall yearly prevalence of running injuries in people has been reported as between 37% and 56% (Van Mechelen, 1992) and a recent study of the 2011 world athletic championships reported an injury incidence rate of 134.5 per 1000 athletes (Alonso et al., 2012). Whilst these injury rates are considerably higher than most of those reported in horse racing, critics of horse racing argue that horses, in contrast to human athletes, are not given a choice in whether or not they take part in this risk. In addition, the injuries sustained by horses are often more severe than those sustained by people and frequently have significant consequences, including death. Considering the serious consequences of some of these injuries it is clear that every attempt should be made to minimise the risk of horse injury. A first step in attempting to reduce this risk is to define how much there is, i.e. how likely is an injury to occur, as this enables evaluation of changes over time and / or changes in response to interventions.

Previous research has shown that the risk of suffering an injury (fatal or not) in jump racing is significantly greater than in flat racing (Williams et al. 2001). In that study a 3 year period of surveillance was conducted from 1996-1998 by The Jockey Club, in which they recorded racing injuries, post-race clinical problems and fatalities from all British racecourses. When they stratified the incidents by race type, they reported that the incidence of clinical events, including fatalities, per 1000 starts was highest in steeplechase racing (24.7), followed by hurdle racing (19.45), National Hunt Flat (NHF) racing (8.46) and was lowest in flat racing (3.97). As a result of this and other work, jump racing has been made a priority in racehorse injury investigation in GB and is the focus of this thesis.

1.1.3 Identifying Risk

Definition of injury risk requires identification of an injury (outcome) of interest and a population to study. One of the first papers to report horse injuries as part of a population was published in 1960’s in relation to “leg injuries” in racehorses (Montgomery, 1965). Since then, not only have the numbers of studies describing the risk of different injuries increased, but so have the number of animals studied, the specificity of injury definitions and attempts to make meaningful conclusions from these studies. This has been facilitated by the introduction of injury recording schemes and the use of computerised databases. Whilst the number and size of studies have increased, as with all scientific studies, the information reported is subject to certain biases and limitations. In a lot of studies the information is collected only from the racecourse, which means that injuries which occur during training or that are diagnosed after leaving the course are not included. Studies also have the potential to be affected by a number of biases which include: “interviewer bias”, where people reporting injuries are more likely to look out for them if they know they need to record them and “measurement bias” resulting from limitations in diagnosis or errors in recording.

1.1.4 Identifying Risk Factors

Identification of risk factors commonly relies on the identification of statistically significant associations between these risk factors and an outcome. In simple terms, statistically significant associations are those that occur more frequently than would be expected by chance. It is also possible to quantify the strength of these associations e.g. how much more likely is an outcome to occur if the variable is present, than if it is not? There is an important difference between statistically significant associations and causal relationships between variables, which can make interpretation of risk factor studies more challenging, especially considering the complex interplay of the multiple variables associated with racing.

Potential risk factors can be grouped based on their origin into those associated with: the horse; the racecourse; the trainer; the jockey; and the individual race. Within these categories there is considerable interconnection, for example a horse’s training history is determined by its trainer, who in turn is picked by the horse’s owner. A simplified graphical representation of these complex confounding relationships is shown in Figure 1-1. There are a large number of factors (biases) associated with these interconnections that determine which starts are made by which horses. These need to be considered when trying to understand apparent significant associations.

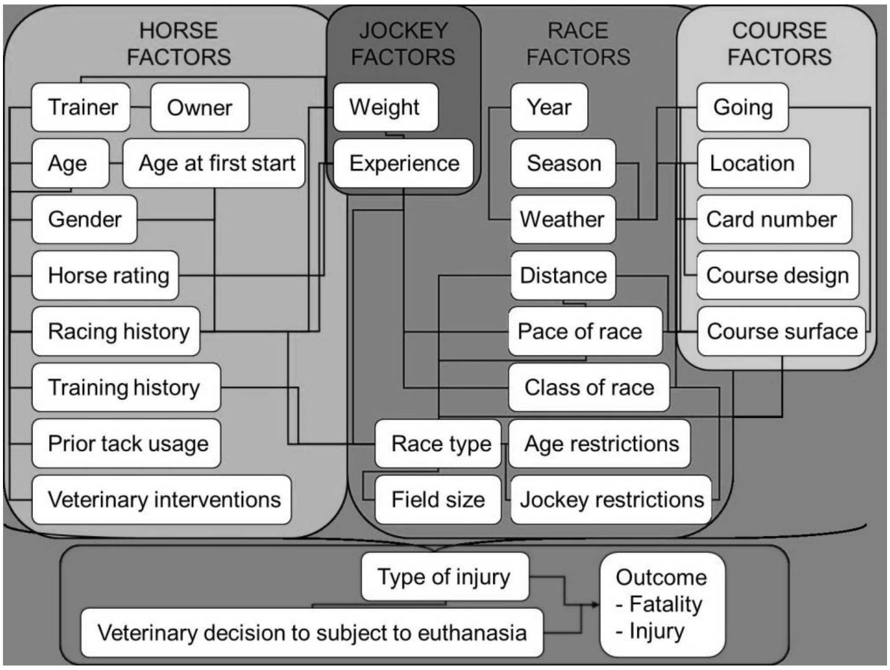


Figure 1-1: Graphical representation of factors associated with each race start and an outcome (injury). After (Parkin, 2010)**.**

Early risk factor studies identified significant associations between individual risk factors and outcomes of interest. Later studies have begun to recognise the importance of not only including as many potential risk factors as possible, but including them as part of analyses which take into account multiple variables at the same time and have sufficient power to identify significant associations. This is important to try and avoid the potential effect of confounding relationships. For example, consider a situation where:

1. There is a significant association between horse age and risk of distal limb fracture; with older horses being more prone to the condition.
2. There is a significant association between horse age and “type of racing” with the population of horses in steeplechase racing being significantly older than those running in flat racing.
3. There is not a significant association between “type of racing” and risk of distal limb fracture.

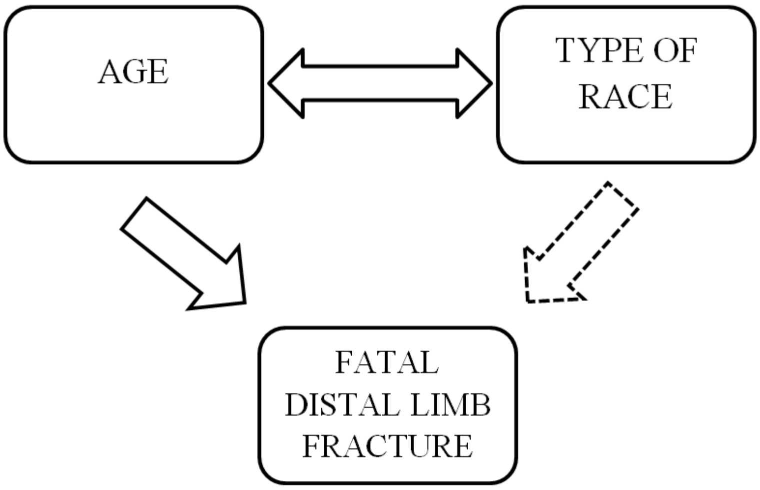


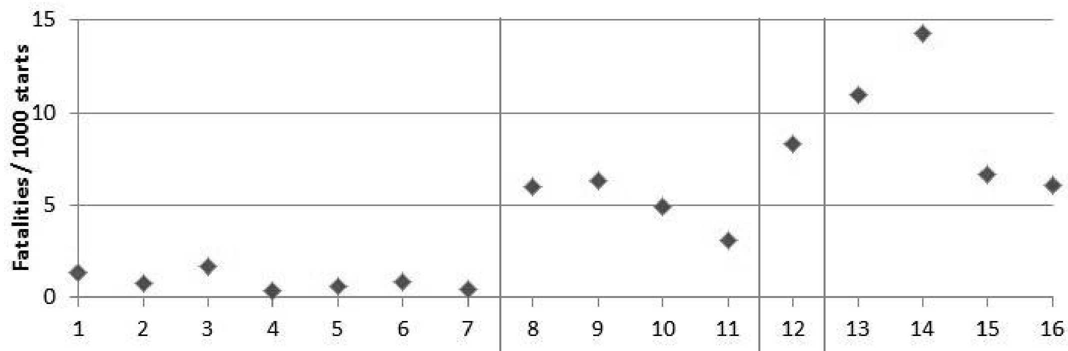
Figure 1-2: Diagram representing associations between variables in the above described hypothetical situation. Arrows represent associations between variables. Dotted arrow represents apparent association, as a result of confounding.

If we analysed the association between type of racing (steeplechase or flat) and distal limb fracture, without taking into account horse age, it is possible that we would conclude that type of racing was significantly associated, because of the confounding effect of horse age (dotted arrow in Figure 1-2). Using a modelling technique that accounted for all the variables together, it is more likely that true associations can be identified. With the development of powerful computers and statistical modelling techniques, the ability to manipulate large sets of data, to take multiple variables into account at once and with sufficient power to identify significant risk factors is perhaps more straightforward than it used to be. Summaries of the studies reporting risk factors for common outcomes and injuries, with discussion of potential aetiologies as well as some of the limitations of these studies, are reviewed in the following pages.

1.2 Fatality

1.2.1 Frequency of Fatality in Thoroughbred horse racing

Fatality rates are commonly reported as number per thousand starts and are reported to range between 0.44-1.7 and 4-14 per thousand starts in flat and jump racing, respectively (Bourke 1994; Peloso et al. 1994; Mckee 1995; Estberg et al. 1996; Bailey et al. 1998; Wood et al. 2000; Stephen et al. 2003; Boden et al. 2006). Reported rates by publication year, country and type of racing are shown in Figure 1-3. Differences in fatality rates are also observed within race type, for example fatality in flat racing between two American states (California and Kentucky) and that reported in Victoria (Australia). These differences could be the result of variation in a variety of factors between countries, such as: the races (race length, speed, surface), the horses, the racing regulations, the climate or the accuracy of reporting. This highlights the need for local evaluation of risk and risk factors.



Country	USA	UK	USA	Aus	Aus	UK	Aus	Aus	Aus	UK	USA	Aus	Aus	Aus	UK	USA
Region	KY		CA	Vic	Mel		Vic	Vic	Mel		Vir	Vic	Vic	Mel		Vir
Year	94	95	96	94	98	00	06	94	98	00	03	06	94	98	00	03
Ref	a	b	c	d	e	f	g	d	e	f	h	g	d	e	f	h
Fatalities	51	-	64	139	196	379	283	57	52	867	9	191	40	53	695	9
RT	Flat							Hurdle				J	Steeplechase			

Figure 1-3: Fatality rates by race type, year and country/region.
Key: USA=United States of America; UK=United Kingdom; Aus=Australia; KY=Kentucky; CA=California; Vic=Victoria; Mel=Melbourne; Vir=Virginia; Year 90s=1900s, 00s=2000s; -=not recorded; RT=Race Type; J=Jump; Ref = References: a=(Peloso et al., 1994); b=(Mckee, 1995); c=(Estberg et al., 1996); d=(Bourke, 1994); e=(Bailey et al., 1998); f=(Wood et al., 2000); g=(Boden et al., 2006); h=(Stephen et al., 2003).

It can be observed that reported fatality rates are based on varying study sizes, which may partially explain some of the differences observed (confidence intervals are not included, as data were not available to produce them for all outcomes). All of the studies report cases of fatality that occurred at the racecourse only and as such are underestimations of the cases of fatality caused by racing, because they do not take into account the number of horses that left the track with an injury (sustained during racing) that they were subsequently euthanased for. Notably a significant proportion of cases were the result of euthanasia, the decisions for which were based on available treatments and/or trainers' or owners' choice. As such, changes in fatality rates over time should be interpreted with caution as factors such as: improvements in treatments or deterioration in economics can have an effect on the decision to attempt treatment rather than euthanase at the racecourse. This is especially important when considering outcomes of low frequency (such as fatality in flat races).

The most frequently reported causes of racehorse fatality include fractures, tendon injuries, vascular ruptures and "sudden death" as described below. Risk factors for fractures and tendon injuries will be discussed separately in this chapter. Sudden death during racing has been reported to have a prevalence of between 0.08-0.29/1000 starts in flat and jump races respectively (Boden et al., 2006) and to make up between 9% and 12% of fatalities in other studies (Johnson et al., 1994; Lyle et al., 2011). A recent study reported that the most common causes of sudden death in the 53% of the population in which a definitive post-mortem diagnosis could be made were: cardiac failure, apparent pulmonary failure, pulmonary haemorrhage, haemorrhage associated with pelvic fractures or with idiopathic blood vessel rupture, and spinal cord injury (Lyle et al., 2011). Information such as this can be very useful for racecourse veterinarians dealing with cases of sudden death at the racecourse.

1.2.2 Risk Factors for Fatality

Table 1-1 represents a summary of variables reported to have an association with the risk of fatality in Thoroughbred racing and demonstrates how the number of variables examined increased over time. Older horse age and male sex are frequently reported as being associated with increased risk of fatality. A plausible explanation for this is that owners would be less willing to spend money for treatment of older horses without potentially long future careers and male horses without breeding potential, resulting in increased likelihood of euthanasia, given an injury, in these categories. Although horse age was not reported as significantly associated in the final models from Australia, it was identified as being significant in both during univariable analysis (Boden et al., 2007a, 2007b). Notably in an earlier study from California (USA) (Johnson et al., 1994) the opposite was reported, with a significantly higher number of training-related deaths in the 2 year old than in the ≥3 year old group.

Table 1-1: Variables reported as being significantly associated with increased likelihood of fatality during racing (+/- training). Grey boxes highlight reported significant associations. White boxes highlight variables examined and not found to be significant. Text in boxes provides further details about the association. NE refers to variables that were not examined.

Lead Author (Year)[a]	Country (Region)	Race Type(s)	Older Horse Age	Male Sex	Race Type	Firmer Track Surface	Increase Race Distance	Racing History	Other
***Johnson* (1994) *[b]**	USA[c] (CA)	Flat			NE	NE	NE	NE	
***Estberg* (1995) ***	USA (CA)	Flat	NE	NE	NE	NE	NE		
***Estberg* (1996) ***	USA (CA)	Flat	4 v 3[d]		NE	NE	NE	NE	
***Cohen* (2000)**	USA (KY)	Flat		NE	NE	NE	NE		
***Hernandez* (2001)**	USA (FL)	Flat		G v F[e]	NE	T v D[f]			
***Williams* (2001)**	UK	Both	Fl & Hu[g]	NE			NE	NE	
***Henley* (2006)**	UK	Both							
***Boden* (2007a)**	Aus (Vic)	Flat			NE	Fast			
***Boden* (2007b)**	Aus (Vic)	Jump							

[a] Year of publication. [b] *=injuries also recorded from training. [c] Country and region abbreviations: USA=United States of America; CA=California; KY=Kentucky; FL=Florida; UK=United Kingdom; Aus=Australia; Vic=Victoria. [d] 4 year olds compared to 3 year olds. [e] Geldings compared to Females. [f] Turf compared to Dirt. [g] Flat and Hurdle races.

Race type was consistently found to be associated with risk of fatality in the studies that evaluated it, with jump and steeplechase races in particular, being associated with higher risk. This has been attributed to the risk of falling at fences in jump racing (Williams et al. 2001; Pinchbeck 2004; Boden et al. 2006), the increased distance travelled in jump races

(Wood et al. 2000; Hernandez et al. 2001; Parkin et al. 2004c, 2004d; Boden et al. 2007a), as well as differences in the population of horses undertaking each type of racing, for example horses undertaking jump racing tend to be older than horses in flat racing (Krook & Maylin 1988; Poole & Meagher 1990). Of the studies that evaluated racing surface only one, a study of risk factors for fatality during jump racing in Victoria (Australia), failed to find an association between "hard" or "fast" racing surface and the risk of fatality (Boden et al., 2007b). This is of interest because a study by the same authors conducted using the same methodology on a population of horses undertaking flat racing did recognise track "going" to be a risk factor. This difference could be the result of another factor taking precedence in the risk during jump racing. Increased race distance was recognised as a significant risk factor in two of the four studies that included it in analyses, with odds ratios of: 1.035 (95% C.I. 1.006-1.065) (per additional furlong [1/5 km]) and 1.45 (95% C.I. 1.05-2.01) (per additional km) (Henley et al., 2006; Boden et al., 2007a), respectively and has been proposed as being associated with increased horse fatigue and/or increased time at risk.

Horses' previous racing and training histories were found to be significantly associated with risk of fatality in every study that examined them, although the categorisation and means of assessment varied between studies. In a study of exercise in training and racing it was determined that the relative risk of fatal musculoskeletal injury during racing was significantly (3 times, 95% C.I. 1.2-7.6) greater for horses which ran cumulative racing and training distances in excess of a cut-off defined in the paper (Estberg et al. 1995). This finding was in contrast to a study from Kentucky which reported that decreased cumulative high-speed exercise in the months preceding a race was a risk factor for fatality (Cohen et al., 2000) and an Australian study which reported that increased previous distance in jump racing reduced the likelihood of suffering a fatality in flat racing (Boden et al., 2007a). Other studies have reported differing association with the numbers of previous starts: with a study from GB reporting increased risk of fatality with decreased previous starts (Henley et al., 2006), whilst one from Australia reported the opposite (Boden et al., 2007b).

Studies have also examined associations with different time periods from the previous race: a study from Florida reporting increased risk of fatality if it was greater than 33 days since the horse's previous race (Hernandez et al., 2001), whilst one study from Victoria (Australia) reported that having run at least once in the 31 to 60 days prior to a start was associated with increased risk of fatality in flat racing (Boden et al., 2007a) and another reported that having run at least once within 14 days prior to a start and having made fewer starts (of any type) in the 60 days prior to a race were associated with increased risk of fatality in jump racing (Boden et al., 2007b). Whilst previous racing and training histories can be observed to have significant associations with the risk of fatality, these associations are not readily comparable, due in part to differences in categorisation of time periods. Subsequent to these studies, at a “Havemeyer Foundation symposium” the issue of time period selection was discussed (Parkin, 2007a) resulting in the conclusion that 30 day periods should be considered the “industry norm” for analysing training and racing data.

Other variables reported as being associated with increased risk of fatality were: horses identified as being at greater risk from pre-race veterinary checks and increased performance grade (Beyer Grade) in the previous race (Cohen et al., 2000); running in a race type that differed from the previous one (Henley et al., 2006); running on a city rather than a country track (Boden et al., 2007a, 2007b) and increased career duration (Boden et al., 2007b). These variables are all worth considering in future risk factor studies.

1.3 Musculoskeletal injury

Musculoskeletal injury (MSI) is a common definition in risk factor studies, although exact injury outcome definitions of MSI vary preventing prevalence estimate comparisons. Some studies only identified cases of MSI which resulted in fatality, (included in Table 1-1) whilst others included a definition of severe MSI, which resulted in either death or a period away from racing (included in Table 1-2). Whilst this combination of outcomes into a “severe injury” group reduces the available information regarding specifics of outcome, it still provides results associated with an outcome of major interest to the racing industry and adds statistical power to the study by increasing the number of available cases. Increased horse age was significantly associated with increased likelihood of serious MSI in all studies, although the relationship was recognised as not being linear in the studies by Bailey (1998) and Perkins (2005) in which they reported a significantly increased risk for horses greater than 3 year olds than younger horses, and for horses greater than or equal to 5 years old than 2 year olds, respectively. Because the outcomes of these studies were either death, complete retirement or a period of retirement, it is possible that this finding is again related to owner’s choice, as previously discussed.

Table 1-2: Variables reported as being associated with increased likelihood of musculoskeletal injury during racing (+/- training). Grey boxes highlight reported significant associations. White boxes highlight variables examined and not found to be significant. Text in boxes provides further details about the association. NE refers to variables that were not examined.

Lead Author (Year)[a]	Country (Region)	Race Type	Outcome of MSI[b]	Older Horse Age	Track Surface	Race/ Train Hx[c]	Other
Mohammed (1991)	USA[d] (NY)	Flat	Not raced within 6m[e] of injury		D v T[f]		
Bailey (1997)	Aus (NSW)	Flat	Not raced or trialled within 6m of injury				
Bailey (1998)	Aus (Mel)	Flat & Jump	Fatality or $\geq$6m off racing	>3[g]			
Estberg (1998) *[h]	USA (CA)	Flat	Fatality or lay-up of $\geq$60d[i]		NE		
Perkins (2005) *	NZ	Flat & Jump	Death or end of training preparation	$\geq$5 v 2[j]	NE		

[a] Year of publication. [b] MSI=Musculoskeletal injury. [c] Hx=History. [d] Country and Region abbreviation: USA=United States of America; NY=New York; Aus=Australia; NSW=New South Wales; Mel=Melbourne; CA=California; NZ=New Zealand. [e] m=months. [f] Dirt compared to Turf. [g] Greater than three years old. [h] *=injuries also recorded from training; [i] d=days. [j] Greater than or equal to five years old compared to two years old.

Firmer tracks and "Dirt" rather than "Turf" tracks are reported as being associated with increased risk of MSI, which were hypothesised to be associated with poor cushioning from these types of tracks (Bailey et al., 1998; Mohammed et al., 1991) and will be discussed later in association with fractures. Numerous associations between previous racing and training histories and likelihood of MSI have been identified. These include: fewer seasons raced, decreased starts per year and increased total number of starts (Mohammed et al., 1991); running in a race of the same distance as the previous race and running in the highest class of race (Bailey et al., 1997); rapid accumulation of high speed exercise during training (Estberg et al. 1998); being within the first training preparation compared to being in the 3rd or later, having made no starts during a period of preparation and having a preparation period of $\leq$ 20 weeks (Perkins et al., 2005a). Other factors reported as being significantly associated with increased likelihood of MSI are: specific racecourses (Bailey et al., 1998; Mohammed et al., 1991); jump compared to flat racing (Bailey et al., 1998); being in the 1st-3rd race of the day at a meet; being in the summer season (Mohammed et al., 1991); having a wide barrier position compared to other positions (Bailey et al., 1997) and being trained by specific trainers (Perkins et al., 2005a).

1.4 Fracture

1.4.1 Frequency of Fractures in Thoroughbred horse racing

Race related fracture incidence has been observed to vary between countries, race types and track surface. Methods for collecting information on racing fracture frequencies are either based on veterinary reports from the racecourse or collection of information at post-mortem. The introduction of post-mortem schemes enabled further evaluation of the fractures that resulted in death, as well as the investigation of risk factors for specific injuries in California, USA (Johnson et al., 1994), Great Britain (GB) (Parkin et al., 2004c) and Victoria, Australia (Boden et al., 2006). Whilst diagnosis at post-mortem provides the most accurate information about site and extent of fractures, studies reporting fracture frequencies based on post-mortem reports only report frequencies of fatal fractures, so may not be directly comparable to other studies. Catastrophic fracture rates have been reported to range from 0.33 to 2.3 per 1000 starts, varying with country and race type (Hill et al. 1986; Peloso et al. 1994; Mckee 1995; Estberg et al. 1996). Reports of specific fracture sites from work in GB report the most frequent injury site prevalence of 0.52 “sesamoid and fetlock” fractures per 1000 starts in all race types (Williams et al. 2001); 0.16 proximal phalangeal fractures per 1000 flat starts on turf, 0.39 proximal sesamoid bone fractures per 1000 flat starts on all-weather surfaces (Parkin et al., 2004c) and 0.3 and 0.35 lateral condylar fractures per 1000 hurdle and steeplechase starts, respectively (Parkin et al., 2004c).

Fractures also occur during training, although the rate of occurrence is not directly comparable to the rates reported per race start. Studies reporting fracture incidence rates of 1.15 and 1.1 per 100 horse months during flat and jump racing training in GB, respectively have been published (Verheyen & Wood 2004; Ely et al. 2009). More specifically, a study evaluating pelvic and tibial stress fractures in training reported 0.15 pelvic and 0.16 tibial stress fractures per 100 horse months and reported that only 12% of the reported fractures occurred during racing (Verheyen et al. 2006), highlighting the importance of considering training as well.

1.4.2 Risk Factors for Fractures:

Studies of risk factors for limb fractures vary between fracture type, race type, country and whether the fracture occurred during training or racing. A summary table of common risk factors is shown in Table 1-3.

Table 1-3: Variables reported as being associated with increased likelihood of fracture during racing (+/- training). Grey boxes highlight reported significant associations. White boxes highlight variables examined and not found to be significant. Text in boxes provides further details about the association. NE refers to variables that were not examined.

Author (Year)[a]	Country (Region)	Race Type	# Type[b]	Age	Sex	Surface	Longer Race length	Race / Training Hx	Other
***Hill* (1986)**	USA[c] (NY)	Flat	Any		NE			NE	
***Carrier* (1998)**	USA (CA)	Flat	Complete Humeral	3[d]	M[e]	NE	NE		
***Carrier* (1998)**	USA (CA)	Flat	Complete Pelvic	Older	F[f]	NE	NE		
***Parkin* (2004a,b)**	UK	Flat & Jump	Fatal Distal Limb			+ Going at prev[g]			
Parkin (2005)	UK	Flat & Jump	Fatal Lateral Condylar	Start at 3-4[h]	NE	Firmer			
***Verheyen* (2006) *[i]**	UK	Flat	Pelvic or Tibial Stress			Train on sand[j]	NE		
***Verheyen* (2006b) ***	UK	Flat	Any in Training			NE	NE		
Anthenill (2007)	USA (CA)	Flat	FL prox sesamoid[k]		EM[l]	NE	NE		
***Ely* (2009) ***	UK	Jump	Any in Training			NE	NE		

[a] Year of publication. [b] Fracture Type. [c] Country and region abbreviations: USA=United States of America; NY=New York; CA=California; UK=United Kingdom. [d] 3 year old horses. [e] Male horses. [f] Female horses. [g] Track going at previous race. [h] Started racing as a 3 year old or a 4 year old. [i] *=injuries also recorded from training. [j] Training on a particular sand gallop. [k] Proximal sesamoid bone fracture in the forelimb. [l] Entire male.

Horse age has been recognised to be associated with risk of fracture: One study reported that three year old horses were at increased risk of complete humeral fracture, whilst "older" horses were at increased risk of complete pelvic fracture (Carrier et al., 1998). Age at first race was recognised as a risk factor for fatal lateral condylar fractures with horses that started racing at 3 or 4 years of age being 2.6 times more likely to suffer a fracture in future starts than horses that started racing at 2 years of age (Parkin et al., 2004b). However studies evaluating risk factors associated with: any fractures in racing, fatal distal limb fractures, pelvic or tibial stress fractures, any fractures in training and forelimb proximal sesamoid bone fractures failed to identify a significant association with age (Hill et al. 1986; Parkin et al. 2004b; Verheyen et al. 2006a; Verheyen et al. 2006b; Anthenill et al. 2007; Ely et al. 2009), suggesting that the association between horse age and risk of fracture is not simple. The reported associations with sex also vary; whilst one study reported that male sex was associated with increased risk of complete humeral fracture (Carrier et al., 1998) and one reported that entire males are at increased risk of forelimb proximal sesamoid fracture (Anthenill et al., 2007), another study reported that female sex was a risk factor for complete pelvic fractures (Carrier et al., 1998) and studies (including training information from GB) report no significant association between sex and risk of fracture (Verheyen et al. 2006a, 2006b; Ely et al. 2009).

Whilst an older study from the USA of 68,397 starts reported that track condition, type of surface and race length had no association with the occurrence of fractures of Thoroughbreds (Hill et al. 1986), firm ground surface has been recognised as a risk factor for distal limb fractures in more recent studies from GB (Parkin et al., 2004a, 2004b). Another study reported an association between a specific type of sand gallop in training and likelihood of pelvic and tibial stress fractures (Verheyen et al. 2006a). It has been proposed that the firmer ground surface might result in increased concussive forces on the bones and / or result in increased race speeds, which might explain the increased risk of fracture. Longer race length has also been recognised as an important risk factor for fatal distal limb fractures and fatal lateral condylar fractures (Parkin et al., 2004a, 2004b). Potential explanations for this include increased horse fatigue and increased time at risk for horses in longer races.

Racing and training histories have been recognised as being significantly associated with the occurrence of fractures. A study investigating complete humeral fractures reported an association with longer lay-up (rest from training) time, shorter time since lay-up, and increased interval between races (Carrier et al., 1998). Conversely another study recognised an association between increased time in training and racing after a lay-up period and increased risk of forelimb proximal sesamoid bone (PSB) fracture (Anthenill et al., 2007). The reason for this disparity in findings is likely to be related to differences in the aetiology of these fractures. Anthenhill *et al.* recognised that making changes to horse training schedules to try to reduce PSB fracture incidence might result in increased numbers of complete humeral fractures, highlighting one of the difficulties in advising racing policy makers and trainers. Other studies have recognised associations between the amount of time in training and risk of fracture, one group reporting increased risk of fatal distal limb fractures for horses in their first year of racing (Parkin et al., 2004b, 2004d); whilst another reported increased time in training and racing was associated with increased risk of forelimb PSB fracture (Anthenill et al., 2007).

Intensity of exercise has been recognised as a risk factor for limb fracture, with some reporting associations with lack of fast work. No gallop work in training was recognised as a risk factor for fatal distal limb fracture in GB (Parkin et al., 2004b, 2004d), whilst others report associations with too much fast work over a short period: Increased canter distance in training during the previous 30 days was reported as a risk factor for pelvic and tibial stress fracture, and increased high intensity exercise over a short period was a risk factor for all fracture types in horses in training in GB (Verheyen et al. 2006a,2006b); higher intensity exercise in the previous 12 months was reported as a risk factor for forelimb PSB fracture (Anthenill et al., 2007). Two studies also report an association between increased accumulated exercise and increased risk of fracture (Verheyen et al. 2006a; Anthenill et al. 2007). There is clearly an important association between risk of fracture and time and intensity of training, which has been described by a number of authors and thought to be related to a balance between subclinical bone damage and adaptation (Poole & Meagher 1990; Stover et al. 1992; Loitz & Zernicke 1992; Riggs et al. 1993; Riggs et al. 1999a, 1999b; Kawcak et al. 2000; Hill et al. 2001), with clinical fractures occurring when this balance is not achieved.

Other reported risk factors include: increased number of runners in the race and fewer days since previous race at the racecourse for fatal distal limb fracture (Parkin et al., 2004a, 2004b). Although the authors did not propose explanations for these associations; races without professional jockeys for fatal lateral condylar fractures, which was proposed as being related to the experience of the jockey in identifying horse distress (Parkin et al., 2004b); and trainer for fractures sustained during jump training and racing, which was proposed to be related to differences in training regimens, veterinary input or horse populations between trainers (Ely et al., 2009). Part of the variation observed between studies is likely to be related to differences in aetiology of different fracture types, as well as differences relating to factors associated with training and racing. Investigation of risk factors and outcomes, using comparable categorisations in the future would be useful to facilitate comparisons between studies.

1.5 Tendon and Ligament injury

1.5.1 Frequency of Tendon and Ligament injuries in Thoroughbred horse racing

Injuries to tendons and ligaments, although commonly less dramatic in appearance than fractures, can have major implications for horse's careers and survival. Reports of tendon and ligament injury frequencies were first published at around the same time as the first fracture frequency reports. A report from the USA reported prevalence of severe tendon injuries as 0.6 and 0.9 per 1000 starts on turf and dirt surfaces, respectively (Wilson et al. 1996). A study from GB, of races between 1996 and 1998 reported the frequency of injuries to the suspensory ligament, superficial and deep digital flexor tendons to be 0.78, 8.07 and 9.12 per 1000 starts in flat, hurdle and steeplechase, respectively (Williams et al. 2001). That study reported that the majority of those injuries were strain or partial rupture of the superficial digital flexor tendon (SDFT) and later studies specifically reported the rate of injury to this structure. In GB between 2000 and 2005 there were 0.55, 6.6 and 8.0 SDFT strains per 1000 starts in flat, hurdle and steeplechase racing, respectively (Parkin et al., 2000).

In Japan and Hong Kong where the majority of horses are trained at racing authority run training centres, accurate information about injuries that occur during training is available. Studies from Japan report the prevalence of forelimb superficial digital flexor (SDF) tendinitis in training or racing on the flat as 11.1% (Kasashima et al., 2004), and 5.5% in horses that had made at least one race start (Takahashi et al., 2004). In Hong Kong tendon injury has been recognised as the most common cause of retirement from racing, with a mean cumulative annual incidence of 3.2% (range 2.3-4.2%) (Lam et al., 2007a). Whilst the ability to follow the entire racing population does not exist in other parts of the world, a number of studies have followed subsets of the flat and jump populations. A study of a cohort of horses in training and racing in New Zealand reported the incidence rates of SDFT and suspensory apparatus injuries as 0.13 and 0.12 per 1000 training days, respectively (Perkins et al., 2005b). Whilst a study of jump horses in GB reported the incidence rate of tendon and ligament injuries as 1.9 per 100 horse months (Ely et al., 2009), which equates to approximately 0.6 per 1000 training days (considerably higher than the study from New Zealand). Ultrasonographic examination of a cohort of that same population reported the prevalence of SDF tendinopathy as 24% (Avella et al., 2009).

1.5.2 Risk Factors for Tendon and Ligament Injuries

Table 1-4 represents a comparison of significant risk factors associated with tendon and/or ligament injury. All the studies that examined age, reported it as a significant risk factor (Perkins et al. 2005a; Lam et al. 2007b; Ely et al. 2009). It has been proposed that the limited adaptive ability of the SDF tendon after maturation contributes to increased risk of tendon fatigue injury in older horses (Parry, et al. 1997; Patterson-Kane et al. 1997; Cherdchutham et al. 1999; Cherdchutham et al. 2001; Smith et al. 2002; Dowling & Dart 2005).

Table 1-4: Variables reported as being associated with increased likelihood of tendon or ligament injury during racing (+/- training). Grey boxes highlight reported significant associations. White boxes highlight variables examined and not found to be significant. NE refers to variables that were not examined.

Lead Author (Year)[a]	Country	Race Type	Injure structure	Age	Male Sex	Race distance	Train / Race Hx[b]	Other
***Takahashi* (2004) *[c]**	Japan	Flat	SDFT[d]	NE				
***Perkins* (2005) ***	NZ[e]	Flat	SDFT and Suspensory			NE		
***Lam* (2007a) ***	HK	Flat	Tendon			NE	NE	
***Lam* (2007b) ***	HK	Flat	Tendon			NE		
***Ely* (2009) ***	UK	Jump	Tendon & Ligament			NE		

[a] year of publication. [b] Training and racing history. [c] *=injuries also recorded from training. [d] Superficial Digital Flexor Tendon. [e] Country abbreviation: NZ=New Zealand; HK=Hong Kong; UK=United Kingdom.

Males and entire males in particular have been observed to be at increased risk of tendon injury (Kasashima et al., 2004; Lam et al., 2007a, 2007b; Perkins et al., 2005b). Proposed theories for this difference include: direct or indirect effects of male hormones on tissue characteristics, animal behaviour, differences in body composition, or extrinsic factors such as training methods or racing patterns (Lam et al., 2007a; Perkins et al., 2005b). A study from GB failed to identify a significant association between sex and risk of superficial digital flexor tendon injury (Ely et al., 2009) which may reflect a difference in horse populations between countries. Longer race distances were recognised as being a risk factor for SDFT injury in one study (Takahashi et al., 2004), which the authors hypothesised to be related to heat-induced tenocyte damage and / or increased fatigue of the deep digital flexor muscle.

Previous racing experience was recognised as being important in a number of studies: horses with steeplechase experience were found to be at increased risk of SDF tendon injury in flat racing in Japan (Takahashi et al., 2004); horses that had previously run on the flat were observed to be at reduced risk of tendon and ligament injury in jump racing in GB (Ely et al., 2009). These associations are hard to explain, but have been hypothesised as being related to the horse populations that change race types and the effect of early training on young tendons in the flat racing population. Other studies have recognised an increased risk of tendon injury for horses that raced few times or trained without ever having previously raced and for horses that underwent reduced exercise intensity over the previous 180 days (Lam et al., 2007b; Perkins et al., 2005b). It is highly plausible that these associations were observed as a result of subclinical injury resulting in reduced ability to train or race. Whilst this is less useful in examining the aetiology of the pathology, recognition of these sorts of risk factors can potentially be useful in identifying horses that are at increased risk of injury during a race. A study evaluating training and racing histories identified significant associations with longer time in training (Lam et al., 2007b).

Other variables significantly associated with likelihood of tendon / ligament injury were: increased horse body weight, which was reported as a risk factor for SDF tendon injury (Takahashi et al., 2004) and was attributed to: increased load on the limbs; season, which has been associated with increased risk of SDF tendon injury in New Zealand (summer/autumn) and GB (summer) (Perkins et al., 2005b), and could be related to firmness of ground, or stage of the racing season; trainer, which was recognised as a risk factor in a study of jump racing in GB (Ely et al., 2009); and having been previously examined for a tendon injury, which was associated with an odds ratio of 19.39 to subsequently retire due to tendon injury (Lam et al., 2007b). Reasons for the association with previous injury are likely related to the high (23–67%) re-injury rates following SDF tendinopathy (Dyson, 2004; Marr et al., 1993; O’Meara et al., 2010).

1.6 Exercise induced pulmonary haemorrhage and Epistaxis (EIPH)

1.6.1 Frequency of EIPH and Epistaxis in Thoroughbred horse racing

Diagnosis of exercise induced pulmonary haemorrhage (EIPH) usually requires endoscopic examination of the airways. Reported prevalence ranges from 43-80% (Pascoe et al. 1981; Raphel & Soma 1982; Mason et al. 1983; Birks et al. 2002; Newton & Wood 2002; Hinchcliff et al. 2005; Hinchcliff 2009), although a study in which tracheoscopy was performed on a random selection of horses after races, reported the presence of EIPH in 100% of horses examined on three or more occasions (n=25 Thoroughbreds and 26 Standardbreds) (Birks et al., 2002), i.e. whilst it occurred in all horses, it did not occur in every race. This suggests that the condition might be even more prevalent than the quoted 43-80%.

The presence of haemorrhage at the nostrils defined as “epistaxis” after racing is usually the result of EIPH, but carries considerably more significance with the racing regulators in a number of countries (including Australia, Hong Kong, New Zealand, South Africa, USA) where repeat episodes of epistaxis (the definitions of which vary) result in compulsory permanent suspension or retirement from racing. Diagnosis does not require endoscopy and as such prevalence studies can be based on observational data from the racecourses, rather than interventional studies. Prevalence of epistaxis in racing Thoroughbreds has been reported to vary between country and racing discipline with ranges reported between 0.08% and 9% (Pfaff 1976; Pascoe et al. 1981; Raphel & Soma 1982; Takahashi et al. 2001; Williams et al. 2001; Weideman et al. 2003; Hinchcliff et al. 2005; Newton et al. 2005) although varying methods for collection and recording of cases were used and the highest reported percentage came from the smallest study population. The more recent studies including larger numbers of race starts report the prevalence of epistaxis in Japan, South Africa and GB as 0.15%, 0.17% and 0.08%, respectively (Newton et al., 2005; Takahashi et al., 2001; Weideman et al., 2003). Notably the study from GB differs from the other two because not all horses were examined post-race, so this number might be artificially lower. Epistaxis has also been recognised to recur, with approximately 13% of cases being reported to experience at least one repeat episode (Takahashi et al., 2001; Weideman et al., 2003).

1.6.2 Risk factors for EIPH and Epistaxis

Table 1-5 represents a comparison of significant risk factors associated with EIPH and/or epistaxis. Older horse age has been recognised as being associated with risk of EIPH and/or epistaxis in multiple studies (Newton et al., 2005; Pascoe et al., 1981; Pfaff, 1976; Raphel and Soma, 1982; Takahashi et al., 2001; Weideman et al., 2003). One study hypothesised that horse age is a proxy measure of "time spent racing" and that increased epistaxis in older horses was the result of repetitive pulmonary strain injury (Newton et al., 2005). A more recent study of 744 horses that underwent endoscopy failed to recognise this association (Hinchcliff et al., 2010), suggesting that this relationship warrants further investigation. Sex has also been identified as a risk factor, although the association is not clear with some studies report geldings to be at greater risk (Pfaff, 1976; Weideman et al., 2003), others reporting all male horses to be at greater risk in hurdle racing (Newton et al., 2005) and others failing to identify an association (Hinchcliff et al., 2010; Raphel and Soma, 1982).

Table 1-5: Variables reported as being associated with increased likelihood of exercise induced pulmonary haemorrhage or epistaxis (or both). Grey boxes highlight reported significant associations. White boxes highlight variables examined and not found to be significant. Text in boxes provides further details about the association. NE refers to variables that were not examined.

Lead Author (Year)[a]	Country (Region)	Race Type	Outcome	Horse Age	Sex	Race Dist[b]	Season	Race Type	Other
Pfaff (1976)	SA[c]	Flat	Epistaxis	4y.o.[d]	G[e]	NE	NE	NE	
Pascoe (1981)	USA	Flat	EIPH[f]	≥5 y.o.[g]	NE	NE	NE	NE	
Raphel (1982)	USA	Flat & Jump	EIPH	Inc[h]		Inc[i]	NE		
Takahashi (2001)	Japan	Flat & Jump	Epistaxis and EIPH	>2y.o.	F[j]	<1 mile[k]	NE		
Weideman (2003)	SA	Flat	Epistaxis	> 3y.o.	G[l]		May-Oct[m]		
Newton (2005)	UK	Flat & Jump	Epistaxis	Inc[h]	M[n]				
Hinchcliff (2010)	Aus (Mel)	Flat	EIPH			<1400 m[o]	NE		

[a] year of publication. [b] Race distance. [c] Country and Region abbreviations: SA=South Africa; USA=United States of America; UK=United Kingdom; Aus=Australia; Mel=Melbourne. [d] Four year old horses. [e] Geldings. [f] Exercise induced pulmonary haemorrhage. [g] Greater than or equal to five years old. [h] Increased horse age. [i] Increased race distance. [j] Female horses. [k] Race distance of less than one mile. [l] Geldings. [m] May to October. [n] Male horses. [o] Race distance of less than 1400 metres.

Associations of EIPH/epistaxis with race distance are contradictory: One study reporting increased race distance as a risk factor for EIPH (Raphel and Soma, 1982), others reporting race distances of less than one mile and less than 1400 metres as being risk factors for "epistaxis and EIPH" and "EIPH of ≥2" (grade), respectively (Hinchcliff et al., 2010;

Takahashi et al., 2001). Other studies failed to identify a significant association with race distance at all (Newton et al., 2005; Weideman et al., 2003).

Season, winter/spring in South Africa (Weideman et al., 2003) and spring in GB (Newton et al., 2005), has also been identified as a risk factor for epistaxis. Whilst the second study attributed the observed association to a relationship with racing seasons, the former hypothesised lower air temperature, which was also recognised as a risk factor in an Australian study which reported ambient air temperature of $<20^oC$ as being associated with increased risk of EIPH (Hinchcliff et al., 2010).

Race type has consistently been identified as an important risk factor EIPH/epistaxis in the studies that included it in their analyses. Jump racing has been recognised as having a higher prevalence of EIPH and epistaxis than flat racing (Raphel and Soma, 1982; Takahashi et al., 2001; Newton et al., 2005), which has been ascribed to altered breathing patterns during jumping and propulsion of blood from the lungs to the nose (Takahashi et al., 2001) and the effect of impact trauma on the thoracic cavity (Newton et al., 2005).

Other reported risk factors include: having had previous epistaxis, which was hypothesised to be associated with lack of recovery of damaged pulmonary vessels (Takahashi et al., 2001); running at sea level rather than at higher altitude, hypothesised to be associated with differences in packed cell volume and red cell numbers at different altitudes (Weideman et al., 2003); firmer ground and increased weight carried, hypothesised to be related to increased impact trauma (Newton et al., 2005).

There is considerable variation in the reported risk factors for EIPH and epistaxis. Whilst these differences might be related to variability in horse populations or investigation techniques, the interpretation and use of these findings are more difficult when the studies appear to contradict each other. Further research is indicated to try to help determine the aetiology of EIPH, which as yet is still unclear.

1.7 Implementation of risk factor study findings

A major objective of these risk factor studies is that of making use of the results to reduce the risk of the outcomes. Reported differences between geographical areas, racing disciplines and injury types suggest that studies specific to these factors are likely to be the most appropriate direction for risk factor evaluation. However, considering the relatively low incidence of the majority of outcomes, being more specific in the populations studied is likely to mean that future studies, in the majority of racing localities, will have to gather racing data for a considerable time to gain sufficient statistical power. Conflicting associations between similar risk factors and outcomes have been recognised within countries between different injuries, suggesting that without examining all important injury outcomes, it is possible that altering variables recognised as a risk factor for one injury might result an increase in incidence of another. A reasonable approach to this risk might be to identify the most important or most frequent outcomes and examine them all before making policy decisions.

Despite these challenges, changes to racing and training practices have been made based on some of these studies. In GB the length of some National Hunt flat races was reduced when it was shown that longer races were associated with higher mortality prevalence (Henley et al., 2006; Wood et al., 2000, 2001) jump racing on ground categorised as “hard” is no longer allowed under BHA regulations following the recognition that the prevalence of fractures was particularly high on this surface; and official measurement of “Going” has been obligatory at all racecourses in GB since January 2009. In Hong Kong specific monitoring of horses at increased risk of tendon injury has been introduced (Lam et al., 2007b). In the USA a number of dirt tracks have been changed to artificial surfaces following the recognition that surface is related to injury prevalence (Mohammed et al., 1991). Following research from California indicating that toe grabs significantly increased the risk of injury (Kane et al. 1996; Hill et al. 2001), a ban on toe grabs above a certain height and other traction devices, was introduced by the US Jockey Club safety commission in June 2008. Interestingly, the most recently published study, which took into account additional explanatory variables, failed to identify a significant association between toe grabs and risk of catastrophic injury (Hernandez et al., 2005). Most recently, jump racing was temporarily banned in Victoria, Australia at the end of the 2010 season, having been deemed to be associated with too high fatality rates following multiple reviews.

It is vital that interventions are made on the basis of strong evidence, especially when they affect a large number of horses and people and are potentially irreversible. There is no question that decision making relating to the welfare of animals, often in the face of strong public opinion, is a very difficult task. It is also clear that scientific evidence is never completely perfect and that the best available evidence may be insufficient to guide definitive decision making, although this can be a concept that is difficult to convey to policy makers and the public. It is extremely important therefore that research continues, in order to provide robust information about racing injuries when it is needed. Whilst this research has associated costs for data collection, management and evaluation, without these studies it is impossible to assess the impact of changes within the sport, and as such it could be suggested that they should be considered mandatory by all racing authorities.

2 Materials and methods – Risk Factor Analysis

2.1 Study Design

Data about races, horses and injuries for the risk factor analyses were collected retrospectively for all horses undertaking National Hunt (NH) racing in GB over the study period, from the resources described below. A cohort of available starts (all from years 2001-2009) was analysed. For all models starts which resulted in a “case” (case starts) were compared to starts which didn’t result in a “case” (control starts).

2.1.1 Background – Injury Information

On January 1st 2000, the British Horseracing Authority (BHA) (the governing body for horseracing in GB) established a computerised database for recording details of all injuries and fatalities that occur during racing called: “The Equine Welfare Database”. Every official race meeting in GB is attended by a BHA employed veterinarian designated a “Veterinary Officer (V.O.)”, with the primary roles of overseeing horse welfare and enforcing veterinary-related rules. The V.O.s also: collect samples for drug testing procedures; confirm the identification of horses; monitor the tack being used on horses; and examine horses for illness or injury when requested to do so by stewards or trainers. The V.O.s also work in conjunction with two to three veterinary surgeons employed by the racecourses to provide first aid treatment to horses injured during racing.

Details of all injuries and fatalities dealt with by the racecourse veterinary surgeons are recorded by the V.O.s. Prior to the year 2000 this information was recorded on paper forms only (examples of which are shown in Appendix 1), but it was recognised that examination and manipulation of the data would be facilitated by introduction of a computerised format. The computerised database uses specific categorisations and sub-categorisations of injuries to guide reporting, as well as providing an additional section for comments. This has the advantage of allowing easy grouping of injury types, rather than requiring examination of multiple individual written descriptions, whilst still providing the opportunity to add additional information if required. On 1st January 2004 a revision was made to the recording system, allowing V.O.s to input injury information directly into the database, whereas previously, the records had been incorporated from the BHA central office.

2.1.1.1 Limitations to the injury data

Because V.O.'s attend every official race, the injury database provides a significant amount of information about the occurrence of injuries and fatalities in racing in GB. However there are three main limitations to the information collected from the racecourses:

1. Because the information is only collected at the racecourse, details of horses that sustained an injury during racing, which was not recognised until the horse left the racecourse, would not be included in the database, unless the trainer or external treating veterinary surgeon reported it to the BHA, which they have no obligation to do. It might be suggested that only mild injuries would not be recognised whilst still at the racecourse, so this is not an important consideration. However, some more severe injuries are not picked up immediately, as high levels of adrenalin post-race can mask signs (such as lameness), also some injuries, such as tendinopathies, are reported to progress in severity over a few days post injury / race.
2. Diagnoses made at the racecourse by attending veterinarians are frequently made based on clinical findings only, as imaging techniques such as radiography and ultrasonography are often unavailable. This is particularly important when considering the accuracy and / or completeness of fracture reporting. The database also allows recording of "possible" fractures, which requires appropriate interpretation.
3. It was not always possible to obtain follow-up information for horses that sustained an injury at the racecourse and were subsequently treated at (external) clinics. This means that the outcomes (and in some cases diagnoses) recorded in the injury database may not have been completely accurate. The reason for this lack of follow-up information is related to the number of different veterinary practices that treat racehorses and client confidentiality makes some of them reticent to pass on such information.

2.1.2 Background – Horse and Race Information

Weatherbys Ltd.[2] is a private organisation that performs the administrative work for Thoroughbred horse racing in GB, under contract from the BHA. The company keeps records for all Thoroughbred horses registered for racing in GB, which include details of

[2] Weatherbys Ltd. Sanders Road, Wellingborough, Northants, NN8 4BX

their breeding and trainer location. The company also provides administration for every race that occurs in GB and keeps records from each race, including: race date, course and time as well as information about the type of ground surface and the number of horses that ran.

2.2 Sample Selection / Study Period

Data was initially available from 1st January 2000 (the beginning of the computerised record keeping of injuries) to 31st December 2009 (the start of the research project). Further data was made available as the project progressed, each additional year of data being made available by February of the following year. It was decided that to facilitate timely production of models, the initial multivariable models should be based on the first 10 years of data and that the subsequent data should be used for model validation.

Because individual race start information was not available for prior to 2000, it was decided that the models should be built using data from 1st January 2001 to allow inclusion of a minimum of one year of accurate start history in the models.

Details of the numbers of starts, horses, jockeys, trainers, racecourses, races, race meets and race dates in each race type analysed in the study are shown in Table 2-1.

Table 2-1: Details of the data available in the study between different National Hunt race types

Number of	Hurdle	Steeplechase	NHF
Starts	169,668	102,894	25,733
Horses	29,285	15,117	12,888
Jockeys	1,274	1,328	875
Trainers	1,369	2,343	1,040
Racecourses	44	44	41
Races	15,050	12,003	2000
Race Meets	4,339	4,347	1923
Race Dates	2,442	2,438	1474

NHF = National Hunt Flat

2.3 Sample Size Calculations

To determine required sample size for logistic regression, it has been recommended that the following equation is used:

$$\mathbf{N = 10\ k / p}$$

Where “N” is the number of cases required; “p” is the smallest of the proportions of negative or positive cases in the population (i.e. if 20% of the population were positive this would be 0.2); and “k” is the number of covariates (or independent variables) (Peduzzi et al., 1996).

In this study, sample size was primarily dictated by available data. The aim of this study being to evaluate risk factors for the most common injuries (or those considered most important by the BHA). The approach taken to power size for the analyses in this thesis was to select outcomes of interest (injuries), considering the above equation and to then perform post-hoc power calculations.

2.4 Available Data

2.4.1 Injury Data

The following details about horse injuries were available from the study period:

- Type of injury e.g. fracture
- Structure involved e.g. left fore proximal phalanx
- Whether the injury resulted in lameness
- Where the injury had occurred e.g. before, during or after the race
- The actual or likely outcome of the injury e.g. died; euthanized; short or long term consequences
- Whether the injury was fall related
- Any actions required next time the horse raced e.g. should it be checked prior to the next race
- Veterinary comments – broad ranging e.g. “appeared lame pre-race”; “kicked out in stalls”; “fell and showed neurological signs”.

Injury details were categorised under specific subheadings, details of which are shown in Appendix 2.

2.4.2 Race Data

- Date
- Season
- Racecourse
- Number of runners
- Ground Surface
- Going
- Race Distance
- Type of race e.g. Hurdle / Steeplechase, Novice / Handicap etc.
- Race number and Position on race card e.g. 4th race, middle of race card
- Speed of winning horse (accurate from 2004 onwards)

2.4.3 Horse Data

The following details about each horse were available:

Signalment:

- Name
- Age
- Sex
- Sire / Dam for two generations
- Country of Birth

Race Performance:
- Finish Position
- Official Rating (where available)
- Prize money won
- Trainer
- Jockey

2.5 Calculated Data

Based on the findings from previous risk factor studies and following discussion with the study collaborators, a number of additional variables were generated from the available data, most of which were related to the horses' previous start histories.

2.5.1 Start Histories

The previous numbers of starts made by each horse over preceding periods of time were calculated for each horse at every start (Figure 2-1). Three month time periods were chosen based on the recommendations from a committee at a Dorothy Havermeyer Foundation symposium held in GB in 2007 (Parkin, 2007b). In addition, one week, one month and greater than one year periods were also generated and examined. The calculation of the number of previous starts in each time period for each start was performed using R (details of the code used are shown in Appendix 3).

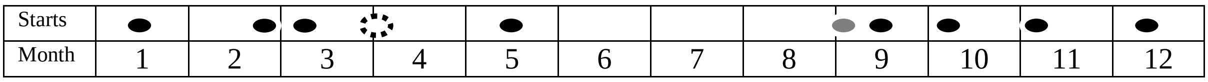


Figure 2-1: Schematic diagram representing the start history for one horse in the study over a 12 month period. Starts are represented by dots on the top row. At the start made between months 3 and 4 (dotted outline) the horse had run three times in the preceding three months, whilst at the start made between months 8 and 9 (grey dot), the horse had not run in the preceding three months and had run three times in the preceding 6 months.

In addition to the number of starts in previous time periods, additional variables, such as total number of career starts, race type of previous race and years completed in racing were examined.

2.5.2 Trainer Performance

In an attempt to examine the effect of trainers' success on likelihood of injuries; three measures of trainer success were calculated. Using the 10 years of available data; percentage of starts made by horses that resulted in "first" or "placed" finishes for each trainer were calculated. In addition, a score was produced in an attempt to include horses that did not finish in the performance measure (30 points for finishing first, 20 points for finishing second or third, 10 points for finishing and 0 points for not finishing), the mean value of the score from the 10 years was used in analyses.

2.5.3 Jockey Performance

In an attempt to examine the effect of jockeys' success on likelihood of injuries; three measures of jockey success were calculated. Using the 10 years of available data; percentage of starts made by horses that resulted in "first" or "placed" finishes for each jockey were calculated. In addition, a score was produced in an attempt to include horses that did not finish in the performance measure (30 points for finishing first, 20 points for finishing second or third, 10 points for finishing and 0 points for not finishing); the mean value of the score from the 10 years was used in analyses.

2.6 Data Processing

All injury and race data were entered into a Mirosoft Excel[3] spreadsheet. Data were checked for errors, consistency and validity using established Excel functions, particularly those for repetition of data relating to injuries. Microsoft Access[3] was used to collate information from the injury database and Weatherbys' database. Once a final database with all required variables was produced, this was imported in Stata™[4] version 11 for analysis.

2.7 Statistical Methods

Descriptive statistics for the available data were produced for the most common injury outcomes using the Excel spread sheet and functions. Further analyses, were conducted in Stata™ versions 11 or 12. Outcomes were defined as present or absent and logistic regression models were used for each. A general overview of the methods used is given here whilst additional information about the methods employed for each outcome is provided in the relevant chapters.

2.7.1 Logistic Regression Principal

Because multiple inter-related explanatory variables were being examined, methods facilitating multivariable analysis were required. Because the outcomes of interest were binary in nature, e.g. presence or absence of injury, logistic regression modelling was selected. Logistic regression models the natural logarithm (ln) of the odds of an outcome for a given value of explanatory variable(s). The odds are defined as the probability of having an outcome (injury) divided by the probability of not having the outcome (no injury). A major advantage of performing logistic regression is that multiple explanatory variables can be considered at once.

---

[3] Microsoft, Thames Valley Park, Reading, Berkshire, U.K. RG6 1WG

[4] StataCorp LP, 4905 Lakeway Drive, College Station, Texas 77845-4512, USA

A logistic regression model can be represented using the following equation:

$$\ln\left[\frac{p}{1-p}\right] = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i$$

In the above equation:

$\ln\left[\frac{p}{1-p}\right]$ = the log transformation of the odds of outcome, where p = probability of outcome

α = the intercept term, which represents the value of y when x=0

βi = the regression coefficients, which represent the change in y for a unit change in xi, whilst the values of the other explanatory variables remain constant

xi = the explanatory variables

2.7.2 Logistic Regression Output

Logistic regression models produce regression coefficients and/or odds ratios, which provide information on the associations between each examined explanatory variable and the outcome (Thrusfield, 2007). The null hypothesis that the individual explanatory variable has no association with the outcome is tested for each using a Wald-test. However, it has been recognised that the results of the Wald test may be unreliable, particularly if the sample sizes are small and therefore it has been recommended that likelihood ratio tests are performed in addition (Dohoo et al., 2010). A likelihood ratio test is performed for each entire model to determine whether the addition of the explanatory variables has a significant effect compared to not having any explanatory variables i.e. is there a significant association between the explanatory variables studied and the outcome? It is also possible to perform likelihood ratio tests for each individual variable by comparing models with and without their inclusion, thus examining whether the selection of the "new" variable significantly improves the model (Dohoo et al., 2010).

2.7.3 Model Building

In order to allow inclusion of horse, race and track as different levels in risk factor analysis, the studies were conducted with the outcome measured at the level of race start (a "start" being a horse starting a race).

2.7.3.1 Univariable Analysis

Examination of Explanatory Variables:

The relationship between each explanatory variable and the outcome was examined by graphical assessment of the log odds, using the "*lintrend*" command in Stata™ version 11 (Garett, 1996). If the relationship was nonlinear (i.e. not continuous), categorical or alternative; binary, polytomous categorical (quartiles or quintiles) or quadratic and cubic, appropriate terms were considered in the univariable and multivariable models, as recommended (Dohoo et al., 2010; Royston and Sauerbrei, 2008). Categorisation was based on sensible/plausible explanations if available (e.g. months could legitimately be grouped as seasons), or were otherwise based on the 'best fit' for the model; attempting to find the most "parsimonious" model (Dohoo et al., 2010), based on Akaike information criteria (AIC) and log-likelihoods. Nominal and ordinal categorical variables were numerically coded sequentially, with a 0 being assigned to the reference group.

Univariable Logistic Regression:

This was performed to identify potential risk factors from all explanatory variables considered biologically plausible or supported by the literature. Variables with Wald P values <0.2, as well as any variable considered biologically plausible and those reported as being significant in other studies, were considered for inclusion in the multivariable models. Previous studies using backward stepwise regression recommended removal of variables with P-values of greater than 0.157 (Sauerbrei and Royston, 1999) whilst other smaller studies (Boden et al., 2007a) have used ≤0.25 for forwards selection, so <0.2 was considered as an appropriate cut off for these analyses.

2.7.3.2 Multivariable Model Building

Variable Submission and Retention:

Variables were ordered by AIC and log likelihood values prior to sequential insertion into a single level multivariable regression model. Although backward stepwise regression has been reported to be favourable to forward selection (Mantel, 1970), forward stepwise selection has been recognised as being needed for large numbers of predictors and/or interaction terms (Dohoo et al., 2010), as was the case in the analyses in this thesis. Variables were retained in the multivariable model if likelihood ratio test P values were <0.05 (Hosmer and Lemeshow, 2000). The Wald test P value was used when comparing categories with the reference category.

The effect of data collection period:

Year was examined as a variable in all models, and included in final models when significantly associated with outcome. This was in order to account for the fact that the data represented a relatively long period, during which changes such as to race track management (in a broad sense); race injury reporting and recording; and diagnostics may have affected the risk of outcome. As such, year was included in addition to the other variables, so that the odds ratios for those variables were adjusted to include its effect.

Confounding:

Potential confounders were evaluated by resubmitting all of the variables from the univariable analyses that were not included in the final model after the forward stepwise process of model building. The effect of each potential confounder on the estimates for variables in the final model was assessed by adding each one, one at a time, into the final model. If the potentially confounding variable altered odds ratios for variables in the final model by >20% (Dohoo et al., 2010), confounding was considered to be present, the confounder was retained in the final model and adjusted odds ratios were reported for variables in the final model.

Correlation:

Although multivariable logistic regression is designed to adjust the outcomes for correlations among predictor variables, if variables are highly correlated this can result in problems. For example, it may be difficult to determine the true strength and direction of association between a variable and the outcome, and to decide which variable(s) to retain in the multivariable models (Dohoo et al., 2010). In these analyses, correlation coefficients were produced for all pairs of variables in the final model, using the "*estat vce, correlation*" command in Stata™ version 11. Variables with correlation coefficients of >0.4 and <-0.4 (considered higher than low) were further examined by investigating the effect of removing them individually from the model; these variables were then removed from the model if their odds ratios changed direction (i.e. changed from a positive to a negative association or vice versa), or if their P-value became >0.05.

Interaction:

Statistical interaction has been described as a situation where two or more factors that are associated with an outcome, result in an increased or decreased frequency of outcome when present in combination (Thrusfield, 2007). To investigate the presence of interactions, biologically plausible interaction terms were created and assessed in the final models, using the "##" symbols in Stata11™. Interaction terms with P values of <0.05 were retained in the final model. The association between the variables found to interact with each other were explored graphically, using code in Stata11™, details of which are shown in Appendix 4.

2.7.4 Clustering of Data

The logistic regression models were produced from the level of the race start. This meant that repeated measurements (starts) were taken from individual horses. In addition to this, other repetitions include that: multiple horses were bred from the same sire, trained at the same yard, ridden by the same jockey and made starts at the same track in the same year. This repetition violates the assumptions of independent observations made in the logistic regression modelling process. It has been recognised that failure to account for such clustering can lead to artificially small standard errors, resulting in narrower confidence intervals, P-values that are too small and therefore inaccurate inferences (Dohoo et al., 2010) i.e. identifying associations that do not exist. To account for this, when the clustering of data was made across a small number e.g. nine years, these variables were included as fixed effects in the models. When the clustering was across larger numbers, such as horse or trainer, mixed-effects models were produced, including random effects terms. It is possible to assess the impact of including random effects by comparing the outputs with those from the model excluding the random effect. Clustering of starts was investigated within the horse, horse dam, horse sire, trainer, jockey, year, course and meet. Residual intraclass correlation coefficients (r) were estimated for each level of clustering, using a latent variable approach (Snijders and Bosker, 1999), by including each hierarchical level as a random effect, one by one, in the final multivariable logistic regression model.

In order to take into account the multiple levels in the data structure, it is theoretically possible to add multiple hierarchies (i.e. multiple of the above random effects) at once or to use cross-classified models (Goldstein et al., 2002; Rodriguez and Goldman, 1995) in association with multivariable logistic regression models. Previous work by some of the project collaborators (Parkin et al. 2000) concluded that it was very difficult to get multivariable models with greater than two levels to appropriately fit the data and that fitting multiple levels failed to significantly affect the results. Based on this it was decided that using techniques to include greater than two levels would not be employed in the analyses in this thesis.

2.7.5 Post-Fit Model Diagnostics

2.7.5.1 Model fit

Following production of a multivariable logistic regression model it is possible to assess how well it fits the observed data, using the Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow, 2000; Dohoo et al., 2010). Using this technique the data is ordered by likelihood of outcome and then subdivided into a number of equal sized groups (usually 10). The predicted likelihood is then compared to the observed likelihood for each of these groups. Identifying statistically significantly different observed and expected likelihoods, provides some evidence of lack of model fit. However, on a technical note, during analysis in a number of models, altering the number of equal sized groups (from the suggested standard 10) resulted in different results obtained from the Hosmer-Lemeshow test, such that sometimes there was evidence of lack of fit, just by altering the number of groups.

2.7.5.2 Influential data

Techniques can be used to examine the results of logistic regression to assess whether certain observations either do not fit the data well, or are having an undue effect on the model i.e. skewing the results. It is possible to identify covariate patterns that have a large effect on the model coefficients, by predicting delta beta values. It is then possible to determine the impact of these influential patterns, by excluding them from the model and determining whether the outcomes change significantly. In a robust model the coefficients would not change very much following removal of the patterns with the largest delta betas (Dohoo et al., 2010), which was performed following model production. If any observations (in all cases – starts) were observed to be having an undue effect on the models, these starts were excluded from analyses.

2.7.5.3 Predictive ability

To assess how well the models predict the outcomes being examined it is possible to determine the sensitivity and specificity and to plot receiver operator characteristic curves (plotting the fraction of true positives out of the positives against the fraction of false positives out of the negatives) for each model. These can then be used to determine the predictive ability of the models, with values of 0.5 indicating no better predictive power than chance and values of 1 indicating perfect predictive power (Altman et al., 2000).

3 Initial Review Of The Injury Database

3.1 Introduction

As a first step in examining the data provided from the BHA and Weatherbys, simple graphical representations of the data, subdivided by findings of potential interest were produced. This was done for a number of reasons: firstly examining the data in this way facilitated identification of errors or missing values in the data; secondly it allowed comparison with previous reported outcome prevalence from other studies (as described in Chapter 1) and thirdly (and probably most importantly for this study) it helped to guide further examination of the data by identifying trends and generating potential hypotheses for links between risk factors and outcomes. The goal of these initial analyses was to provide information for discussions with the project collaborators in the fourth month of the study.

3.2 Method

Data were represented graphically and incidence rates were calculated using Excel™[5]. Relative risks and P-values were produced using chi squared with Yates correction in EpiInfo Stat Calc™[6]. For reference, details of injuries and starts in flat racing were included in the initial analyses.

3.3 Starts

From 1st January 2000 to 31st December 2009 there were 185,826 hurdle starts, 113,327 steeplechase (steeple) starts, 27,848 NHF starts and 570,249 flat starts (Figure 3-1).

[5] Microsoft, Reading, UK

[6] Centers for disease control and prevention, Atlanta, USA

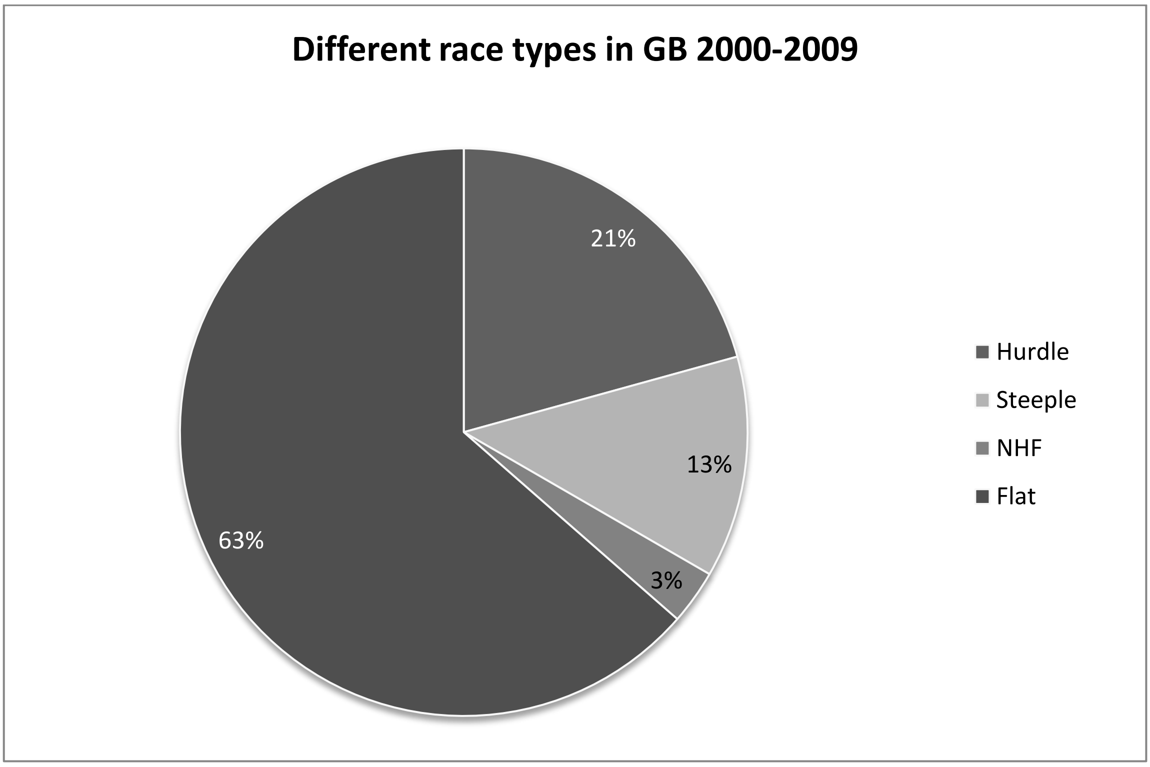


Figure 3-1: Pie chart showing percentage of Great British race starts in each race type over the 10 years of the study. NHF = National Hunt Flat. Steeple = Steeplechase

3.4 Events (Injuries)

The frequency of all injuries (events), fatalities and the five most common event types varied between race types (Table 3-1). The incidence rates of events was highest in steeplechase racing (39.4/1000 starts) and was significantly ($p<0.001$) higher in this discipline than in all other types of racing, with a risk of injury four times greater than flat, three times greater than NHF and 1.2 times greater than hurdle racing. Relative risk comparisons for events between each type of racing are shown in Table 3-2.

Table 3-1: Details of common events for each race type during study period.

	Hurdle	Steeple	NHF	Flat	TOTAL
Starts	**185826**	**113327**	**27848**	**570249**	**897250**
All events (per 1000 starts)	**6184** (33.3)	**4469** (39.4)	**357** (12.8)	**5187** (9.1)	**16197** (18.1)
Fatalities (per 1000 starts)	**860** (4.6)	**705** (6.2)	**76** (2.7)	**445** (0.8)	**2086** (2.3)
Tendon / Ligament injury (per 1000 starts)	**1492** (8)	**951** (8.4)	**66** (2.4)	**367** (0.6)	**2876** (3.2)
Laceration / Wound (per 1000 starts)	**1263** (6.8)	**746** (6.6)	**29** (1)	**766** (1.3)	**2804** (3.1)
Epistaxis (per 1000 starts)	**645** (3.5)	**593** (5.2)	**24** (0.9)	**701** (1.2)	**1963** (2.2)
Fracture (per 1000 starts)	**602** (3.2)	**568** (5)	**62** (2.2)	**477** (0.8)	**1709** (1.9)
Lameness (per 1000 starts)	**407** (2.2)	**341** (3)	**34** (1.2)	**735** (1.3)	**1517** (1.7)

Key: Steeple=Steeplechase; NHF=National Hunt Flat

Table 3-2: Relative risk of an event in the different types of racing: rows compared to columns.

RR Event	Hurdle	Steeplechase	NHF	Flat
Hurdle RR (C.I.s)	-	**0.84** (0.81-0.88) P<0.001	**2.64** (2.37-2.93) P<0.001	**3.66** (3.53-3.79) P<0.001
Steeplechase RR (C.I.s)	**1.18** (1.14-1.23) P<0.001	-	**3.13** (2.81-3.48) P<0.001	**4.34** (4.17-4.51) P<0.001
NHF RR (C.I.s)	**0.38** (0.34-0.42) P<0.001	**0.32** (0.29-0.36) P<0.001	-	**1.39** (1.25-1.54) P<0.001
Flat RR (C.I.s)	**0.27** (0.26-0.28) P<0.001	**0.23** (0.22-0.24) P<0.001	**0.72** (0.65-0.8) P<0.001	-

Key: RR = relative risk; C.I.s = Confidence Intervals; NHF = National Hunt Flat; P-values calculated using Chi^2 with Yates correction.

3.4.1 Events per year

From 2000 to 2009 in GB, there was an increase in the number of starts in hurdle (16,421 to 19,144), steeplechase (10,563 to 11,699) and NHF (2,184 to 3,184) races. Over the same time period, the number of events per 1000 starts also increased (Figure 3-2), with a noticeable increase in the incidence rates of events in hurdle and steeplechase racing after 2004. When the highest yearly event rate was compared to the lowest for each race type, significant differences were observed: In hurdle racing there was 1.86 (1.65-2.09 $p<0.001$) times the risk of an event occurring in 2009 than in 2002; In steeplechase racing there was 1.64 (1.43-1.87 $p<0.001$) times the risk of an event occurring in 2009 than in 2001; In NHF racing there was 2.45 (1.39-4.34 $p=0.002$) times the risk of an event occurring in 2008 than in 2000.

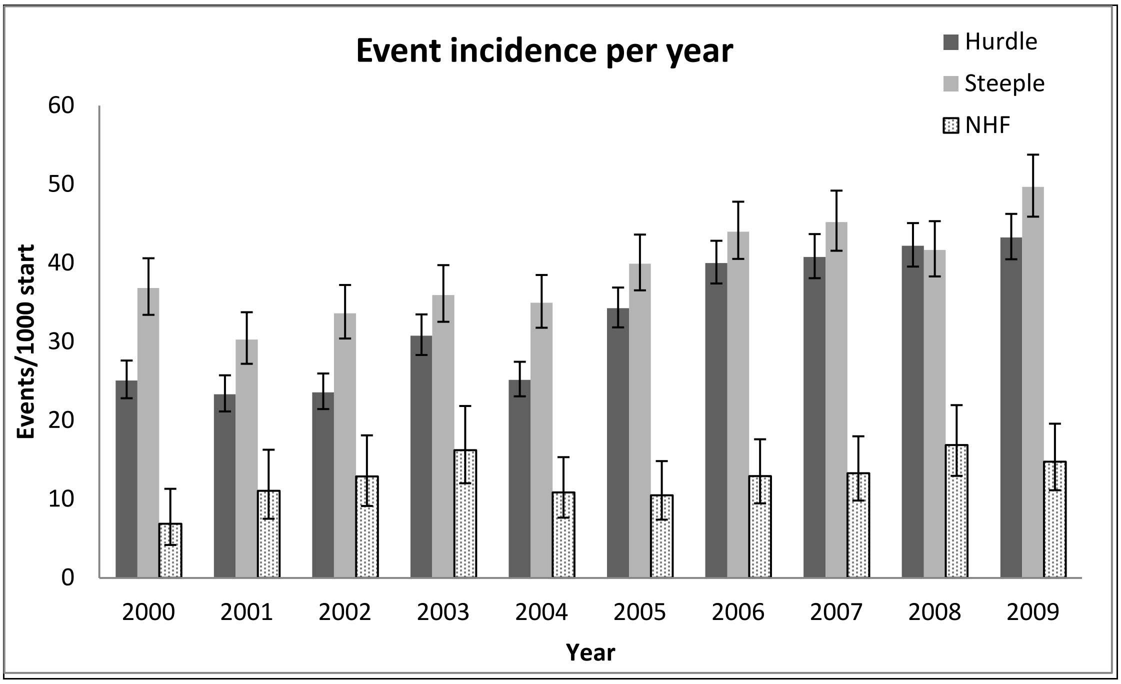


Figure 3-2: Graph showing number of events per 1000 starts in each race type by year. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**.**

3.4.2 Events per month

When events were stratified by month, there was a trend for increased incidence rate of events in June-September for hurdle, steeplechase and NHF. The incidence rates of events by month for the 10 year study period are shown in Figure 3-3. The relative risk of an event occurring between 1st June and 1st October was significantly higher than during the other months for all race types (Table 3-3).

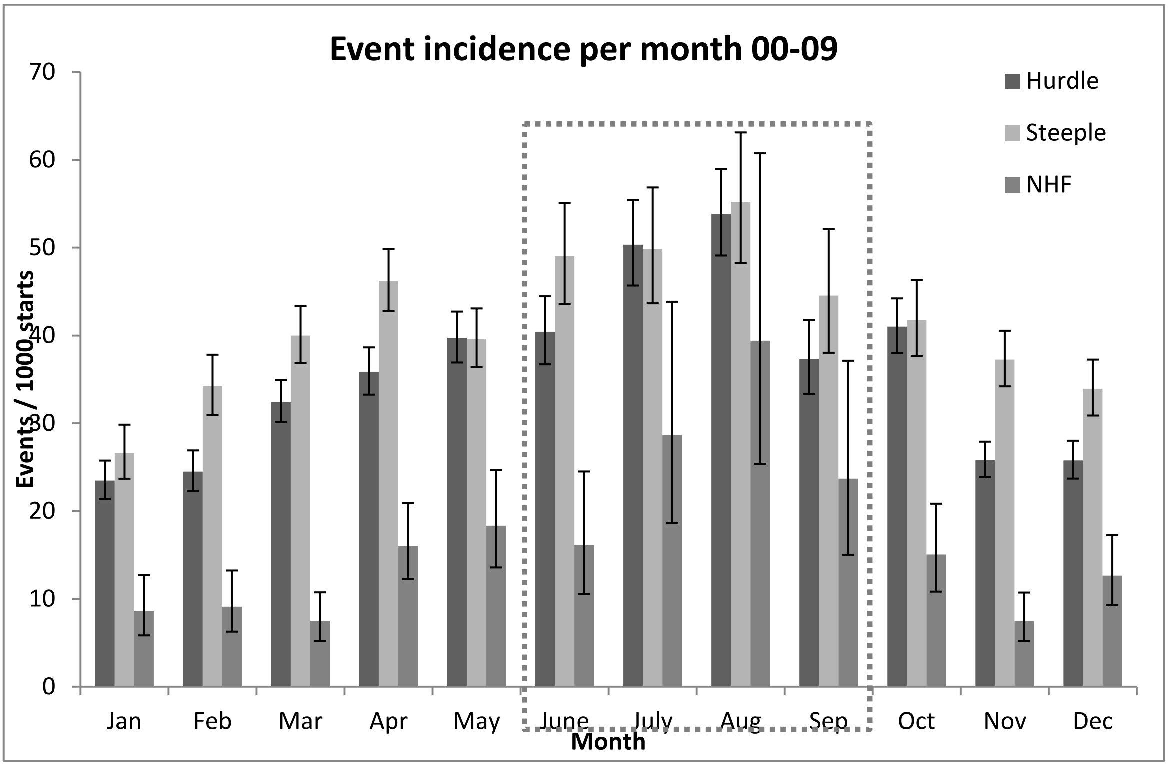


Figure 3-3: Graph representing number of events per month in 2000-2009. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. Jan=January; Feb=February; Mar=March; Apr=April; Aug=August; Sep=September; Oct=October; Nov=November; Dec=December. Dotted box represents months included for relative risk comparisons in Table 3.3.**

Table 3-3: Relative risk of "an event" occurring between 1st June and 1st October compared to the rest of the year for each race type. NHF = National Hunt Flat.

	Relative Risk	C.I.	P-value
Hurdle	**1.48**	1.39-1.56	<0.001
Steeplechase	**1.32**	1.22-1.42	<0.001
NHF	**2.12**	1.65-2.72	<0.001

Key: C.I.=Confidence interval; P-Value= calculated using Chi^2 with Yates correction; NHF=National Hunt Flat.

3.4.3 Events per racecourse

The incidence rate of events on each racecourse for hurdle, steeplechase and NHF racing combined over the 10 year period (2000-2009) ranged from 15/1000 (95% C.I. 12.04-18.29) starts to 79/1000 (95% C.I. 56.52-109.41) starts. The numbers of events per 1000 starts on each course are shown for each course in Figure 3-4.

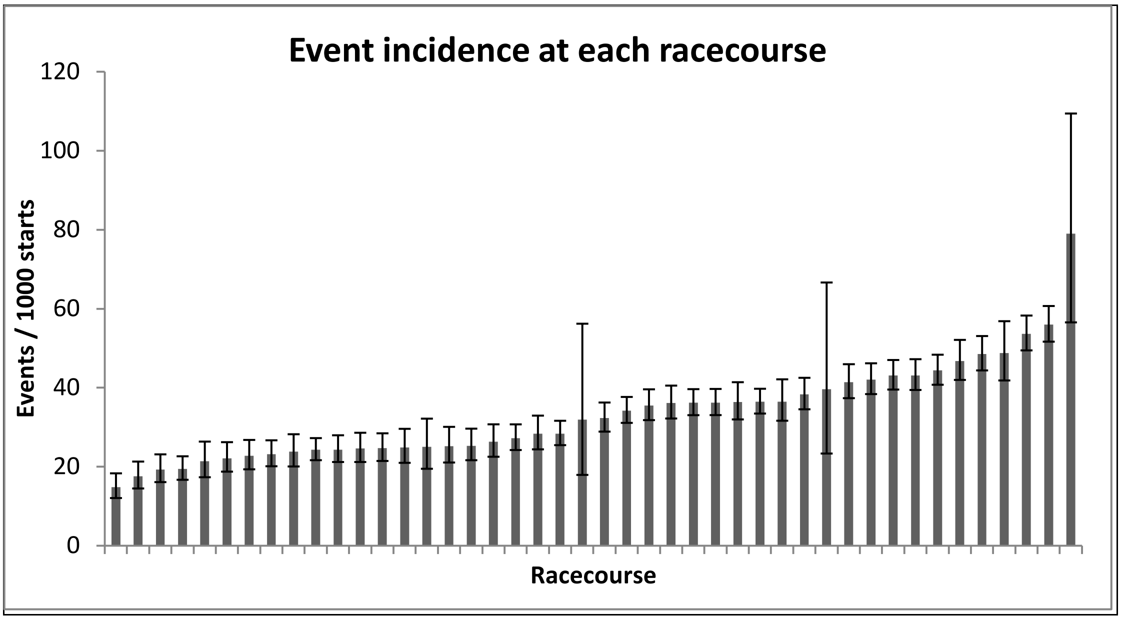


Figure 3-4: incidence rate of events at different racecourses for all types of jump racing between 2000 and 2009. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**.**

3.4.4 Events by race distance

The incidence rates of events at different race distances, for each race type are shown in Figure 3-5. The incidence rates of events in hurdle and steeplechase racing were generally increased in longer distance races. There was a marked increased incidence rate of events at the 7.2 km distance in steeplechase racing; with a relative risk of an event occurring at this distance (60/399) being 3.9 (3.04-4.87; p<0.001) times greater than all other distances of steeplechase racing combined (4410/112928). The large confidence interval associated with the 5.6 km distance in hurdle racing, is the result of a low number (20) of starts at this distance during the period studied.

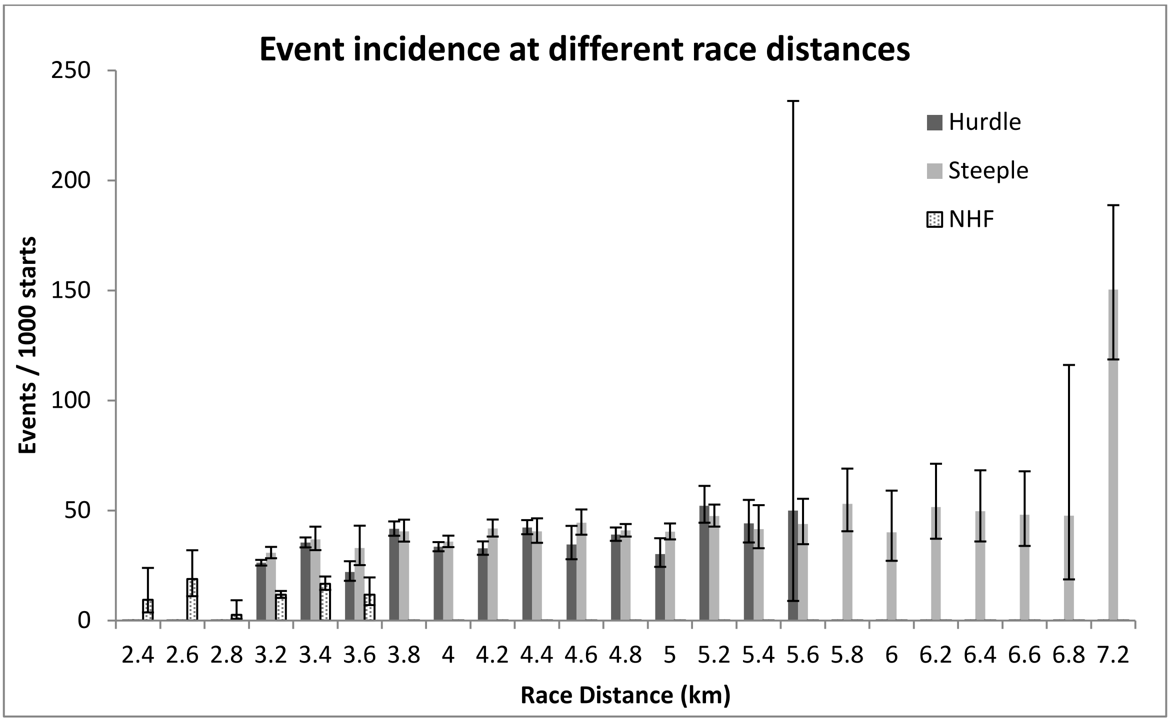


Figure 3-5: Graph representing the incidence rates of events over different race distances. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. NHF = National Hunt Flat; km=kilometres**

3.4.5 Events by "Going"

The incidence rates of events at different surface firmness (going) for each race type are shown in Figure 3-6. The incidence rates of events in all three race types were generally increased on firmer going. Standard going refers to that recorded for "all-weather" artificial surface tracks, with only flat races run on this type of surface.

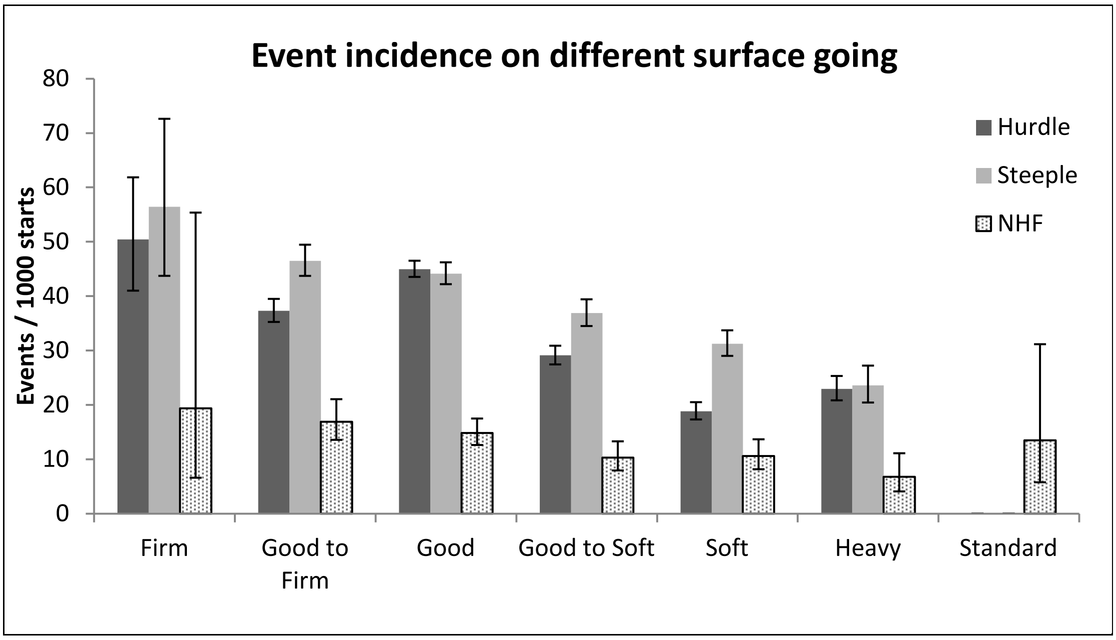


Figure 3-6: Incidence rates of events on different surface going. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. NHF = National Hunt Flat.**

3.4.6 Event Types

The 11 most common events were identified and the frequency of each is shown graphically in Figure 3-7. Tendon and/ or ligament injuries were the most common event in all race types.

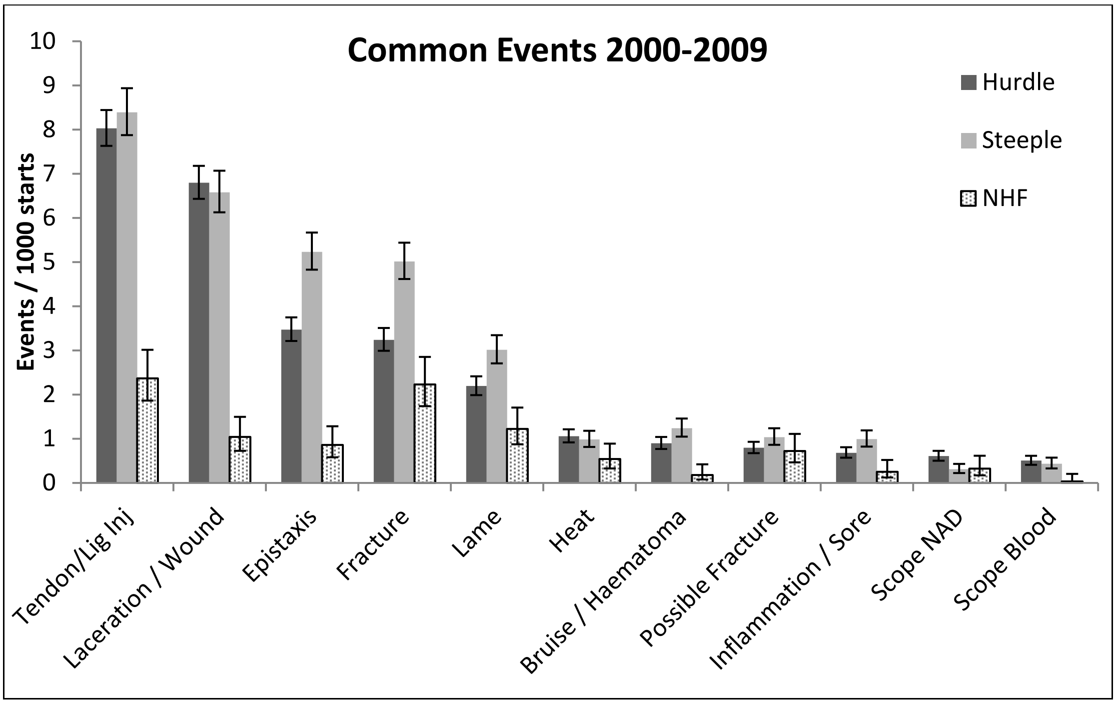


Figure 3-7: incidence rates of the 12 most common event types. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. NHF = National Hunt Flat; Tendon/Lig Inj = Tendon and/or ligament injury.**

The relative risks of each of the four most common outcomes were calculated between race types and are shown in Table 3-4. It can be observed that significant differences in relative risk were present for all events except those of tendon and/or ligament injury and laceration and/or wound between hurdle and steeplechase starts.

Table 3-4: Relative risk of the four most frequent outcomes between the different types of National Hunt racing.

Outcome	RR of injury between H and St (95% C.I.) *P-value*	RR of injury between H and NHF (95% C.I.) *P-value*	RR of injury between St and NHF (95% C.I.) *P-value*
Tendon / Ligament Injury	**0.96** (0.88-1.04) *P=0.29*	**3.4** (2.6-4.3) *P<0.001*	**3.5** (2.8-4.5) *P<0.001*
Laceration / Wound	**1.03** (0.94-1.13) *P=0.5*	**6.53** (4.5-9.4) *P<0.001*	**6.32** (4.4-9.2) *P<0.001*
Epistaxis	**0.66** (0.6-0.7) *P<0.001*	**4.03** (2.7-6.1) *P<0.001*	**6.07** (4-9.1) *P<0.001*
Fracture	**0.65** (0.6-0.7) *P<0.001*	**1.46** (1.1-1.9) *P=0.006*	**2.25** (1.7-2.9) *P<0.001*

Key: RR = relative risk; H=Hurdle; St=Steeplechase; NHF = National Hunt Flat; C.I.s = Confidence Intervals; P-values calculated using Chi^2 with Yates correction. Significant differences highlighted by grey box fill.

3.4.6.1 Common event types by month

One of the goals of the project was to determine the relative safety of summer jump racing (defined by the BHA as occurring between June and September). To represent this graphically, the five most common event types were stratified by month for each race type and are shown in Figures 3-8 through 3-10. The incidence rates of the most common events in each race type, stratified by season and relative risks between summer and the other seasons combined are shown in Table 3-5. It can be observed that the relative risk of tendon and/or ligament injuries, lacerations and/or wounds, fractures and lameness were all significantly increased in summer as compared to the other seasons for all race types (except for the relative risk of lameness in steeplechase and national hunt flat racing, where no significant difference was observed). The relative risk of epistaxis did not differ significantly between summer and the other seasons.

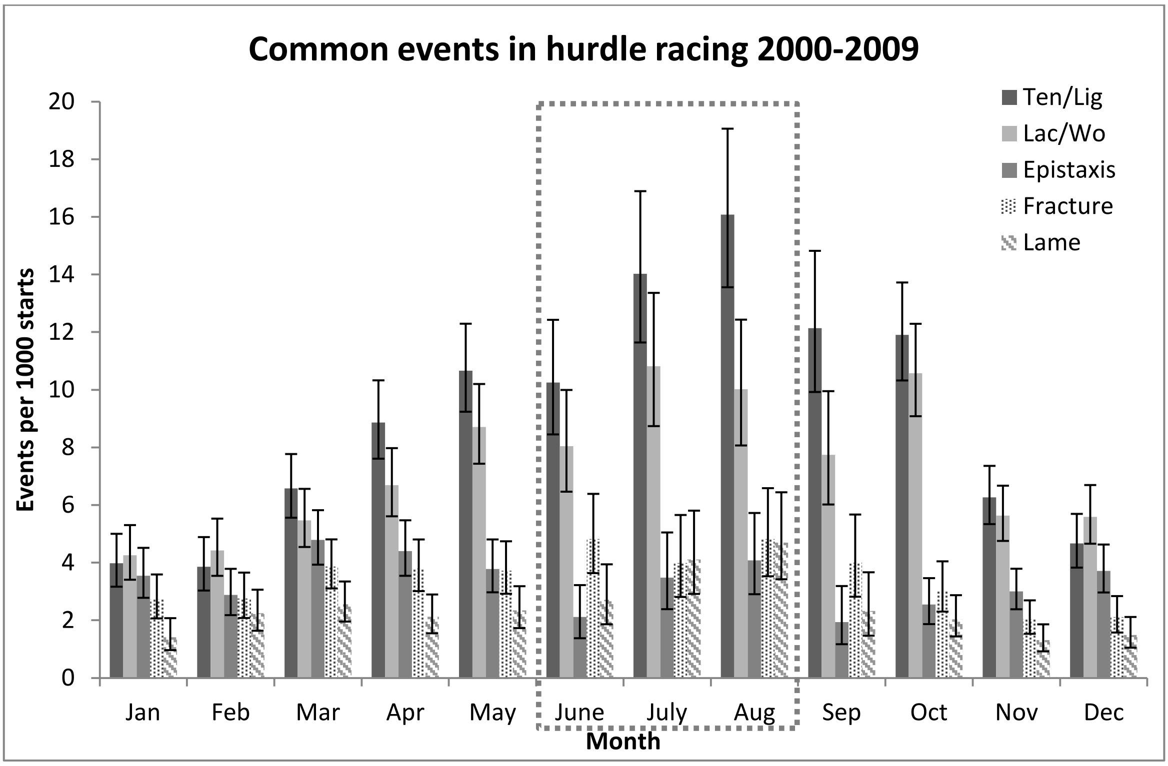


Figure 3-8: Graph of the five most common events in hurdle racing, stratified by month. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. Key: Ten/Lig: Tendon and/or ligament injury; Lac/Wo: Laceration and/or wound. Dotted box represents "summer" months included for relative risk comparisons in Table 3-5.**

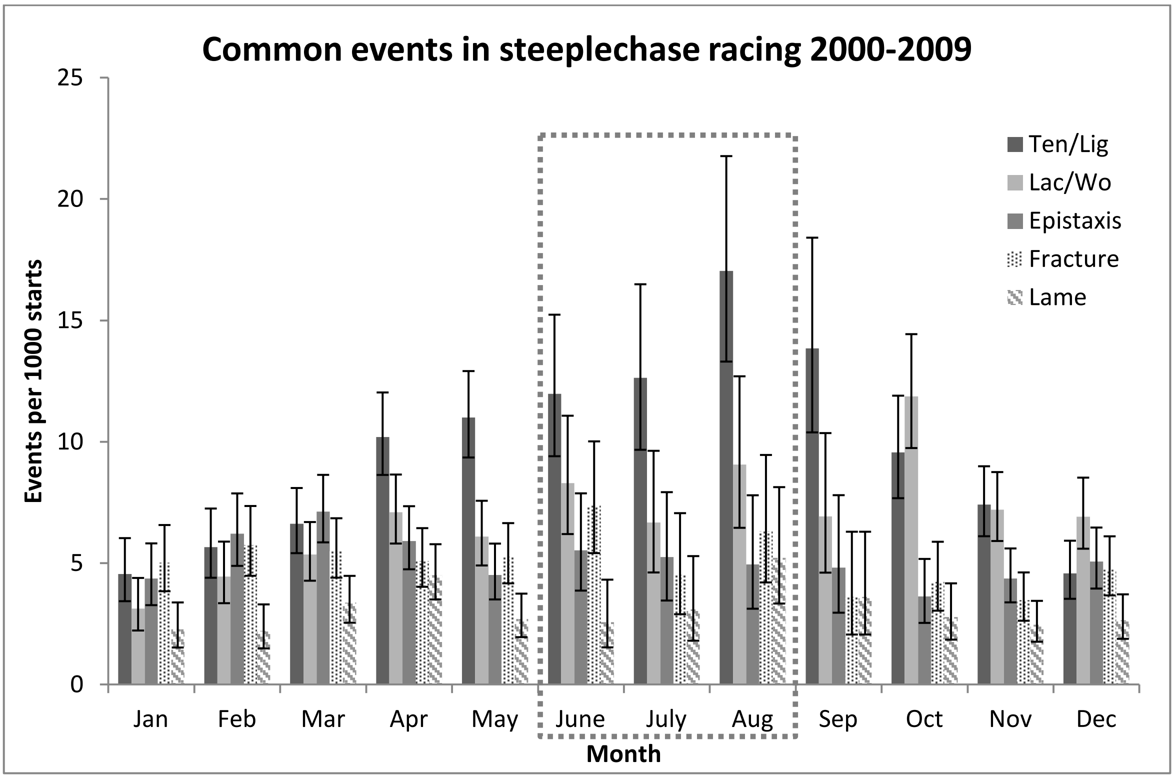


Figure 3-9: Graph of the five most common events in Steeplechase racing, stratified by month. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. Key: Ten/Lig: Tendon and/or ligament injury; Lac/Wo: Laceration and/or wound. Dotted box represents "summer" months included for relative risk comparisons in Table 3-5.**

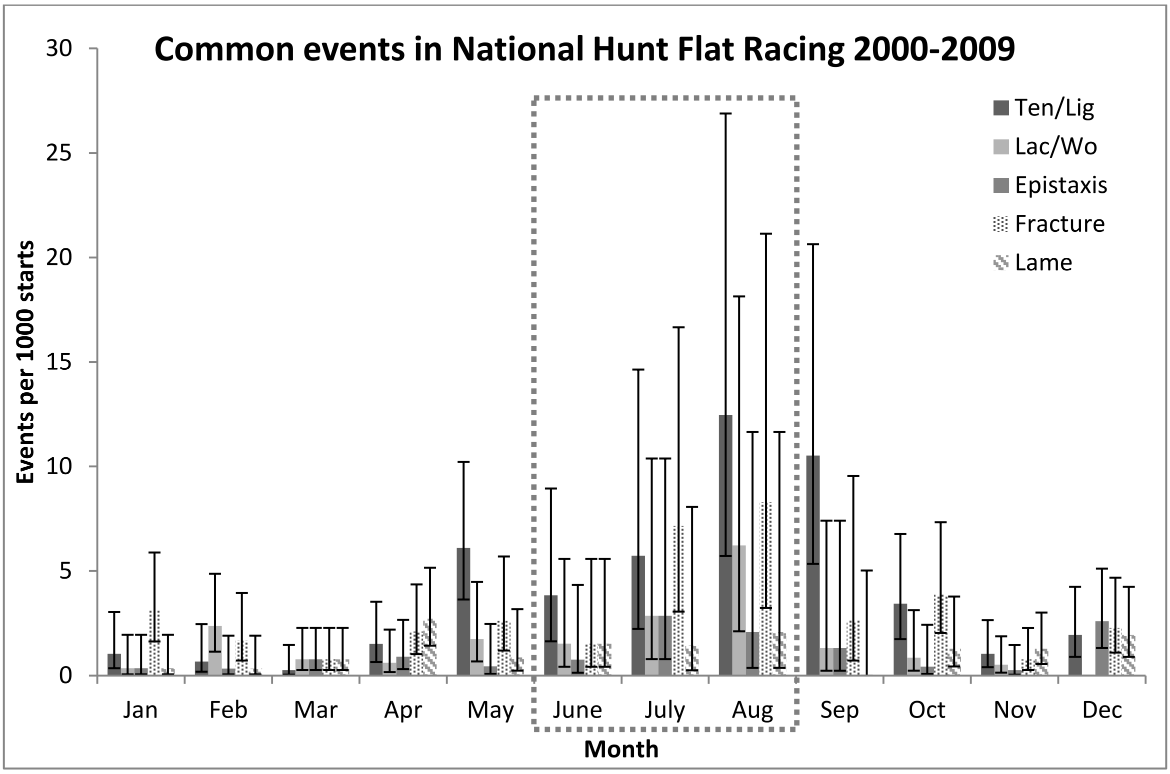


Figure 3-10: Graph of the five most common events in National Hunt Flat racing, stratified by month. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. Key: Ten/Lig: Tendon and/or ligament injury; Lac/Wo: Laceration and/or wound. Dotted box represents "summer" months included for relative risk comparisons in Table 3-5.**

Table 3-5: Incidence rates of the most common events in each race type, stratified by season and relative risks between summer and the combined other seasons.

Event	Season	Hurdle Incidence rate (95% C.I.)	RR S vs NS (P)	Steeplechase Incidence rate (95% C.I.)	RR S vs NS (P)	NHF Incidence rate (95% C.I.)	RR S vs NS (P)
Tendon /	Winter	4.2 (3.7-4.8)		4.9 (4.2-5.7)		1.2 (0.7-2.2)	
Ligament	Spring	8.6 (7.9-9.4)		9.2 (8.3-10.2)		2.1 (1.4-3.3)	
Injury	Summer	13.2 (11.9-14.7)	1.84	13.6 (11.7-15.7)	1.76	6. (3.7-9.9)	3
	Autumn	9.1 (8.3-10)	(<0.001)	9 (7.9-10.2)	(<0.001)	2.9 (1.9-4.4)	(<0.001)
Laceration /	Winter	4.8 (4.3-5.4)		5 (4.3-5.8)		0.9 (0.5-1.8)	
Wound	Spring	6.9 (6.2-7.6)		6.2 (5.5-7)		0.9 (0.5-1.8)	
	Summer	9.5 (8.4-10.8)	1.49	8 (6.6-9.7)	1.25	2.8 (1.4-5.8)	3.25
	Autumn	7.6 (6.9-8.5)	(<0.001)	8.7 (7.6-9.9)	(0.037)	0.7 (0.3-1.7)	(0.011)
Epistaxis	Winter	3.4 (3-3.9)		5.2 (4.5-6)		1.1 (0.6-2.1)	
	Spring	4.4 (3.8-4.9)		5.9 (5.2-6.7)		0.7 (0.4-1.5)	
	Summer	3.1 (2.5-3.9)	0.89	5.3 (4.2-6.7)	1.01	1.6 (0.6-4.1)	2.04
	Autumn	2.7 (2.2-3.2)	(0.36)	4.2 (3.5-5.1)	(0.98)	0.4 (0.1-1.3)	(0.33)
Fracture	Winter	2.5 (2.1-3)		5.2 (4.4-6)		2.4 (1.5-3.6)	
	Spring	3.8 (3.3-4.3)		5.3 (4.6-6)		1.7 (1-2.7)	
	Summer	4.6 (3.8-5.5)	1.51	6.2 (5-7.7)	1.27	4.4 (2.5-7.9)	2.2
	Autumn	2.7 (2.3-3.2)	(<0.001)	3.8 (3.1-4.6)	(0.049)	2. (1.2-3.4)	(0.027)
Lame	Winter	1.7 (1.4-2.1)		2.4 (1.9-3)		0.9 (0.5-1.8)	
	Spring	2.4 (2-2.8)		3.5 (3-4.2)		1.5 (0.9-2.5)	
	Summer	3.8 (3.1-4.6)	1.94	3.5 (2.6-4.6)	1.18	1.6 (0.6-4.1)	1.36
	Autumn	1.7 (1.4-2.1)	(<0.001)	2.7 (2.2-3.4)	(0.344)	1.2 (0.6-2.3)	(0.78)

Key: C.I.=Confidence Interval; RR=Relative Risk; S=Summer season; NS=Season other than summer; P=P-Value calculated using Chi^2 with Yates correction; NHF=National Hunt Flat.

3.5 Fatality

The incidence rates of fatalities in each type of racing are shown in Table 3-6. The incidence rate was highest in steeplechase racing (6.2/1000 starts) and was significantly (p<0.001) higher than all other types of racing, with a risk of fatality nearly eight times greater than the lowest risk (flat racing 0.78/1000 starts). Relative risk comparisons for fatality between each type of racing are shown in table four. The death rates for this population are compared with the findings from published studies in Table 3-7.

Table 3-6: Relative risk of Fatality in the different types of racing: rows compared to columns.

RR Fatality	Hurdle	Steeplechase	NHF	Flat
Hurdle RR (C.I.s)	-	**0.74** (0.67-0.82) p<0.001	**1.7** (1.34-2.14) p<0.001	**5.93** (5.29-6.65) p<0.001
Steeplechase RR (C.I.s)	**1.34** (1.22-1.48) p<0.001	-	**2.28** (1.8-2.89) p<0.001	**7.97** (7.08-8.97) p<0.001
NHF RR (C.I.s)	**0.59** (0.47-0.75) p<0.001	**0.44** (0.35-0.56) p<0.001	-	**3.5** (2.74-4.46) p<0.001
Flat RR (C.I.s)	**0.17** (0.15-0.19) p<0.001	**0.13** (0.11-0.14) p<0.001	**0.29** (0.22-0.36) p<0.001	-

Key: RR = relative risk; C.I.s = Confidence Intervals; NHF = National Hunt Flat; P-values calculated using Chi^2 with Yates correction.

Table 3-7: Comparison of death rates from published studies.

Race Type	**UK 00-09 Death/1000 (starts)**	**UK 90-99 Death/1000 (starts) Ref. 1**	**Virginia 96-00 Death/1000 (starts) Ref. 2**	**Victoria 86-93 Death/1000 (starts) Ref. 3**	**Victoria 89-04 Death/1000 (starts) Ref. 4**
Hurdle	**4.6** 185826	**4.9** 176951	**3.1** 1624	**6** **(___)**	**8.3** 23857
Steeple (Timber)*	**6.2** 113327	**6.7** 103712	**6.1*** 326	**11** **(___)**	
NHF	**2.7** 27848	**3.8** 17942	**N/A**	**N/A**	**N/A**

1. *Henley et al.* 2006: A comparison of survival models for assessing risk of racehorse fatality. 2. *Stephen et al.* 2003: Risk factors and prevalence of injuries in horses during various types of steeplechase racing. 3. *Bourke* 1994: Fatalities on racecourses in Victoria: a seven year study. 4. *Boden et al.* 2006: Risk of fatality and causes of death of Thoroughbred horses associated with racing in Victoria, Australia: 1989-2004.

Relative risks of death were calculated between the Henley 2006 paper and the current data set and were found not be significantly different (when assessed using a Chi squared test with Yates correction): Hurdle 1.07 (0.97-1.17) P=0.982; Steeplechase: 1.08 (0.97-1.20) P=0.171; NHF: 1.39 (1.0-1.93) P=0.0583.

3.5.1 Fatalities per year

The number of fatalities varied between year and with race type, such that yearly changes in hurdle fatality rate did not necessarily change in a similar fashion to steeplechase of NHF racing; for example between 2003 and 2004 the fatality rate declined in hurdle racing, but increased in steeplechase racing. The fatality rate per 1000 starts and number of fatalities that occurred at the racecourse for each year and with each race type are shown in Table 3-8 and represented graphically in Figure 3-11.

Table 3-8: Table showing the fatality rate per 1000 starts and number of fatalities each year, subdivided between the different types of national hunt racing.

Fatality	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Hurdle / 1000 (number)	4.57 (75)	4.27 (71)	4.27 (74)	6.72 (116)	3.94 (77)	4.78 (95)	3.98 (80)	3.81 (73)	4.96 (101)	5.12 (98)
Steeple / 1000 (number)	**7.86** (83)	**5.41** (57)	**6.56** (71)	**5.54** (57)	**7.44** (86)	**3.74** (44)	**6.29** (77)	**6.32** (72)	**5.30** (66)	**7.86** (92)
NHF / 1000 (number)	**3.21** (7)	**2.65** (6)	**2.81** (7)	**4.63** (12)	**2.09** (6)	**1.69** (5)	**1.99** (6)	**3.24** (10)	**3.12** (10)	**2.20** (7)

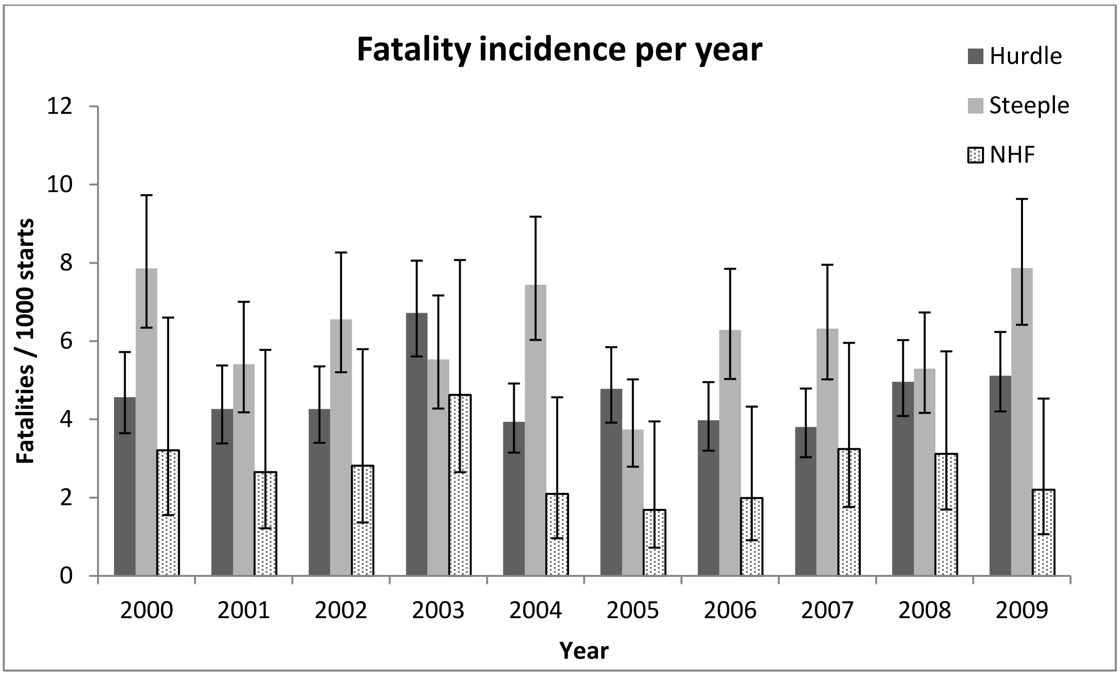


Figure 3-11: Graph showing number of fatalities per 1000 starts in each race type by year. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**.**

3.5.2 Fatalities per month

There was an increased incidence rate of fatality in the summer months (June-September) for hurdle, steeplechase and NHF. The incidence rates of fatality each month from the 10 year study period are shown in Figure 3-12. Relative risk of fatality in the summer months (1st June – 1st September) compared to the rest of the year for each race type are shown in Table 3-9.

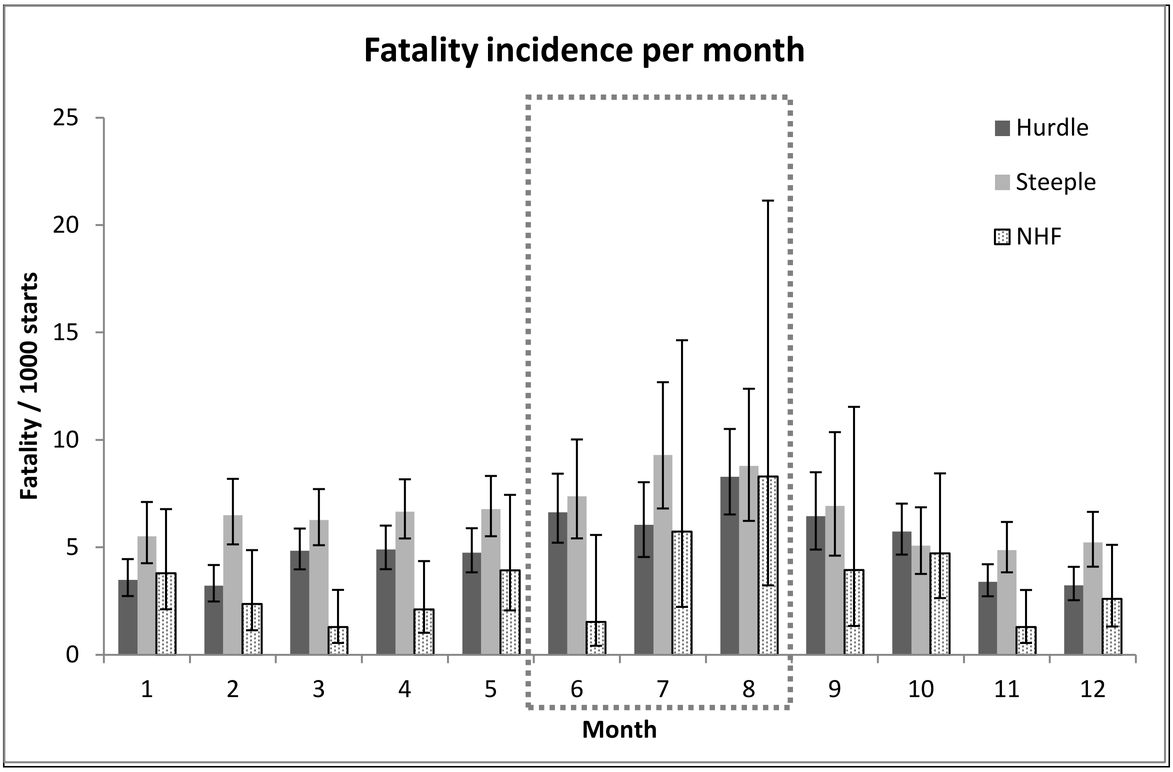


Figure 3-12: Graph representing number of fatalities per month (1=January … 12=December) in 2000-2009. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. Dotted box represents months included for relative risk comparisons in Table 3.3.**

Table 3-9: Relative risk of fatality occurring in summer (1st June to 1st September) compared to rest of the year for each race type.

	Relative Risk	C.I.	P-value
Hurdle	**1.64**	1.39-1.93	<0.001
Steeplechase	**1.47**	1.2-1.8	<0.001
NHF	**1.5**	0.7-2.9	0.31

Key: C.I.=Confidence interval; P-Value= calculated using Chi^2 with Yates correction; NHF=National Hunt Flat.

3.5.3 Fatalities per racecourse

The incidence rates of fatalities on each racecourse for hurdle, steeplechase and NHF racing combined over the 10 year period is shown in Figure 3-13. The course with the highest incidence rate (Figure 3-13) demonstrated 9.32 times (C.I. 5.8-15.1; $p<0.001$) increased risk of fatality compared to the other courses: (16/345 starts c.f. 1625/326656 starts). Jump racing only occurred at that course for two years: 2004 and 2005. The data was re-plotted without that course in Figure 3-14, in which it can be observed that the fatality rates are comparable between the different courses.

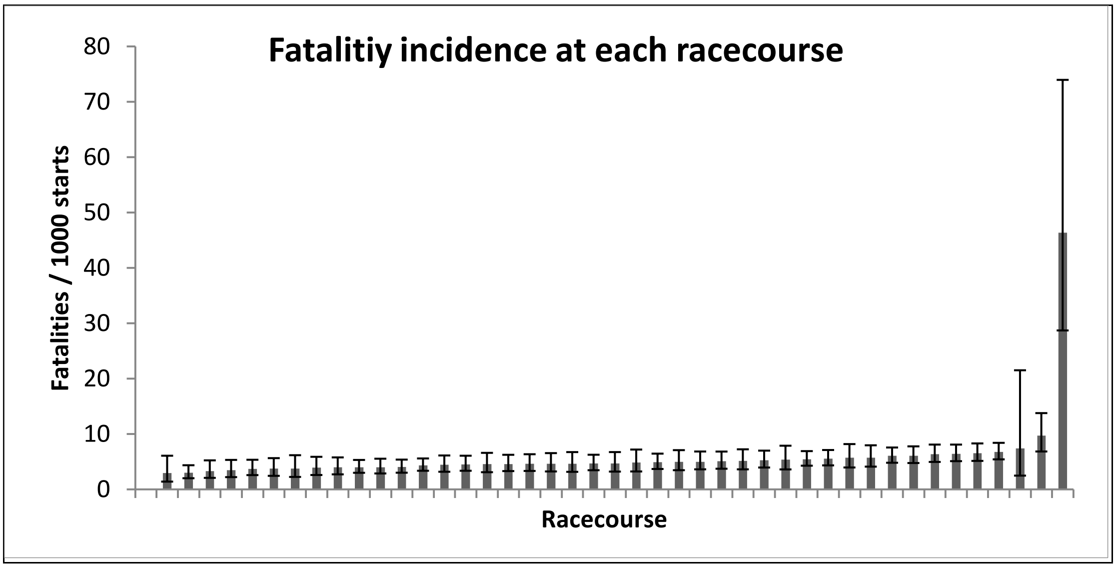


Figure 3-13: Incidence rates of fatality at different racecourses for all types of jump racing between 2000 and 2009. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**.**

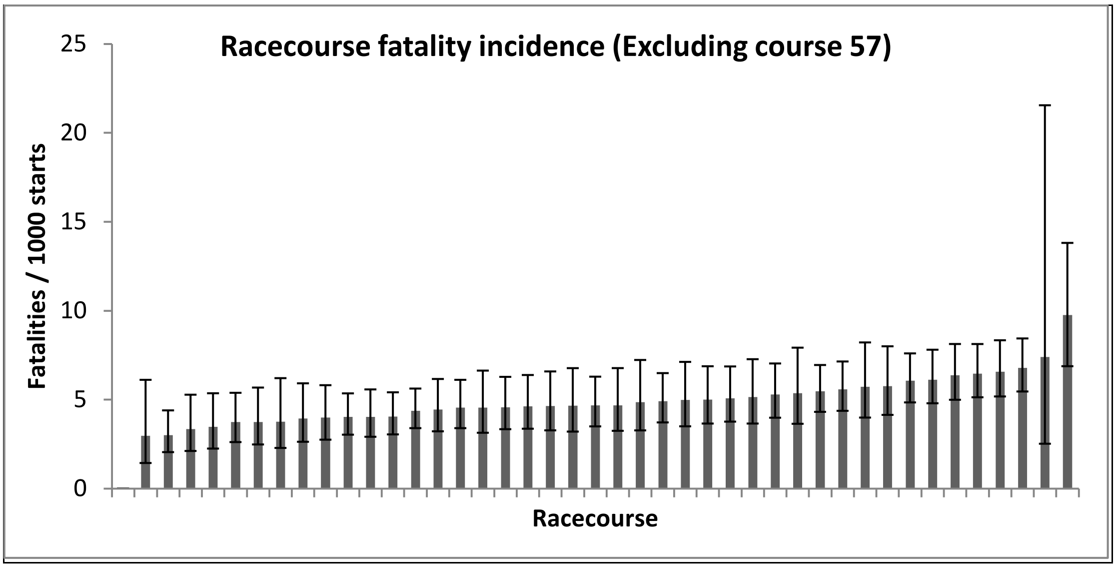


Figure 3-14: Incidence rates of fatality at different racecourses (excluding course 57) for all types of jump racing between 2000 and 2009. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**.**

3.5.4 Fatalities by race distance

The incidence rates of fatality at different race distances, for each race type are shown in Figure 3-15. The incidence rates of fatality in hurdle and steeplechase racing were generally increased in longer distance races. There was a marked increase in fatality incidence rate in steeplechase races greater than 6.4km. The numbers of starts and fatalities at each race distance divided by race type are shown in Table 3-10. The largest confidence intervals are related to the race distances with the lowest number of starts.

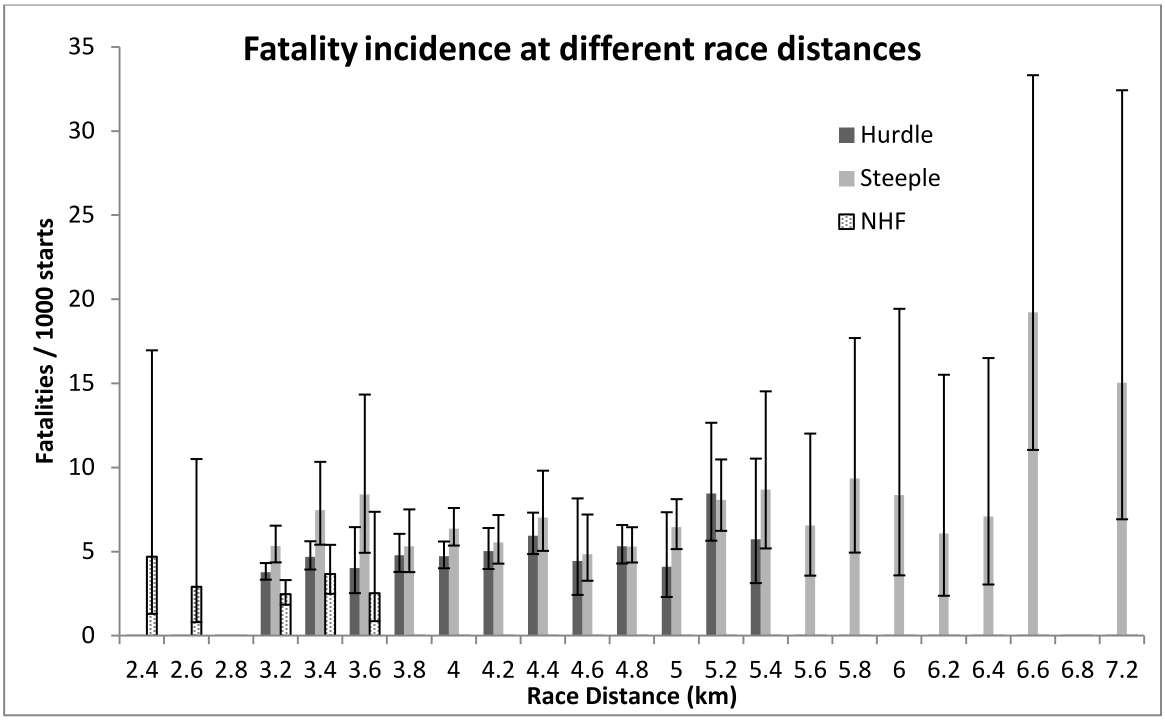


Figure 3-15: Graph representing the incidence rates of fatality at different race distances. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927)**. NHF = National Hunt Flat; km=kilometres.**

Table 3-10: Numbers of starts and fatalities in each National Hunt race type, at different race distances over the 10 year period.

Distance (km)	Hurdle Starts	Steeple Starts	NHF Starts	Hurdle Fatalities	Steeple Fatalities	NHF Fatalities
2.4	0	0	426	0	0	2
2.6	0	0	691	0	0	2
2.8	0	0	789	0	0	0
3.2	59497	17263	17909	225	92	44
3.4	25588	4819	6838	120	36	25
3.6	4219	1547	1195	17	13	3
3.8	14433	6017	0	69	32	0
4.0	28767	19629	0	136	125	0
4.2	13124	10300	0	66	57	0
4.4	15131	4840	0	90	34	0
4.6	2253	4958	0	10	24	0
4.8	15645	18535	0	83	98	0
5.0	2682	11310	0	11	73	0
5.2	2722	6937	0	23	56	0
5.4	1745	1613	0	10	14	0
5.6	20	1528	0	0	10	0
5.8	0	962	0	0	9	0
6.0	0	598	0	0	5	0
6.2	0	659	0	0	4	0
6.4	0	705	0	0	5	0
6.6	0	624	0	0	12	0
6.8	0	84	0	0	0	0
7.2	0	399	0	0	6	0

Key: km=kilometres; Steeple=steeplechase; NHF=National Hunt Flat.

3.5.5 Fatalities by Going

The incidence rates of fatality at different surface firmness (going) for each race type are shown in Figure 3-16. Firmer going was associated with higher fatality incidence rates in each of the three types of National Hunt racing. Standard going refers to that recorded for "all-weather" artificial surface tracks, with only flat races run on this type of surface.

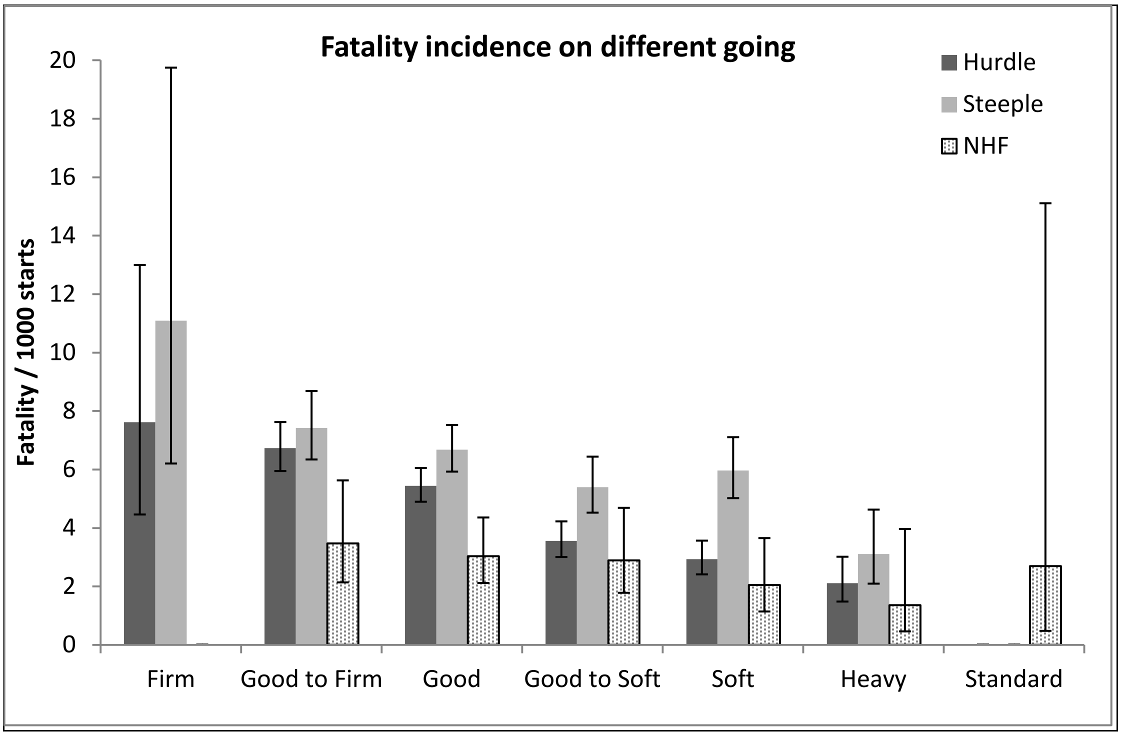


Figure 3-16: Incidence rates of fatality on different surface going. Error bars represent 95% confidence intervals calculated using the "Wilson" method (Wilson 1927). **NHF = National Hunt Flat; Steeple = steeplechase**

3.5.6 Causes of fatality

Fractures were the predominant cause of fatality in all three race types. The frequencies of the five most common causes of fatality are shown in Figure 3-17.

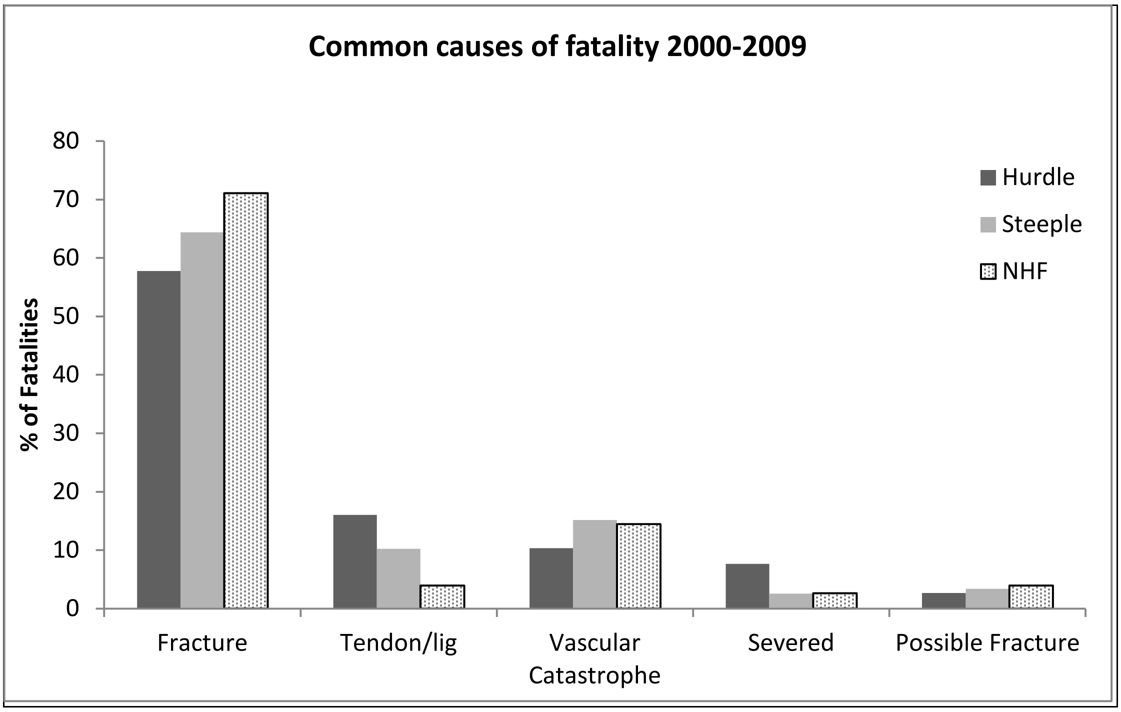


Figure 3-17: Frequency of the different causes of fatality as percentage cause of total deaths. NHF = National Hunt Flat; Lig = ligament.

3.6 Discussion

3.6.1 Race Type

During the 10 years 2000-2009 inclusive, the frequency of all events (injuries) and fatalities was significantly higher in steeplechase racing than all other race types. This higher frequency of injuries was likely because of: 1. the presence of obstacles (as compared to flat and NHF), which are of increased size and difficulty compared to hurdle fences and 2. the increased race distances compared to flat, hurdle and NHF (see Appendix 5 for details of obstacles and distances in each race type). The association between presence of obstacles and increased injury and fatality rates was demonstrated by the significantly increased relative risk of an event occurring in hurdle and steeple races compared to flat or NHF. It is unremarkable that the presence of obstacles results in increased injury rates both from falls when jumping the obstacles and also from collisions with them.

3.6.2 Year

The yearly number of starts increased in all race types over the study period. There was also an increase in the frequency of events, with a noticeable increase in the incidence rate of events in hurdle and steeplechase racing from 2005. This increase in number of events may suggest that more injuries were occurring on the racecourses, despite efforts being made by the BHA to reduce them. However this increase may also reflect an increased diligence in injury recording, because in 2005 an increased emphasis was placed on the importance of event recording by the V.O.s and potentially more (minor) injuries have been recorded since 2005. A similar increase was not observed in the frequency of fatalities (Figure 3-11) or fractures from 2005 onwards, which might support this suggestion (as these major events were unlikely to have been unrecorded or missed in the first half of the recording period) and indicates that the increase in events was likely to be of more minor injuries.

3.6.3 Month

Increased injury and fatality frequency in the summer months (1st June to 31st August) was observed for all three race types. When the five most frequent event types were stratified by month (Figures 3-8 through 3-10), marked increases in tendon and/or ligament injuries and lacerations and/or wounds were observed in the summer months for all three race types; likely as a result of the firmer ground resulting in higher forces being transmitted to the soft tissue structures of the limb. Interestingly the increased incidence rate of fractures in the summer months was not as dramatic as the increase in incidence rate of soft tissue injuries in hurdle and steeplechase racing. The reason for this is unknown but highlights the need for further investigation into the factors causing these common soft tissue injuries. The marked increase in relative risk of fatality in NHF racing in the summer season may also be worth investigating.

3.6.4 Racecourse

Event and fatality frequencies varied between racecourses, suggesting that racecourse-related factors might be (at least partly) responsible for some of the events. It is hoped that comparisons between courses will allow identification of local factors predisposing to events, which can then be improved. The courses in Figure 3-4, with very wide confidence intervals tended to have fewer jump starts (e.g. fewer than 500 starts over the 10 year period compared to a mean of 7,949 starts at the other courses).

3.6.5 Race Distance

A general trend towards increased event and fatality frequency with increasing race distance was observed in hurdle and steeplechase racing. It could be suggested that length of race is likely to be directly associated with injury and fatality frequency because the time at risk increases with race distance and horses become more fatigued over longer distances. Other studies have shown association between injury and race distance (Wood et al. 2000, 2001; Hernandez et al. 2001; Parkin et al. 2004b, 2005; Boden et al. 2007b). Another study showed that the risk of falling in steeplechase racing was associated with race distance, although this relationship was not a simple linear one; with increasing risk of falling up to 28 furlongs, then a decreasing risk at distances greater than this (Pinchbeck et al., 2002). The lack of clear linear association may be related to other variables associated with the different distances such as the obstacles involved and the quality of horses running. The marked increase in event frequency at the 7.2 km distance in this data set, is of unknown cause, but could be related to the difficulty of the obstacles in races of this distance and the associated increased fatigue.

3.6.6 Surface going

Going is an assessment of the firmness of the ground of the whole track, made at each racecourse on the day of racing. In 2001 an electronic measure “Going Stick”[7] was introduced in an attempt to add objectivity to what had previous been a purely subjective measurement. This alteration in technique occurred early in this data set, and will be considered later, when further investigation into “going” is undertaken. The going was found to be associated with the incidence rate of events and fatalities; generally the firmer the ground, the more frequently events and fatalities occurred in all types of racing. This has been recognised in previous studies of distal limb fractures, and fatalities (Hernandez et al. 2001; Williams et al. 2001; Parkin et al. 2004b, 2004c; Henley et al. 2006; Boden et al. 2007a) and is likely to be as a result of the increased forces acting on the limbs and the higher speeds achieved on firmer ground.

3.6.7 Common Event Types

A variety of different event types were identified over the ten year period (Figure 3-7). In order to optimise further investigations it is important to identify not only which events are common, but also which events lead to the most significant outcomes e.g. long term morbidity, retirement from racing and / or death. Further examination of the data and discussion with relevant racing authorities and veterinarians will guide more in-depth research of specific injuries at racecourses in GB. Brief discussions of the common events are presented in the following sections, with more details provided in subsequent chapters.

3.6.7.1 Tendon / Ligament Injury

Tendon and ligament injuries were the most commonly reported event, with the superficial digital flexor tendon (SDFT) being the most frequently reported injured structure. Severity of injury was also reported, with moderate strain injuries being the most common injury type reported in this database. However, it is likely that definition of degree (severe, moderate or slight) of acute injury to a tendon or ligament is unlikely to be very accurate and is likely to vary between examining veterinarians. Injuries to the tendons and ligaments and specifically the SDFT, frequently result in protracted morbidity and/or

[7] TurfTrax Ltd., St Neots, Cambridgeshire, UK.

retirement from racing and combined with their apparent frequency, warrant further investigation.

3.6.7.2 Lacerations and Wounds

Lacerations and wounds were the second most common event diagnosis, with distal limb sites being affected most frequently. The sites of these injuries and the lower frequency in NHF racing compared to jump, would suggest that many of these injuries occur as a result of contact with fences. Whilst all injuries are undesirable, minor lacerations and wounds are unlikely to be a cause of long term morbidity. More in-depth examination of this category of injury to determine which resulted in long term problems such as septic arthritis would not be possible with the current data set, as the majority of this type of clinical investigation is performed following removal of the horse from the racecourse. Nevertheless, these types of injuries remained a concern for the BHA, partly because of their potential high visibility to spectators. As a result, modifications to fences (hurdles in particular), including a padded top rail were introduced to try and reduce these type of injuries.

3.6.7.3 Epistaxis

Epistaxis was observed more frequently in steeplechase than hurdle racing; with steeplechase racing carrying 1.5 times the risk of a horse developing epistaxis than hurdle racing; and six times the risk of NHF racing. The increased prevalence in jump as compared to flat racing has been reported (Newton et al., 2005) and is of interest because the aetiology of epistaxis is not currently fully understood. Epistaxis has been shown to adversely affect performance in racing (Newton et al., 2005) and with this variation in occurrence between the different race types; further investigation into causal factors is indicated.

3.6.7.4 Fractures

Although the ability to repair limb fractures in horses has improved over the past two decades (Richardson, 2012), there is still a clear link between fractures and fatality (the most common cause in this analysis) and also with long term morbidity and retirement from racing, making further investigation into its predisposing factors a priority. Previous studies have examined risk factors for specific fracture types, such as fatal distal limb fractures (Parkin et al. 2004b, 2004c, 2004d). In this study, fractures of the third metacarpal/tarsal bones (fore greater than hind) were the most frequent, with cervical fractures being second most common. Fracture types of interest were determined from the available data and from priorities defined by the BHA, which dictated risk factor analyses.

3.6.7.5 Lame

The event type “Lame” was recorded as the fifth most frequently occurring event, with the fore limbs being affected significantly more frequently (relative risk 2.23 [1.99-2.51, $P<0.001$]) than the hind. Although right limbs were affected more frequently than the left, this difference was not statistically significant. Increased prevalence of forelimb injuries have been recognised previously (Ross, 2011) and could be partly related to the increased ease of identification of forelimb compared to hind limb lameness (Keegan et al., 2010). The diagnosis of “lame” covers a broad number of injuries and its relatively low incidence rate means that further investigation is unlikely to be performed as part of this examination of risk factors.

3.7 Conclusions

On 15th April 2010 a meeting was held with the project collaborators and BHA veterinarians. Preliminary descriptive results, as outlined in this chapter, were provided and priorities for further investigation were discussed with the following preliminary plans:

1. **Fatality in all jump races**
2. **Fatality in hurdle racing separately (if indicated)**
3. **Fatality in steeplechase racing separately (if indicated)**
4. **Tendon strain injury in hurdle and steeplechase races**
5. **Epistaxis in all jump races**
6. **Epistaxis in hurdle racing separately (if indicated)**
7. **Epistaxis in steeplechase racing separately (if indicated)**
8. **Hind limb fracture (excluding pelvic fracture) in all jump races**
9. **Hind limb fracture in hurdle racing separately (if indicated)**
10. **Hind limb fracture in steeplechase racing separately (if indicated)**
11. **Pelvic fracture in all jump races**

This list of priority outcomes was determined by a number of factors including injury incidence rate (which in turn determined likely statistical power); severity of consequence of the outcome; importance to the BHA; and number of previous epidemiological analyses of that outcome (considered likely to be associated with the probability of the research team being able to publish results in peer reviewed journals).

3.7.1 Hypotheses for the rest of the study

Based on the preliminary analyses of the data presented in this chapter, a number of trends and associations can be observed. These provide the ability to produce hypotheses for the risk factor analyses devised following the meeting with the BHA.

It is hypothesised that: race type (steeplechase compared to hurdle); season (summer compared to all others); longer race distance and firmer ground surface will be found to be associated with increased likelihood of the majority of the outcomes. It is hypothesised that specific years of the study will be associated with increased likelihood of the less severe outcomes (such as epistaxis and minor injuries), but not the more severe outcomes (such as fracture or fatality). It is recognised that year should be included in analyses to account for changes in associated factors. It is also hypothesised that likelihood of most outcomes will not differ significantly between racecourses once other variables are taken into account.

It will be interesting to observe whether these predicted associations/hypotheses (based on preliminary examination) are found to remain significant, once multiple variables are taken into account at once. With regards to providing policy advice, it will also be important to determine whether the predicted associations are observed for each outcome and in such a way that they can be manipulated without the risk of increasing the frequency of an alternate untoward outcome.

4 Risk factors for Fatality

4.1 Introduction

Reducing the incidence of racehorse fatality during races is rightly a major priority of racing regulatory bodies around the world. Internal audits performed by the BHA include regular reviews of fatality rates, to facilitate identification of increasing levels. In addition, annual reviews of recorded fatalities are provided to each racecourse clerk and manager to ensure that they are aware of the likelihood of fatality on their own track and to be able to compare themselves to their own previous likelihood and to other racecourses in GB. Courses identified as having high or increasing frequency of fatalities are investigated by the BHA.

Whilst internal audits facilitate subjective evaluation of potential risk factors, detailed risk factor analysis is required to determine true associations of these factors. There is some question of the relevance of using fatality as an outcome, as for example, it is likely that risk factors for fatal distal limb fractures are very different from risk factors for vascular catastrophe, both of which result in horse death. As a result investigation of the outcome as a whole might result in dilution of risk factors which are more strongly associated with, or even unique to, specific outcomes. This means that results from the analysis of fatality as a whole is likely to either identify largely common risk factors, or risk factors that are very strongly associated with specific (one or a few) outcomes. Unfortunately it is not possible to tell which is the case, hence the real need to conduct risk factor analysis for very specific outcomes as well as for very general (all encompassing) outcomes. Ultimately though, fatality is the major outcome of interest for those related to racing, so determining broad risk factors for this outcome, if modifiable, might result in reductions in fatality rates.

Previous studies that have been reviewed in Chapter 1 have reported the prevalence of and risk factors for fatality in different racing populations. The aim of this part of the study was to identify risk factors for all causes of fatality in hurdle and steeplechase racing, using multivariable logistic regression models, including random effects where indicated.

4.2 Materials and Methods

Potential risk factors for fatality in hurdle and steeplechase starts in GB were assessed using cohort studies. In order to allow inclusion of horse, race and track as different levels in risk factor analysis, the studies were conducted at the start level (a “start” being a horse starting a race) and included 752 case starts and 168,916 control starts in the hurdle study and 606 cases starts and 102,288 control starts in the steeplechase study.

4.2.1 Selection of cases and controls

A case start was defined as a start in a race, subsequent to which the horse died or was euthanased, whilst still at the racecourse. Control starts were defined as any start in a race, which did not end in fatality or euthanasia of the horse whilst still at the racecourse.

4.2.2 Risk factors

A total of 122 variables for each start (32 horse-related variables, 50 prior racing history-related variables, 25 race-related variables, 5 trainer-related variables, 5 jockey-related variables and 5 track-related variables) were available for analysis, details of which are reported in Chapter 2.

4.2.3 Power of the study

The hurdle model had at least 80% power to identify odds ratios of 1.3 or more, with 95% confidence, when the prevalence of exposure in the control population was between 17% and 77%. The steeplechase model had at least 80% power to identify odds ratios of 1.3 or more, with 95% confidence, when the prevalence of exposure in the control population was between 21% and 69%.

4.3 Results

Details of the numbers of starts, horses, jockeys, trainers, racecourses, races, race meets and race dates in each race type analysed in the study are presented in Chapter 2.

For the nine years between 2001 and 2009 inclusive there were 752 and 606 recorded cases of fatality in hurdle and steeplechase racing, respectively. For the study period the incidence rates of fatality were:

- 4.4/1000 starts in hurdle racing
- 5.9/1000 starts in steeplechase racing

4.3.1 Causes of fatality

The most frequently recorded causes of fatality in hurdle and steeplechase racing between 2001 and 2009, along with the percentage of cases that were euthanased, are shown in Table 4-1. The most common cause of fatality in both race types was fracture. Fractures recorded as “possible fractures” are included in the “fracture” diagnosis because it was considered that if they were deemed significant enough to warrant euthanasia, they were likely to be a true fracture. Details of fracture sites and frequencies are shown in Table 4-2.

Table 4-1: Injuries leading to fatality in hurdle and steeplechase racing between 01/01/01 and 31/12/09. Fracture cases include those classified as "possible fractures".

Cause of Fatality	Hurdle [% col tot] (% Euthanased)	Steeple [% col tot] (% Euthanased)	Total (per 1000 starts)
Fracture	485 [64] (84)	431 [71] (86)	917 (3.36)
Vascular catastrophe	84 [11] (5)	93 [15.5] (2)	177 (0.65)
Tendon / Ligament strain	103 [14] (100)	55 [9] (100)	157 (0.58)
Laceration / Wound	67 [9] (99)	18 [3] (100)	85 (0.31)
Dislocation	13 [2] (100)	9 [1.5] (100)	22 (0.08)
TOTAL	752 [100] (79)	606 [100] (75)	1358 (4.98)

Key: col tot=column total; Steeple=Steeplechase.

Table 4-2: Diagnosed fracture locations for horses that died as the result of a fracture in hurdle and steeplechase racing between 01/01/01 and 31/12/09.

Fractured Bone	Hurdle (% of Hurdle)	Steeplechase (% of Steeplechase)	Total (% of Total)
Cervical	87 (17.9)	84 (19.5)	165 (18.7)
Third Metacarpal	84 (17.3)	35 (8.1)	119 (13)
Proximal Phalanx	46 (9.5)	26 (6)	72 (7.9)
Third Metatarsal	33 (6.8)	24 (5.6)	57 (6.2)
Scapula	33 (6.8)	30 (7)	63 (6.9)
Radius / Ulna	31 (6.4)	33 (7.7)	64 (7)
Humerus	29 (6)	55 (12.8)	84 (9.2)
Tibia/Fibula	29 (6)	21 (4.9)	50 (5.5)
Pelvis	28 (5.8)	25 (5.8)	53 (5.8)
Carpal	27 (5.6)	12 (2.8)	39 (4.3)
Thoracolumbar	26 (5.4)	56 (13)	82 (9)
Sesamoid	10 (2.1)	7 (1.6)	17 (1.9)
Unspecified	9 (1.9)	7 (1.6)	16 (1.7)
Femur	7 (1.4)	7 (1.6)	14 (1.5)
Costal	2 (0.4)	0 (0)	2 (0.2)
Tarsal	2 (0.4)	6 (1.4)	8 (0.9)
Second Metacarpal	1 (0.2)	0 (0)	1 (0.1)
Skull	1 (0.2)	0 (0)	1 (0.1)
Second Phalanx	0 (0)	3 (0.7)	3 (0.3)
Total	485 (100)	431 (100)	916 (100)

4.3.2 Univariable analysis

Of the 122 variables screened at the univariable level, 37 were taken forward for consideration in each of the multivariable manual forward stepwise analyses. Details of these variables are shown in Appendix 6.

4.3.3 Multivariable analyses

In the final multivariable models, 12 and 9 variables were found to be significantly associated with fatality in hurdle and steeplechase racing, respectively (Tables 4-3 and 4-4).

4.3.3.1 Hurdle Racing

Variables found to be significantly associated with **increased** odds of fatality in hurdle racing were: running on going firmer than “good to soft” compared to running on softer going (Odds Ratio (OR) 1.69, 95% C.I. 1.44-1.99); running in the year 2003 compared to running in any other year in the study (OR 1.4, 95% C.I. 1.14-1.72); running in the summer compared to running in any other season (OR 1.3, 95% C.I. 1.08-1.56); increased race distance (OR for each km 1.28, 95% C.I. 1.12-1.46); running at a racecourse which held more than 5824 starts (was within the top quartile of tracks) during the study period (OR 1.2, 95% C.I. 1.02-1.42); being trained by a trainer with a higher percentage of first places (OR for each 10% increase 1.39, 95% C.I. 1.21-1.61); having an increased percentage of previous career starts in flat racing (OR for each 10% increase 1.24, 95% C.I. 1.2-1.29) and increased horse age (OR per extra year 1.26, 95% C.I. 1.19-1.33).

Variables found to be significantly associated with **decreased** odds of fatality in hurdle racing were: starting in a maiden or a novice race compared to starting in any other type of race (OR 0.71, 95% C.I. 0.6-0.84); starting in a different race type to the previous race that the horse competed in (OR 0.76, 95% C.I. 0.63-0.92); having made at least one start in the previous 10-12 months compared to having made none (OR 0.81, 95% C.I. 0.7-0.94); and increased number of starts greater than one year previously (OR per extra start 0.88, 95% C.I. 0.87-0.9).

4.3.3.1.1 Interaction terms

The variable "number of starts greater than one year previously" was found to have significant interactions with a. percentage of previous career starts in flat racing and b. horse age. The influences of these interactions on the main effects were included in the final model and are shown at the bottom of Table 4.3. Graphs representing the effect of a one unit change (increase) in number of starts greater than one year previously, at different levels of a. percentages of previous career on flat and b. horse age are shown in Figures 4-1 and 4-2 respectively.

a. *Number of starts greater than one year previously and percentage of previous career in flat racing.*

It can be seen in Figure 4-1 that the effect of the number of starts greater than one year previously varied with the percentage of the previous racing career spent in flat racing. A gradually reducing likelihood of fatality per start can be observed as the percentage of the previous career spent flat racing increased, throughout which the difference between groups remained statistically significant.

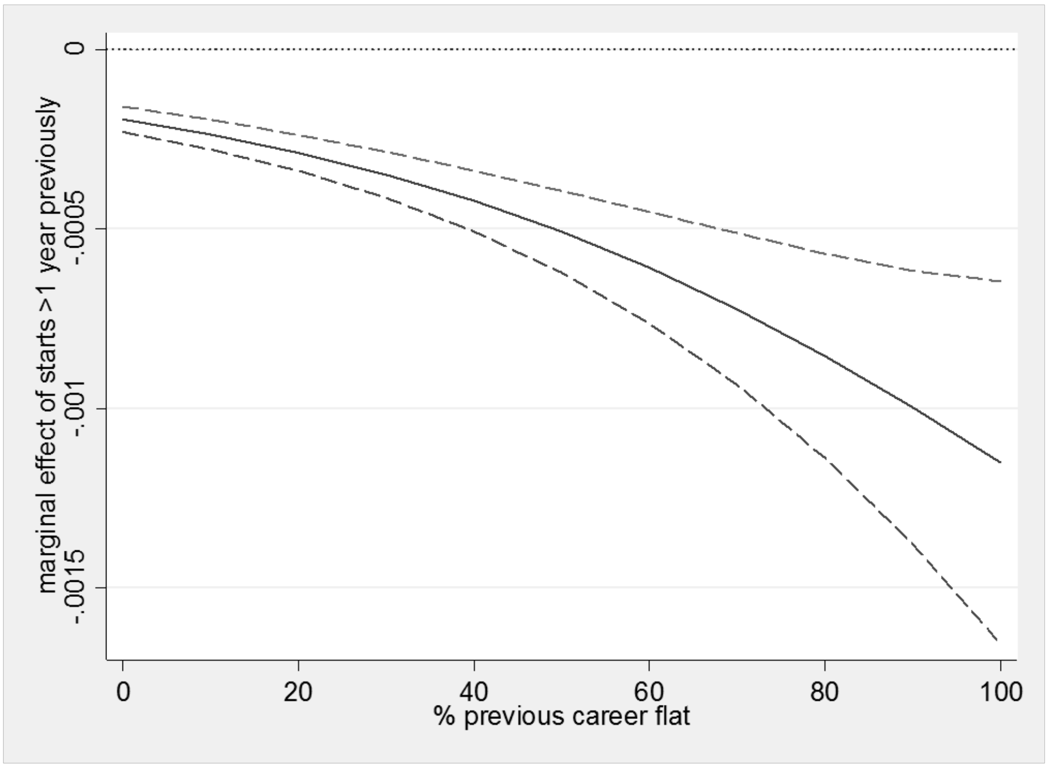


Figure 4-1: Line graph representing the effect of a one unit change (increase) in number of starts greater than one year previously on the likelihood of fatality at different percentages of previous career spent in flat racing. Solid line represents the mean; upper and lower dashed lines represent 95% upper and lower confidence intervals, respectively.

b. Number of starts greater than one year previously and horse age.

It can be seen in Figure 4-2 that the effect of the number of starts greater than one year previously varied with horse age, with a gradually reducing likelihood of fatality per extra start as horses got older, until approximately 13 years of age, at which time the effect of increased number of starts was no longer statistically significant (the upper confidence interval crossing 0).

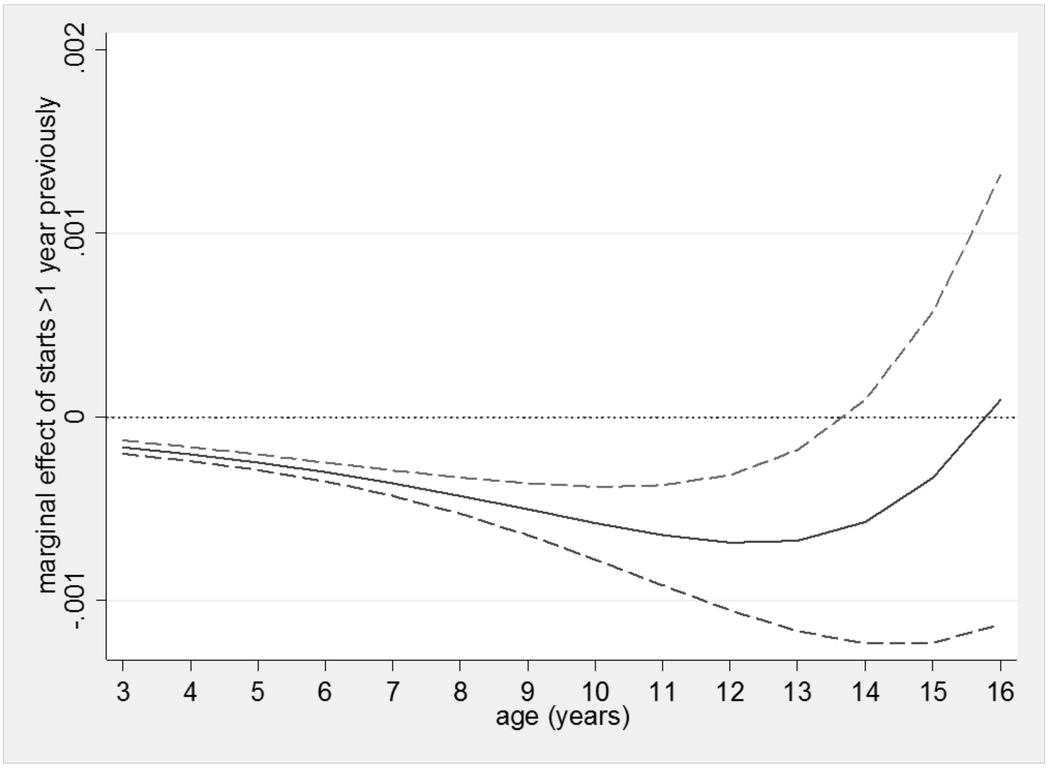


Figure 4-2: Line graph representing the effect of a one unit change (increase) in number of starts greater than one year previously on likelihood of fatality, at different horse ages. Solid line represents the mean; upper and lower dashed lines represent 95% upper and lower confidence intervals, respectively.

Table 4-3: Multivariable model showing variables significantly associated with the likelihood of fatality in hurdle racing.

Variable	TOTAL (%) n=169668	Cases (%) n=752	Controls (%) n=168916	**P-value**	Odds Ratio (OR)	95% Confidence Interval
			RACE RELATED VARIABLES			
Going						
“Heavy” to “GTS”	76796 (45.26)	228 (30.32)	76568 (45.33)			
"Good" to “Firm”	92872 (54.74)	524 (69.68)	92348 (54.67)	**<0.001**	1.69	1.44-1.99
Year 2003						
No	152376 (89.81)	647 (86.04)	151729 (89.83)			
Yes	17292 (10.19)	105 (13.96)	17187 (10.17)	**0.002**	1.4	1.14-1.72
Summer Season						
No	145809 (85.94)	590 (78.46)	145219 (85.97)			
Yes	23859 (14.06)	162 (21.54)	23697 (14.03)	**0.007**	1.3	1.08-1.56
Race Distance (Km)				**<0.001**	1.28	1.12-1.46
Maiden or Novice Race						
No	78431 (46.23)	375 (49.87)	78056 (46.21)			
Yes	91237 (53.77)	377 (50.13)	90860 (53.79)	**<0.001**	0.71	0.6-0.84
			COURSE RELATED VARIABLES			
Starts at that racecourse						
178 to 5824	130307 (76.8)	526 (69.95)	129781 (76.83)			
> 5824 (5825-7766)	39361 (23.2)	226 (30.05)	39135 (23.17)	**0.027**	1.2	1.02-1.42
			TRAINER RELATED VARIABLES			
Trainer Percentage of first places (per 10%)				**<0.001**	1.39	1.21-1.61
			HORSE RELATED VARIABLES			
Percentage of previous starts on flat (10%)				**<0.001**	1.24	1.2-1.29
Age (years)				**<0.001**	1.26	1.19-1.33
Change race type since previous race						
No	133733 (78.82)	604 (80.32)	133129 (78.81)			
Yes	35935 (21.18)	148 (19.68)	35787 (21.19)	**0.004**	0.76	0.63-0.92
Starts in previous 10-12 months						
None	86832 (51.18)	428 (56.91)	86404 (51.15)			
>0 (1-16)	82836 (48.82)	324 (43.09)	82512 (48.85)	**0.007**	0.81	0.7-0.94
Starts >1 year previously				**<0.001**	0.88	0.87-0.9
			INTERACTION			
Starts >1 year previously and percentage of previous starts on flat (10%)				**<0.001**	1	1-1.01
Starts >1 year previously and horse age (years)				**<0.001**	1.01	1-1.01

Bolded P-values are likelihood ratio test P-values. “GTS”=good to soft.

4.3.3.2 Steeplechase Racing

Variables found to be significantly associated with an **increased** likelihood of fatality in steeplechase racing were: running on “soft” to “good-to-firm” going and running on “firm” going compared to running on heavy going (OR 2.11, 95% C.I. 1.34-3.32 and 4.25, 95% C.I. 1.92-9.39 respectively); running in a race greater than 4.8km compared to running in a shorter race (OR 1.32, 95% C.I. 1.09-1.59); running in the year 2009 compared to running in any other year in the study (OR 1.52, 95% C.I. 1.2-1.95); running in the summer season compared to any other season (OR 1.4, 95% C.I. 1.11-1.76); increased horse age (OR per year 1.14, 95% C.I. 1.06-1.23); increased percentage of previous starts in flat racing (OR per extra 10% 1.34, 95% C.I. 1.25-1.43); starting in a different race type to the previous race for that horse (OR 1.53, 95% C.I. 1.2-1.95).

Variables found to be significantly associated with **decreased** likelihood of fatality in steeplechase racing were: having made at least one start in the previous 10-12 months compared to having made none (OR 0.85, 95% C.I. 0.72-1.02); and increased number of starts greater than one year previously (OR per extra start 0.92, 95% C.I. 0.9-0.95).

4.3.3.2.1 Interaction terms

Significant interactions were identified between change in race type since the last race for that horse and the percentage of previous career racing on flat, and between number of starts greater than 365 days previously and horse age. The influences of these interactions on the main effects were included in the final model and are shown at the bottom of Table 4-4.

a. *Change race type from previous race and percentage of previous career on flat*

Figure 4-3 represents how the **difference in probability** of fatality varied between the two “change race type from previous race” groups: “yes” and “no”, across percentages of previous career on flat. It can be observed that the two groups were only significantly different from each other when the percentages of previous starts in flat racing were below approximately 20%.

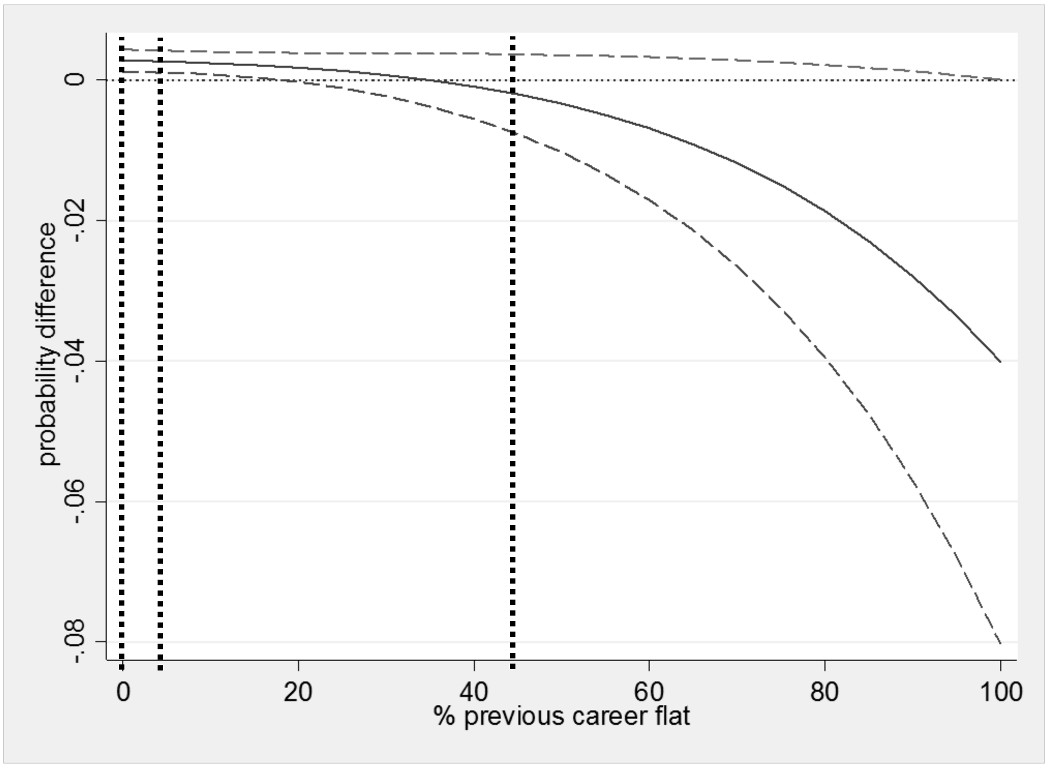


Figure 4-3: Line graph representing the difference in probability of fatality between the two categories of change race type from previous (yes or no) at a number of different “percentage of previous career on flat” values. Solid line represents the mean; upper and lower dashed lines represent the 95% upper and lower confidence intervals, respectively. Dotted vertical lines represent the median (0) upper 75% (5%) and upper 95% (43%) of previous starts on flat values from all steeplechase starts.

b. Number of starts greater than one year previously and horse age.

It can be seen from Figure 4-4 that the effect of the number of starts greater than one year previously varied with horse age, with a gradually reducing likelihood of fatality per extra start as horses got older, until approximately 11 years of age. For horses aged approximately 13 years and over, the effect of increased number of starts greater than one year previously were no longer significantly associated with the likelihood of fatality (the upper confidence interval crossing 0).

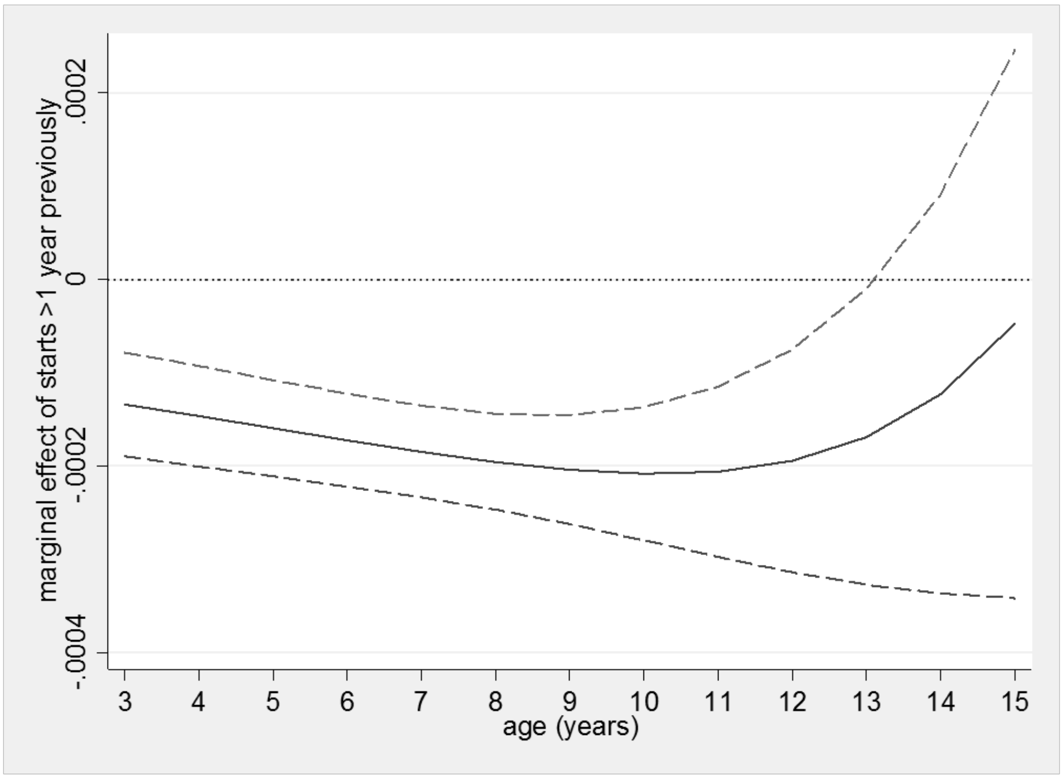


Figure 4-4: Line graph representing the effect of a one unit change (increase) in number of starts greater than one year previously on likelihood of fatality, at different horse ages. Solid line represents the mean; upper and lower dashed lines represent 95% upper and lower confidence intervals, respectively.

Table 4-4: Multivariable model showing variables significantly associated with the likelihood of fatality in steeplechase racing. Horse (residual intraclass correlation coefficient=0.34) is included as a random effect.

Variable	TOTAL (%) n=102894	Cases (%) n=606	Controls (%) n=102288	**P-value**	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES						
Going						
Heavy	7067 (6.87)	20 (3.3)	7047 (6.89)		1 (Ref)	
Soft to GTF	94983 (92.31)	576 (95.05)	94407 (92.3)	0.001	2.11	1.34-3.32
Firm	844 (0.82)	10 (1.65)	834 (0.82)	<0.001	4.25	1.92-9.39
Race Distance (km)						
3.2 to 4.8	80060 (77.81)	448 (73.93)	79612 (77.83)		1 (Ref)	
>4.8 (5.0-7.2)	22834 (22.19)	158 (26.07)	22676 (22.17)	0.01	1.3	1.06-1.58
Year 2009						
No	91185 (88.62)	517 (85.31)	90668 (88.64)		1 (Ref)	
Yes	11709 (11.38)	89 (14.69)	11620 (11.36)	0.001	1.52	1.2-1.95
Summer Season						
No	90739 (88.19)	508 (83.83)	90231 (88.21)		1 (Ref)	
Yes	12155 (11.81)	98 (16.17)	12057 (11.79)	0.005	1.4	1.11-1.76
HORSE RELATED VARIABLES						
Horse age (years)				<0.001	1.14	1.06-1.23
% prev career on flat (10%)				<0.001	1.34	1.25-1.43
Change race type from prev race						
No	85589 (83.18)	476 (78.55)	85113 (83.21)		1 (Ref)	
Yes	17305 (16.82)	130 (21.45)	17175 (16.79)	0.001	1.53	1.2-1.95
Starts prev 10-12 months						
None	43666 (42.44)	307 (50.66)	43359 (42.39)		1 (Ref)	
>0 (1-15)	59228 (57.56)	299 (49.34)	58929 (57.61)	0.08	0.85	0.72-1.02
Starts > 1 year prev				<0.001	0.92	0.9-0.95
INTERACTIONS						
Changed race type & % prev career on flat				0.007	0.87	0.79-0.96
Starts >1 year prev & Horse Age				<0.001	1.005	1.002-1.008

Bolded P-values are likelihood ratio test P-values. GTF=good- to- firm; km=kilometres; prev=previous.

4.3.4 Assessment of clustering

Residual intraclass correlation coefficients (*rho*) were estimated for horse, horse dam, horse sire, trainer, jockey, course, race and meet for each model and are shown in Table 4-5. Coefficients and standard errors associated with variables included in the single level multivariable models were altered by less than 10% when any of these random effects were included, except for the standard errors for firm going (10.3% change), year group (11% change) and previous career on flat (12.5% change) when horse was included as a random effect in the steeplechase model. As a result horse was retained as a random effect in the steeplechase model.

Table 4-5: Residual intraclass correlation estimates for different variables included in the final multivariable models.

	Horse	**Dam**	**Sire**	**Trainer**	**Jockey**	**Course**	**Race**	**Meet**
Hurdle	<0.001	0.062	0.034	0.026	<0.001	<0.001	0.11	0.046
Steeplechase	0.34	<0.001	0.012	0.003	0.02	0.004	0.12	0.094

4.3.5 Performance of the fixed-effects multivariable models

The final multivariable models were not affected by influential covariate patterns. There were sufficient cases per coefficient to justify the complexity of each model (Bagley et al., 2001). The Hosmer-Lemeshow goodness-of-fit statistic was 4.04 (8 degrees of freedom, P value = 0.85) for the hurdle model and 11.57 (8 degrees of freedom, P value = 0.17) for the steeplechase model; indicating no evidence of a lack of fit of either model. The area under the ROC curve was 0.71 for the hurdle model and 0.64 for the steeplechase model indicating moderate predictive ability for both models.

4.4 Discussion

This chapter reports the results of a study with the primary goal of identifying risk factors specific for fatality that occurred as a result of hurdle and steeplechase racing in GB. These analyses benefited from access to a large number of cases and controls, which are likely to have helped in the identification of significant risk factors. However, there are a few important considerations when interpreting the results. Firstly, the study includes all-cause mortality and it is likely that the risk factors for different fatalities differ. This may partly explain the moderate areas under the ROCs and the presence of a number of interaction terms. Secondly, the cases of fatality included those that were euthanased (frequently quite a high percentage), which results in the addition of bias, because decisions were made about diagnosis and treatment by different veterinarians, trainers and owners. Thirdly, it is likely that a significant proportion of fatalities were the result of underlying problems or injuries that occurred in their pre-race training. For example post mortem studies of fatal equine racing fractures performed in California found that there is almost always evidence of stress remodelling in the contralateral limb at the same site as the fracture (Stover, 2012) and similar findings have been observed in GB (Parkin et al., 2006). Whilst trainer and previous racing histories were included in the analyses, unfortunately it was not within the bounds of this study to include training data in the analyses and as a result it is possible that unmeasured factors away from the racecourse may have contributed to the likelihood of fatality.

To facilitate interpretation, the discussion section has been divided into sections for risk factors common to hurdle and steeplechase and for those specific to hurdle racing. There were no risk factors identified solely in steeplechase racing.

4.4.1 Risk factors common to hurdle and steeplechase racing

4.4.1.1 Surface going

The likelihood of fatality was observed to be higher on firmer ground surfaces in both hurdle and steeplechase racing. This association has been observed previously (Hernandez et al. 2001; Williams et al. 2001; Henley et al. 2006; Boden et al. 2007a) and could be attributed to the increased speed of races on firmer surfaces, as well as reduced shock absorbance caused by firm ground. Unfortunately, reliable race speed data was not available for starts made between 2000 and 2004 and as such was not included in the analyses.

4.4.1.2 Year of racing

The years 2003 and 2009 were observed to carry significantly higher likelihood of fatality than the other years in hurdle and steeplechase racing, respectively. The reason for this is unknown, but could simply be related to an anomaly in the results for those years. Despite this, the variables were retained in the final models in order to account for the variation imposed by having analysed races over a nine year period. As discussed previously, multiple factors have the potential to change over time, including those directly associated with the horses (such as alterations in training regimens), the racecourses (such as changes to regulations affecting fence heights and race lengths) and also those associated with data collection (for example changes to the recording system, or awareness of and hence sensitivity in detecting certain injuries). Because of the number of factors that potentially change over time and because they change variably (for example it might be that a new “safer” training schedule was published during a year in the study, but not adopted by all trainers), it is impossible to account for each of them individually. Instead, it was decided that year could be used as a proxy measure, to account for these potential changes.

4.4.1.3 Summer season

Starts in the summer season carried a greater likelihood of fatality than racing in the other seasons, in both hurdle and steeplechase racing. This was found despite the inclusion of track going in the model, which tends to suggest that some other factor(s) related to the summer season predisposes to fatality. For example, this could be related to the increased temperatures experienced in the summer months, which could contribute to horse fatigue. It is also possible that the track “going” measures do not effectively measure the interaction between hoof and track, such that the “going” measure only accounts for some of this effect, which is why season remains significant.

4.4.1.4 Increased race distance

Interestingly this association varied slightly between hurdle and steeplechase races, with a linear association observed in the hurdle model and an association with races greater than 4.8km in steeplechase racing. This difference could be associated with another variable, such as the type of races that are over 4.8km in steeplechase racing being of greater difficulty, or the type of horses involved in the two types of jump racing. Previous studies have reported an increased likelihood of horse injury associated with increased race distance (Estberg et al., 1995; Takahashi et al., 2004) as observed in the hurdle and steeplechase models. It is plausible that the association is because of increased time at risk in longer races. It is also possible that longer races result in increased horse fatigue, which predisposes them to falling, or to overloading of the musculoskeletal or cardiovascular systems (the two most common causes of death).

4.4.1.5 Percentage of previous career in flat racing

In both final multivariable models, increasing percentage of previous career in flat racing was associated with increased likelihood of fatality. This could be because these horses have collected more cumulative musculoskeletal pathological changes during high speed flat racing, making them more prone to subsequent injury. Other studies have recognised an association between the accumulation of high speed exercise and increased likelihood of injury (Carrier et al., 1998; Estberg et al., 1996, 1995). Alternatively, to have a high percentage of career flat starts, horses would be likely to be near the beginning of their jump racing careers, so potentially a risk factor associated with this leads to the observed effect. It could also be related to differences in the types of horses that come from a flat racing career, for example, traditionally Thoroughbred horses bred for jump racing have been of larger stature than those bred for pure flat racing. However, this association is not straightforward, as examination of the variable first race type, with flat categorised as yes or no, was not observed to be significant at the univariable level, i.e. having started the racing career in flat racing was not a significant risk factor for suffering fatality in a jump race.

4.4.1.6 Horse age

Increasing horse age was found to be associated with increased likelihood of fatality in both hurdle and steeplechase racing. This association with horse age has been recognised in other studies (Estberg et al. 1996; Cohen et al. 2000; Williams et al. 2001; Henley et al. 2006). Plausible explanations for this include: normal age-related changes to the musculoskeletal system resulting in increased likelihood of injury; increased cumulative exercise resulting in increased damage and hence likelihood of injury; increased time at risk; and the possibility that attempted treatment is less frequent for horses deemed to have shorter potential future careers.

4.4.1.7 Starting in a different race type to the previous race

Horses that had started in a different race type in their previous race were observed to have a lower likelihood of fatality in the hurdle model, but a higher likelihood of fatality in the steeplechase model. The reasons for this are unclear but could be related to the transitions of horses between race types. The majority of changes in race type for horses in hurdle racing were from flat or NHF, as relatively few horses move from steeplechase to hurdle racing. Therefore, horses in this category in hurdle racing would tend to have been early in their hurdle careers, which might partly explain why they demonstrated a reduced likelihood of fatality. Whilst horses move from flat and NHF racing to steeplechase racing, a reasonable number of horses also move from hurdle racing to steeplechase racing. It is possible that the increased height and difficulty of fences, as well as the greater race distances experienced in steeplechase racing compared to hurdle racing predispose horses to fatality. The likelihood of fatality for starts made within the first few races of the steeplechase career (for horses that have just moved from hurdle racing) would be interesting.

4.4.1.8 Starts in previous time periods

Whilst it might seem that the outcome “fatality” has a causative association with these risk factors, because the analysis was performed at the level of the start and the variables refer to starts in previous races, these are actually not affected by the outcome and can be considered potential true predictors or risk factors.

4.4.1.8.1 Starts in the previous 10-12 months

Having made at least one start in the previous 10-12 month period was associated with decreased likelihood of fatality in both the hurdle and steeplechase models. Starts in this period would have been made in the previous racing season, so reasons for this association could be related to an effect of having raced in the previous season. For example it might be that horses that have survived at least one previous racing season are less likely to subsequently die during racing. This is sometimes referred to as "the healthy horse effect". In this instance it could be postulated that some horses have the wrong phenotype to be successful racehorses and that these are "weaned out" of jump racing within one season, whereas those that have survived at least one season, are more likely to continue to survive. Being able to predict which of these two groups that horses belong to, before the start of their racing careers would be ideal, but considering the number of variables associated with every start made by every horse, this assessment is likely to be a considerable challenge. A commercial company claim to have already identified a gene relating to "speed" in Thoroughbred racehorses (Equinome.com[8]) and it is plausible that similar work might help to identify horses that are poor candidates for racing. Other work has already been started investigating whether genotype is related to certain disorders (including, epistaxis, tendon injury, distal limb fracture) (Parkin and Welsh, 2012).

4.4.1.8.2 Starts greater than one year previously

Increased number of starts, greater than one year previously was associated with a decreased likelihood of fatality in both models. The reason for this association is also likely to be associated with the "healthy horse effect" in that horses without clinical or subclinical injury are able to run more frequently, over longer careers and are less likely to subsequently die during racing.

4.4.2 Risk factors only observed in hurdle racing

4.4.2.1 Running at a race course which held greater than 5,824 starts (was within the top quartile of tracks) during the study period

In order to try and account for how busy each racecourse was, a count of the number of jump racing starts over the 10 years of the study was included in the analysis. The categorical form of the variable, comparing the top quartile (busiest 25%) with less busy tracks fitted the data best. It was observed that likelihood of fatality was significantly

[8] Equinome Ltd., Dublin, Ireland

higher on the busier tracks, than the less busy ones. Whilst this is an interesting finding it is difficult to explain, because it could be related to so many other variables, including type of races run at the busier tracks, type of horses or type of trainer. Busier tracks may hold races with bigger prize money, which may result in increased motivation to compete and win and for jockeys to push their horses harder. The fact that it was retained in the final multivariable model despite the addition of the other potential explanatory variables and once random effects were included in the model would tend to suggest that this variable is worthy of further investigation. It might be for example that another, unmeasured variable, related to the condition of the tracks that have the most races might be associated with the likelihood of fatality. Interestingly the variable “days since previous race at that track” categorised as greater than or less than and equal to 7 days was found to be significant at the univariable level, with starts carrying a greater likelihood of fatality if they were less than 8 days since the previous start of that type at that racecourse. However, this variable was not retained in the final multivariable model. Further investigation of track related variables and specifically the busiest tracks would be warranted.

4.4.2.2 Trainer with increased percentage of first places

Percentage of trainer’s horses’ starts that finished in first place was found to be significantly associated with likelihood of fatality. Increases in this percentage were associated with increased likelihood of fatality, which could be interpreted as showing that the more successful trainers were associated with greater likelihood of fatality in their horses. This could be related to the training regimens employed by successful trainers resulting in more underlying pathological changes, or could simply be a reflection of the quality or health of the horses trained at different training yards, which in turn may be related to breeding and genetics.

4.4.2.3 Maiden or Novice races

Horses starting in maiden or novice races were observed to be have a decreased likelihood of fatality compared to horses running in normal (i.e. not maiden or novice) races. Maiden and Novice races are for horses with limited hurdle racing experience and are early in their jump racing careers. The reason for this association might therefore be related to horse age, although this is also included in the model, so does not explain all of the relationship. The association could also be the result of something to do with these types of races, such as the distance travelled, or the competitiveness of the races. For example, these races generally have lower prize funds so it might be that the horses are not being pushed as hard as for some of the more prestigious races.

4.4.3 Interaction terms

4.4.3.1 Hurdle

In the final multivariable model for hurdle racing two significant interaction terms were identified, both of which were associated with the number of starts greater than one year previously.

a. The effect of increased number of starts greater than one year previously could be observed to vary across percentages of previous career in flat racing. For horses with a large percentage of their previous careers in flat racing, an increase in number of races greater than one year ago was observed to reduce the likelihood of fatality more than it did for horses with a low percentage of their previous careers in flat racing. Notably, the relationship between starts greater than one year ago and fatality remained significant across the range of percentage of previous career in flat racing. It is possible that some function of being early in their jump racing career, but still having had starts greater than a year previously is protective for fatality and that this protective effect is less marked once the horse has been in jump racing for a prolonged time (or has not run in flat racing).

b. The effect of increased number of starts greater than one year previously varied with horse age, with the biggest effect being observed at approximately 13 years of age, after which the effect of increased number of starts stopped being statistically significant (potentially because of the low number of horses that raced above this age). This relationship shows that having started in a race greater than a year previously was more protective against fatality for older horses than younger horses. This would tend to suggest that horses that had not made any starts by the time they were older were at increased likelihood of fatality. Interestingly, age at first start was not observed to be significant at the univariable level analysis, which indicates that this relationship is not straightforward.

4.4.3.2 Steeplechase

Significant interactions between change in race type and percentage of previous career on flat and between number of starts greater than one year previously and horse age were identified.

a. The difference in probability of fatality varied between the two "change race type from previous race" groups: "yes" and "no", across percentages of previous career on flat. The two groups were only observed to vary significantly from each other when the percentage of previous starts in flat racing were below approximately 20%. This interaction term is likely to be related to the fact that both risk factors are associated with horses' previous race type.

b. Similar to the interaction observed in the hurdle model, the effect of the number of starts greater than one year previously varied with horse age, with a gradually reducing likelihood of fatality as horses got older and is likely to be the result of similar reasons to above.

4.5 Conclusions

Multiple similar risk factors for fatality were identified in hurdle and steeplechase racing, many of which have been reported in previous risk factor studies. This agreement between studies will hopefully help to determine which factors are of genuine importance. For example it would appear that ground firmness, season, horse age, race distance and previous start histories are all important risk factors for fatality and should be considered when determining approaches to reduce the rate of fatality in jump racing. However, as discussed in Chapter 1, making decisions based on these findings is not straightforward, particularly when the number of fatalities is so low. It might be for example, that based on these models it is advised that jump racing in the summer season should be banned – for this study period, this would have resulted in cancelling 36,014 starts in order to avoid 260 fatalities. The impact of stopping races is difficult to assess, but could be considered likely to also result in fewer racehorses and this needs to be weighed against what is considered a reasonable level of risk by the racing authorities.

A major concern of making recommendations based on overall fatality rates, is that different causes of fatality might have different risk factors. Further investigations, examining specific injuries and causes of fatality are warranted to determine the significance of some of the findings in this study. Some of this work is presented in the following chapters.

5 Risk Factors for Superficial Digital Flexor Tendinopathy

The prevalence of SDF tendinopathy has been observed to differ between hurdle and steeplechase races (Williams et al. 2001) and was also observed to differ in this data set. In addition, the incidence rate was high in both race types, i.e. 6.08 and 6.3 per 1000 starts in hurdle and steeplechase, respectively. As a result of the importance of this type of injury, a decision was made to produce separate risk factor models for it for each race type.

5.1 Introduction

Tendon injuries occur in horses competing in all disciplines. Superficial digital flexor tendinopathy has previously been identified as one of the most common musculoskeletal injuries in Thoroughbred racehorses with a reported cumulative incidence of 11–30% (over a 1–10 year period) (Marr et al. 1993; Williams et al. 2001; Takahashi et al. 2004; Ely et al. 2004; Pinchbeck 2004; Lam et al. 2007a; Avella et al. 2009); and a reported incidence rate of 1.7/100 horse months in training (Ely et al., 2009). Treatment of the condition requires rehabilitation of at least nine months, with severe cases requiring up to 18 months until the maturation phase of tendon healing is completed (Davis and Smith, 2006). Re-injury rates are high: 23–67% of horses with tendon injury treated using conservative methods will re-injure their tendons within two years of the original injury (Dyson, 2004; Marr et al., 1993). As such, SDF tendinopathy is of major importance when considering the health and welfare of Thoroughbred racehorses.

Previous epidemiological studies have identified risk factors for SDF tendinopathy which include: older age, male gender, longer race distance, frequent high-speed work, heavier mean bodyweight at race time, race track surface and longer training careers (Mohammed et al., 1992; Estberg et al., 1995; Kasashima et al., 2004; Perkins et al., 2005a; Lam et al., 2007b). Other proposed risk factors include: fatigue and lack of fitness (Butcher et al., 2007) conformation and inco-ordinate action (Jorgensen and Genovese, 2003; Weller et al., 2006). These studies provide useful information, but were mostly performed outside GB where track surfaces, distance and weather conditions all differ. These studies were only performed on horses racing on the flat, which is of significance considering the significantly higher prevalence of tendon injury in horses racing over hurdles (Williams et al. 2001). A study investigating the effect of complex modelling techniques, using a subset of the current data (2000-2007), identified: firmer going; summer season; increased race distance; increased horse age and previous tendon injury as risk factors for SDF tendinopathy in horses undertaking hurdle racing in GB (Parkin et al., 2009). Whilst that study identified all important risk factors, it did not take into account a number of potentially important risk factors and did not examine their associations in detail.

The aims of this part of the study were to conduct a comprehensive analysis to help identify risk factors for SDF tendinopathy in Thoroughbred Racehorses running in hurdle and steeplechase races in GB.

5.2 Materials and Methods

Potential risk factors for SDF tendinopathy in hurdle and steeplechase starts in GB were assessed using cohort studies. In order to allow inclusion of horse, race and track as different levels in risk factor analysis, the study was conducted at the start level (a “start” being a horse starting a race) and included 1,031 case starts and 168,637 control starts in the hurdle study and 648 cases starts and 102,246 control starts in the steeplechase study.

5.2.1 Selection of cases and controls

A case start was defined as a start in a race, subsequent to which the horse was diagnosed with SDF tendinopathy, whilst still at the racecourse. Cases were identified by racecourse veterinary surgeons based on the findings of physical examination as recorded by attending veterinary officers. Control starts were defined as any start in a race, which did not result in the subsequent diagnosis of SDF tendinopathy, whilst the horse was still at the racecourse.

5.2.2 Risk factors

A total of 122 variables for each start (32 horse-related variables, 50 prior racing history-related variables, 25 race related variables, 5 trainer-related variables, 5 jockey-related variables and 5 track-related variables) were available for analysis. Previous SDF injury was identified from all cases of SDF tendinopathy recorded in the BHA database from any type of race from the years 2000-2009. Such that, horses which had previously sustained a SDF tendinopathy whilst running in flat, hurdle, steeplechase or national hunt flat races, were labelled as having had a previous tendon injury. Notably though, horses that had sustained SDF tendinopathy in training would not have been recorded as having had a previous SDF tendinopathy in this study.

5.2.3 Power of the study

The hurdle model had at least 80% power to identify odds ratios of 1.3 or more, with 95% confidence, when the prevalence of exposure in the control population was between 12% and 82%. The steeplechase model had at least 80% power to identify odds ratios of 1.4 or more, with 95% confidence, when the prevalence of exposure in the control population was between 11% and 82%.

5.3 Results

5.3.1 Hurdle SDF Tendinopathy Risk Factor Model

The 169,668 study starts were represented in the study population by 29,285 horses, 1,274 jockeys, 1,369 trainers and 44 racecourses. The study starts occurred in 15,050 races at 4,339 race meets and on 2,442 race dates with 1,031 SDF tendinopathies recorded in 1,001 horses. One hundred and seventy eight horses started in at least one hurdle race subsequent to suffering a SDF tendinopathy, and 30 of these horses (17%) sustained another SDF tendinopathy, whilst racing in hurdle races.

5.3.1.1 Univariable analysis

Of the 122 variables screened at the univariable level 38 were taken forward for consideration in the multivariable forward stepwise analysis. Details of these variables are shown in Appendix 6.

5.3.1.2 Multivariable analysis

In the final multivariable model 20 variables were found to be significantly associated with SDF tendinopathy (Table 5-1).

Variables found to result in an increased odds of SDF tendinopathy were: increasing track firmness (going); increasing race distance; a history of previous SDF injury; races in the summer season compared to the other seasons; starts in selling or claiming races; increasing percentage of career on the flat; increased age at first race; first race type being National hunt flat compared to other race types; starts in a race 1 to 2.4km shorter than the previous race compared to any other change in distance since the previous race; carrying a weight of 161 to 186lbs compared to lower weights; more than 90 days since the last hurdle race was held at that track; increasing years completed in racing; starts in 2003 or 2005 compared to all other years between 2001 and 2009.

Variables found to result in decreased odds of SDF tendinopathy were: starts in which the horse's previous start was not in a hurdle race; increased trainer score (trainer score ranged from 0 to 30 with 25^{th}, 50^{th} and 75^{th} percentiles at 11, 12 and 13 respectively); number of runners in a race being 13 to 30 compared to fewer runners; starting late in the run sequence compared to early or middle; morning or evening race times compared to afternoon races; horses having started one to seven times in the previous three months compared to any other number of starts; number of starts in the previous nine to 12 months.

None of the interaction terms investigated were found to be significant.

Table 5-1: Results of multivariable logistic regression model investigating risk factors for superficial digital flexor tendinopathy in horses undertaking hurdle racing in Great Britain

Risk Factor for SDF tendinopathy	TOTAL n=169668	Cases (%) n=1031	Controls (%) n=168637	P-value	Odds Ratio (OR)	95% Confidence Interval
			TRACK RELATED VARIABLES			
Track Going				**<0.001**		
Heavy	12816	21 (2)	12795 (7)		1 (REF)	
Soft	30319	86 (8)	30233 (18)	*0.025*	1.73	1.07-2.78
Good to Soft	33661	140 (14)	33521 (20)	*<0.001*	2.57	1.62-4.07
Good	57579	404(39)	57175 (34)	*<0.001*	4.03	2.59-6.26
Good to Firm	33765	356 (35)	33409 (20)	*<0.001*	5.26	3.36-8.24
Firm	1528	24 (2)	1504 (1)	*<0.001*	7.98	4.4-14.5
Days since last hurdle race at that track						
0 to 90	156086	917 (89)	155169 (92)		1 (REF)	
≥ 91	13582	114 (11)	13468 (8)	**0.001**	1.42	1.16-1.74
			RACE RELATED VARIABLES			
Year 2003 or 2005						
No	132487	744 (72)	131743 (78)		1 (REF)	
Yes	37181	287 (28)	36894 (22)	**<0.001**	1.28	1.12-1.47
Season						
Spring, Autumn or Winter	145809	783 (76)	145026 (86)		1 (REF)	
Summer	23859	248 (24)	23611 (14)	**<0.001**	1.39	1.19-1.63
Time of race						
Afternoon	156737	952 (92)	155785 (92)		1 (REF)	
Morning or Evening	12931	79 (8)	12852 (8)	**<0.001**	0.66	0.52-0.83
Race position in run sequence						
Early and middle	113741	745 (72)	112996 (67)		1 (REF)	
Late	55927	286 (28)	55641 (33)	**<0.001**	0.77	0.67-0.89
Race Distance (km)				**<0.001**	2.15	1.92-2.39
Number of runners in race						
1 to 12	85457	565 (55)	84892 (50)		1 (REF)	
13 to 30	84211	466 (45)	83745 (50)	**0.011**	0.85	0.75-0.96
Sell / Claim Race						
No	149481	836 (81)	148645 (88)		1 (REF)	
Yes	20187	195 (19)	19992 (12)	**<0.001**	1.54	1.29-1.83
			TRAINER RELATED VARIABLES			
Trainer Score				**<0.001**	0.9	0.87-0.93
			HORSE RELATED VARIABLES			
Age at first race				**<0.001**	1.21	1.14-1.29
Previous start not Hurdle						
No	133733	865 (84)	132868 (79)		1 (REF)	
Yes	35935	166 (16)	35769 (21)	**<0.001**	0.65	0.55-0.77
Horse had previous SDF tendinopathy						
No	169447	999 (97)	168448 (99.9)		1 (REF)	
Yes	221	32 (3)	189 (0.1)	**<0.001**	20.6	13.79-30.77
% of career on the flat				**<0.001**	1.02	1.01-1.02
First Race Type						
Flat, Steeple or Hurdle	110696	604 (59)	110092 (65)		1 (REF)	
National Hunt Flat	58972	427 (41)	58545 (35)	**<0.001**	1.74	1.48-2.04
Change in running distance since last race						
-800m to +2200m	163983	988 (96)	162950 (97)		1 (REF)	
-2400m to -1000m	5730	43 (4)	5687 (3)	**0.008**	1.57	1.15-2.16
Weight carried						
130 to 160lbs	150150	900 (87)	149250 (89)		1 (REF)	
161 to 186lbs	19518	131 (13)	19387 (11)	**0.012**	1.28	1.06-1.55
Horse years completed in racing				**0.004**	1.05	1.02-1.09
Horse number of starts in the previous three months						
0 and 8 to 16	37500	278 (27)	37222 (22)		1 (REF)	
1 to 7	132168	753 (73)	131415 (78)	**<0.001**	0.7	0.61-0.81
Horse number of starts in the previous 10 to 12 months				**<0.001**	0.86	0.82-0.9

Bolded P values are likelihood ratio test P values and italicised P values are Wald test P values.

5.3.1.3 Assessment of clustering

Residual intraclass correlation coefficients (rho) were estimated for horse (rho <0.001), horse dam (rho 0.06), horse sire (rho 0.04), trainer (rho 0.05), jockey (rho 0.01), course (rho 0.003), race (rho 0.16) and meet (rho 0.08). Model coefficients and associated standard errors were altered by less than 10% for all random effects models compared with the single level model.

5.3.1.4 Performance of the fixed-effects multivariable model

The final multivariable model was not affected by influential covariate patterns. There were sufficient cases per coefficient to justify the complexity of the model (Bagley et al., 2001). The Hosmer-Lemeshow goodness-of-fit statistic was 2.55 (8 degrees of freedom, P value = 0.96) indicating no evidence for lack of fit of the model. The area under the ROC curve was 0.75 indicating moderate predictive ability.

5.3.2 Steeplechase SDF Tendinopathy Risk Factor Model

The 102,894 study starts were represented in the study population by 15,117 horses, 1,328 jockeys, 2,343 trainers and 44 racecourses. The study starts occurred in 12,003 races at 4,347 race meets and on 2,438 race dates. Six hundred and forty eight SDF tendinopathies were recorded in 626 horses. One hundred and thirty one horses started in at least one steeplechase race subsequent to SDF tendinopathy, 40 of these (31%) sustained another SDF tendinopathy and later, 2 (5%) of these sustained a third SDF tendinopathy, whilst racing in steeplechase races.

5.3.2.1 Univariable analysis

Of the 122 variables screened at the univariable level 38 were taken forward for consideration in the multivariable forward stepwise analysis. Details of these variables are shown in Appendix 6.

5.3.2.2 Multivariable analysis

In the final multivariable model 12 variables were found to be significantly associated with SDF tendinopathy (Table 5-2).

Variables found to result in increased odds of SDF tendinopathy were: Increasing track firmness (track going); increasing race distance (km); races in the summer season compared to the other seasons; increasing percentage of career as a flat horse (10%); increased horse age (years); horse having had a previous SDF tendinopathy.

Variables found to result in decreased odds of SDF tendinopathy were: Horse official rating being in the top quartile of scores compared to the others; starting middle or late in the run sequence compared to early; time of race being morning or evening compared to afternoon; horse having started two to four times in the last three months compared to any other number of starts, including zero; horse having started one to seven times in the previous nine to 12 months compared to any other number of starts, including zero; horse having started greater than 15 times during the period: more than one year prior to each start, compared to any other number of starts in that time period, including zero.

None of the interaction terms investigated were found to be statistically significant.

Table 5-2: Results of multivariable logistic regression analysis of risk factors for superficial digital flexor tendinopathy in horses undertaking steeplechase racing in Great Britain (2001-2009).

Risk Factor for SDF tendinopathy	TOTAL n=102894	Cases (%) n=648	Controls (%) n=102246	P-value	Odds Ratio (OR)	95% Confidence Interval
TRACK RELATED VARIABLES						
Track Going				**<0.001**		
Heavy and Soft	25775	66 (10)	25709 (25)		1 (REF)	
Good to Soft	20417	102 (16)	20315 (20)	<0.001	1.98	1.45-2.7
Good	36852	277(43)	36575 (36)	<0.001	2.77	2.11-3.63
Good to Firm	19006	194 (30)	18812 (18)	<0.001	3.42	2.55-4.58
Firm	844	9 (1)	885 (1)	<0.001	3.53	1.74-7.14
RACE RELATED VARIABLES						
Race Distance (km)				**<0.001**	1.37	1.23-1.53
Season						
Spring, Autumn or Winter	90739	517 (80)	90222 (88)		1 (REF)	
Summer	12155	131 (20)	12024 (12)	**0.001**	1.42	1.16-1.75
Time of race						
Afternoon	93061	571 (88)	92490 (90)		1 (REF)	
Morning or Evening	9833	77 (12)	9756 (10)	**0.013**	0.74	0.58-0.95
Race position in run sequence						
Early	24790	179 (28)	24611 (24)		1 (REF)	
Middle or Late	78104	469 (72)	77635 (76)	**0.039**	0.83	0.69-0.99
HORSE RELATED VARIABLES						
Age (years)				**<0.001**	1.19	1.14-1.25
Horse had previous SDF tendinopathy						
No	102199	606 (93.5)	101593 (99)		1 (REF)	
Yes	695	42 (6.5)	653 (1)	**<0.001**	8.51	6.1-11.88
Horse Official Rating						
0-115	78947	567 (84)	78380 (77)		1 (REF)	
>115	23947	81 (16)	23866 (23)	**<0.001**	0.65	0.51-0.83
% of Career as flat (per 10%)				**<0.001**	1.22	1.16-1.28
Horse number of starts in the previous 3 months				**0.031**		
0 to 1	23258	169 (26)	23089 (23)		1 (REF)	
2 to 4	50493	285 (44)	50208 (49)	0.008	0.77	0.63-0.93
>4	29143	194 (30)	28949 (28)	0.1	0.84	0.68-1.03
Horse number of starts in the previous 10 to 12 months				**<0.001**		
0	43666	393 (60.7)	43273 (42.3)		1 (REF)	
1 to 7	58977	251 (38.7)	58726 (57.4)	<0.001	0.61	0.52-0.72
>7	251	4 (0.6)	247 (0.3)	0.17	2.03	0.75-5.53
Horse number of starts greater than 1 year previously						
0 to 15	52319	394 (61)	51925 (51)		1 (REF)	
>15	50575	254 (39)	50321 (49)	**<0.001**	0.42	0.34-0.51

Bolded *P* values are likelihood ratio test *P* values and unbolded *P* values are Wald test *P* values.

5.3.2.3 Assessment of clustering

Residual intra-class correlation coefficients (rho) were estimated for horse (rho 0.00002), horse dam (rho 0.00003), horse sire (rho 0.05), trainer (rho 0.04), jockey (rho 0.002), course (rho 0.009), race (0.10) and meet (rho 0.12). Changes in model coefficients and associated standard errors were less than 10% for all assessed random effects compared with the single level model.

5.3.2.4 Performance of the fixed-effects multivariable model

The final multivariable model was not affected by influential covariate patterns. There were sufficient cases per coefficient to justify the complexity of the model (Bagley et al., 2001). The Hosmer-Lemeshow goodness-of-fit statistic was 8.16 (8 degrees of freedom, P value = 0.42) indicating no evidence for lack of fit. The area under the ROC curve was 0.73 of the model indicating moderate predictive ability.

5.4 Discussion

This chapter reports the results of studies with the primary goal of identifying risk factors specific to SDF tendinopathy sustained during hurdle and steeplechase racing in GB. These analyses benefitted from access to a large number of cases and controls, but were limited by the reliance on diagnosis of SDF tendinopathy at the racecourse, which is likely to have resulted in under estimation of numbers of true cases and some misclassification of controls. It is likely that this number of missed SDF tendinopathy cases will proportionately be very small and will not make any difference to the control population. Along with this, the previous history of SDF tendinopathy is reliant on the horse having had the condition diagnosed at the racecourse and does not take into account any SDF lesions diagnosed whilst in training, or racing outside GB. A recent study of the epidemiology of musculoskeletal injuries in National Hunt racehorses showed that 57% of SDF tendon injuries occurred during training (Ely et al., 2009), which indicates that to fully understand risk factors for SDF tendinopathy, training data also needs to be considered.

To facilitate interpretation, the discussion section has been divided into sections for risk factors common to hurdle and steeplechase and for those specific to each race type.

5.4.1 Risk factors common to hurdle and steeplechase racing

5.4.1.1 Surface going

Associations between increased track firmness and other musculoskeletal injuries, such as fractures, have been made in a number of studies (Parkin et al., 2004a; Henley et al., 2006; Boden et al., 2007a). This association has been hypothesised to be the result of the increased speed of the races and reduced shock absorbance caused by firm ground, which could also explain the association of track firmness with SDF tendinopathy. Unfortunately reliable race speed data were not available for starts made between 2000 and 2004 and as such was not included in the analyses.

5.4.1.2 Race distance

Previous studies have reported an increased risk of injury associated with increased race distance (Takahashi et al., 2004; Parkin et al., 2009;) as observed in the hurdle and steeplechase models. Heat induced tenocyte damage (Ker, 1981; Hosaka et al., 2006); micro-damage inducing abnormal loading events (Kai et al. 1999; Arnoczky et al. 2008); and increased fatigue of the deep digital flexor muscle (Butcher et al., 2007) are all potential explanations for this observed association. It is also possible that the association is because of increased time at risk in longer races.

5.4.1.3 Previous tendinopathy

Horses which had previously had SDF tendinopathy diagnosed at the racecourse were found to be approximately 20 and eight times more likely (hurdle and steeplechase respectively) to sustain another SDF lesion during racing. Previous studies have recognised high (23-67%) re-injury rates following SDF tendinopathy (Marr et al., 1993; Dyson, 2004; O’Meara et al., 2010). In this study, because information relating to veterinary history away from the racecourse was not available, there will have been both case and control horses which will have sustained previous SDF tendinopathy during training. There will therefore be some degree of misclassification of both case and control horse starts in terms of previous SDF tendon injury. This emphasises the need for future studies of racecourse injury to include details of previous medical histories, although this is unlikely to be easy to achieve, on a large scale at least, as observed by others (Ely, 2010).

5.4.1.4 Summer season

Starts in the summer season carried a greater likelihood of SDF tendinopathy than starts at any other time of year. This association was significant even when the going of the track was also taken into account, which suggests that other factors apart from firmness of ground are related to this particular SDF tendinopathy risk. This could be related to the increased temperatures experienced in the summer months, which could contribute to increased tendon temperature and horse fatigue. Alternatively it is possible that other factors relating to ground surface (such as surface irregularity), not taken into account by the “going” measure predispose to SDF tendinopathy in the summer season. It is also possible that the current measure of going is not very good and is only partly accurate in defining firmness. If a better measure was available it is possible that the percentage of confounding would be higher, such that summer season would not be retained in the model.

5.4.1.5 Percentage of previous career in flat racing

Increasing percentage of career on the flat was found to increase the likelihood of SDF tendinopathy. This could be because these horses have collected more cumulative pathological changes in their tendons during high speed flat racing, making them more prone to subsequent injury. Other studies have recognised an association between the accumulation of high speed exercise and increased risk of injury (Estberg et al. 1995; Carrier et al. 1998; Parkin et al. 2004e; Cogger et al. 2006; Boden et al. 2007b). However this variable should be interpreted with caution, because for horses which had flat starts, these will be a comparatively higher percentage of their career starts if the number of jump starts is low because they had to retire due to SDF tendinopathy soon after the start of their jumping careers. Indeed, although increased number of flat starts was not retained in the final multivariable models, it was found to have a protective effect during univariable analyses. This could simply be the result of a healthy horse effect, with healthy horses being able to run more frequently. Alternatively it could be due to a protective effect conferred by running flat races, such as better development of tendon structures in animals which start racing at an early age (see below) as has been hypothesised by others (Goodship and Birch, 2001; Smith, 2011).

5.4.1.6 Horse age / age at first start

Horse age was found to be a risk factor for SDF tendinopathy in steeplechase racing. The predisposition of older horses to suffer from this condition has been recognised (Williams et al., 2001; Perkins et al., 2005b). A number of studies have demonstrated that increased cumulative exercise is a risk factor for this condition (Estberg et al., 1995,1998; Lam et al., 2007b) and it is considered likely that older horses would have undergone a greater amount of exercise than younger ones. Although the association between SDF tendinopathy and increasing horse age was observed at the univariable level in the hurdle analysis, it was not retained in the final multivariable model following the inclusion of age at first start. Conversely in the steeplechase model, whilst age at first start was found to be significant at the univariable level, it was not retained within the multivariable model once horse age was included. The inclusion of only one of these variables in each final model is most likely the result of correlation between them rather than a different causal relationship. However, this difference may also be the result of differences in racing careers or age groups between the two racing disciplines: The steeplechase horses were generally older: median age 8 years (5-16), compared to 6 years (3-16) in the hurdle group; of greater age at first start: median age at first start 4 years (2 - 13) compared to 3 years (2 - 13); and fewer horses 29% (4311/15117) competing in steeplechase races had run in flat races compared to 46% (13479/29285) of horses competing in hurdle races.

5.4.1.7 Position in run sequence

In the hurdle model, starts late in the run sequence had reduced likelihood of SDF tendinopathy compared to those early or middle. In the steeplechase model, starts middle or late in the run sequence were at reduced risk compared to those in the early part. The reason for this finding and the difference between race types is unclear, although it could be related to an unmeasured track-related variable. Alternatively this could be related to the class of horses (although if this was the case, it might be expected that official rating would have been significant and confounded this variable), with potentially different quality horses running at different stages of the race card. The difference between race types could be explained by differences in the allocation of races between the two disciplines.

5.4.1.8 Time of race

Races run in the mornings or evenings were associated with a reduced likelihood of SDF tendinopathy compared to those run in the afternoon, in both the hurdle and steeplechase models. The reason for the association with time of racing is unclear and is potentially related to some climatic or track associated variable. Notably only a small percentage of races were run in the morning or evening (8% and 10% in hurdle and steeplechase respectively) so any potential impact on the overall risk of tendon injury that may result from identifying the reason for this finding is likely to be small.

5.4.1.9 Starts in previous time periods

The numbers of starts made in previous time periods were found to be associated with the likelihood of sustaining an SDF injury in both hurdle and steeplechase racing, although the time periods and number of starts varied between the race types. It is likely that the association between injury and previous start history is the result of the balance between horses being healthy enough to run frequently and not having run too frequently to predispose to injury. This balance is very likely to be horse dependent, i.e. the correct balance for horse ‘A’ might be very different to the correct balance for horse ‘B’. Because the outcome has the potential to affect the risk factor (i.e. injured horses are not able to run as frequently) and because the study does not include information about injuries sustained during training, it is more difficult to make firm conclusions based on the following findings.

Start in the previous three months

In hurdle racing, having made one to seven starts in the previous three months resulted in reduced likelihood of SDF tendinopathy as compared to having made no starts or greater than seven starts. Whilst in steeplechase racing, having made two to four starts was associated with reduced likelihood compared to horses that had made no or one start, whilst the likelihood of SDF tendinopathy was not significantly different for horses that had made greater than four starts in that time period. Starts greater than three months after the previous start may be: at the beginning of a new season (which could be a risk factor for SDF tendinopathy) or, subsequent to a period of rest following injury. It is possible that having more than seven starts in a three month period results in excessive cumulative strain being placed on the SDF tendon resulting in increased risk of tendinopathy, although this was not observed in the steeplechase population.

Start in the previous 10 to 12 months

A decreased likelihood of SDF tendinopathy was observed with an increased number of starts in the preceding 10 to 12 months in both the hurdle and steeplechase models, although the association was not significant in the steeplechase model with greater than seven starts in this time period.

Starts greater than one year previously

Horses that had made more than 15 starts greater than one year previously were found to be at decreased likelihood of SDF tendinopathy in the steeplechase model. This association was recognised at the univariable level in the hurdle model (Appendix 6) but was not retained in the final model.

The reason for the above two previous start history associations are unclear, but could be related to a “healthy horse” effect, as horses that are able to run many times in a season are unlikely to be suffering from an underlying SDF lesion and are therefore less likely to suffer tendinopathy. Also horses with these previous start histories must have competed in at least one previous season and so proven that they can withstand the strains of racing.

5.4.2 Risk factors identified only in hurdle racing

5.4.2.1 Career length

A number of published studies have demonstrated increased likelihood of tendinopathy with increased cumulative racing (Estberg et al., 1998b, 1995; Lam et al., 2007b) and training distances (Ely, 2010) and in the hurdle model, increasing racing career length was found to be associated with increased likelihood of SDF tendinopathy. This is likely as a result of increased time at risk of injury and potentially related to increased cumulative tendinopathy over a longer career. This once again fits with the theory and associated graph proposed by Smith (2011), in which tendon strength declines with age and can be increased with appropriate training at the correct age.

5.4.2.2 “Selling” or “Claiming” races

In selling and claiming races, horses are put up for sale or auction following the race. The reason for the increased likelihood of SDF tendinopathy in hurdle selling or claiming races is unclear. However, it is possible that the reason for sale is previous poor performance, which may be associated with underlying tendon pathology which itself is likely to be associated with more severe injury.

5.4.2.3 First start type

Horses move to jump racing from either flat or NHF races. Reasons for the increased risk of SDF tendinopathy in hurdle racing when the horse's first ever start was in NHF are hard to explain, but might be related to the quality or age of horses that start in this type of racing. It is also possible that NHF races predispose to SDF tendinopathy; previous studies have demonstrated an increased risk of fracture in this type of race (Parkin et al., 2004d, 2004e) and it is conceivable that this type of race leads to subclinical tendinopathy as well, which becomes clinically apparent in subsequent hurdle races.

5.4.2.4 Change in race distance

Increased risk of SDF tendinopathy was observed in starts in hurdle races that were 1 to 2.4km shorter than the horse's previous start. This is in contrast to the finding of increased risk associated with increased race length. It is possible that this is because the horses are being entered into shorter races because they are perceived to have had a problem during training, or because horses that are returning from injury are also entered into shorter races. It is also possible that the horses run faster than they are used to in the shorter races, which may predispose to injury.

5.4.2.5 Weight carried

Carrying a weight greater than 160lbs resulted in an increased risk of SDF tendinopathy in hurdle racing in comparison to carrying a lower weight. This could be related to increased fatigue and could be considered likely to make the horse more prone to abnormal loading of the limbs.

5.4.2.6 Days since previous hurdle race at that track

The only racecourse factor found to be of importance was: starts more than 90 days since the previous hurdle race at that track which resulted in an increased risk of SDF tendinopathy. This finding could be a proxy measure for the first race of a new racing season at each track. Alternatively it is possible that a series of postponements caused by bad weather, resulting in an extended period without racing at a track, may produce track surfaces that are in some way (other than that measured by going) more likely to result in SDF tendon injury. Further examination of methods to gain a better understanding of hoof – surface interaction is warranted.

5.4.2.7 Year

Hurdle starts in the years 2003 and 2005 were found to carry an increased likelihood of SDF tendinopathy compared to starts in the other years. The reasons for this are unclear, although it is possible that those years experienced some climatic conditions pre-disposing to SDF tendinopathy. For example the monthly rainfall in GB for 2003 and 2005 was lower than the average for 2000-2009 (89.5%), whilst for the most of the other years it was higher than average (mean of 108.5%) (Metoffice, 2011). This area requires further investigation to include regions, more specific time periods and other climatic conditions (temperature, hour of sunshine etc.). Most racetracks have their own weather stations, which record meteorological details including temperature, wind speed and rainfall, so further investigation of these factors should be possible.

5.4.2.8 Race type of previous start

Horses which had run in a race other than a hurdle race in their previous start had lower likelihood of sustaining a SDF tendinopathy in the hurdle model. It is possible that trainers and owners would not be inclined to introduce horses to a new racing discipline if they were demonstrating signs of underlying SDF injury. The majority of changes in race type in this group of horses were from flat or NHF to hurdle racing, as relatively few horses move from steeplechase to hurdle racing. Therefore, these horses would tend to be early in their racing careers in comparison to horses that had been consistently racing over hurdles for some time and as a result may be at lower risk of sustaining tendinopathy. An increased risk of injury during the first race of a new type has been recognised previously (Henley et al., 2006). This could theoretically be the result of the increased strain placed on the tendons during maximal exertion in a race over fences in comparison to training or racing on the flat.

5.4.2.9 Success of trainer / jockey

Based on the data available, it was decided that a simple proxy for performance would be to score trainers and jockeys based on the success of the horses that they trained or rode during the study date period (2001-2009). Whilst all the measures were found to be significant at the univariable level, once included in the multivariable model, the only variable found to be significant was the finish position score of the trainer. Horses trained by trainers with a high score had a reduced likelihood of sustaining SDF tendinopathy compared to those with lower scores. This could be related to the training regimens employed by successful trainers resulting in less SDF pathology, or could simply be a reflection of the quality or health (including underlying tendon health) of the horses trained at different training yards.

5.4.2.10 Number of runners

Starts in races with 13 to 30 runners were less likely to result in SDF tendinopathy than starts in races with fewer runners. The reason for this relationship is unclear, but is potentially related to an unmeasured factor such as the quality of horses in these races, or the speed of the race; as it is plausible that horses in larger fields may be more inclined to start at a slower speed.

5.4.3 Risk factors identified only in steeplechase racing

5.4.3.1 Official rating

Horses with official ratings in the top quartile of official ratings were observed to have a reduced likelihood of sustaining a SDF tendinopathy. This could be the result of a genetic or anatomical trait in these animals making them better athletes and less prone to injury or could simply be related to the fact that horses with (subclinical) injuries run less well and so obtain a lower official rating, a manifestation of the “healthy horse effect”. Addition of the official rating variable to the multilevel model resulted in exclusion of the trainer score variable, which suggests that the association between trainer score and SDF tendinopathy can be explained (at least partially) by the quality of the horses being trained. Interestingly in the multivariable model for SDF tendinopathy in hurdle racing, official rating was not retained in the final multivariable model, but trainer score was, so this association is not straightforward and would benefit from further analysis on different data sets.

5.5 Conclusions

Superficial digital flexor tendinopathy is a relatively common condition that has significant implications for horses’ racing careers and welfare. Multiple risk factors have been identified in this study and it is hoped that the information can be used to decrease the incidence rate of the condition. It would seem prudent for horses with previous tendinopathies to be closely monitored, to ensure sufficient rest and healing prior to further racing. It would also seem prudent for horses at apparent increased risk i.e. those that have had a previous injury, or of older age, to be included in races that potentially carry lower risk, such as on softer going or over shorter distances. However, a difficult balance needs to be struck, for example the safest approach to reduce SDF tendinopathy would appear to be: to only run young horses, without previous tendon injury in races on heavy going on flat surfaces. However, to do this, the number of races and therefore horses would have to be drastically reduced to decrease the already relatively low incidence rate of tendon injuries. Overall, it is important that information about the risk factors identified in this study is conveyed to veterinary surgeons and racehorse trainers, as the information equally applies to injuries sustained during training. In addition, these are the people who make the decision about horse entry into races, so need to be aware of the risks faced by their horses. This transfer of information will be facilitated with the policy advice document, to be published at the end of this project.

The multiple risk factors identified provide information that can be used to improve the understanding of the aetiology of SDF tendinopathy during racing. The information is also helpful for reviewing current regulations and racecourse management techniques. Not all of the observed associations can be readily explained by the data currently available. As a result further research investigating unmeasured factors (such as position of running rails, frequency and volume of watering and dates of fence changes) at racecourses might be worthwhile.

From this study, it would appear that factors resulting in increased cumulative fatigue; firm ground and the presence of previous tendon injury are all important risk factors for the development of SDF tendinopathy and should be considered when attempting to minimise the likelihood of sustaining an SDF tendinopathy during racing.

6 Epistaxis

6.1 Introduction

Epistaxis during exercise (from here-on termed “epistaxis”) is recognised as being associated with poor performance in racehorses (Mason et al. 1983; Newton et al. 2005). It is commonly the result of EIPH, although the relationship between epistaxis and severity of EIPH remains unclear, with a lack of association between epistaxis and the most severe grade of EIPH reported (Raphel and Soma, 1982). Epistaxis is considered of such significance in some racing jurisdictions (Australia, Hong Kong, New Zealand, South Africa, USA) that repeat episodes (the definitions of which vary) result in compulsory permanent retirement from racing, although this is not currently the case in GB or Ireland.

The prevalence of reported epistaxis varies between countries (Takahashi et al. 2001; Weideman et al. 2003; Newton et al. 2005; Stewart 2011) and within countries between racing disciplines (Takahashi et al. 2001; Newton et al. 2005; Egan 2011). Overall prevalence has been reported to range from between 0.08% to as high as 9% in one study (Pfaff 1976; Pascoe et al. 1981; Raphel & Soma 1982; Mason et al. 1983; Takahashi et al. 2001; Williams et al. 2001; Weideman et al. 2003; Hinchcliff et al. 2005; Newton et al. 2005), although it is important to recognise that these figures are affected by varying methods of collection and recording. This disorder can recur, with approximately 13% of cases experiencing at least one repeat episode (Takahashi et al., 2001; Weideman et al., 2003).

Previous epidemiological studies have examined potential risk factors for developing epistaxis while racing. Factors identified as increasing the risk of developing epistaxis include: increasing age (Cook, 1974; Pascoe et al., 1981; Pfaff, 1976; Raphel and Soma, 1982; Takahashi et al., 2001); increasing accumulated racing distance (Newton et al., 2005); gender (females at greater risk than males (Takahashi et al., 2001)) (geldings greater risk than colts or fillies (Weideman et al., 2003)); racing over longer distances (Raphel and Soma, 1982; Takahashi et al., 2001); jump racing compared to flat (Takahashi et al. 2001; Newton et al. 2005; Egan 2011); steeplechase compared to hurdle racing (Cook 1974; Raphel & Soma 1982; Newton et al. 2005); season (Weideman et al. 2003; Newton et al. 2005); lower ambient temperature (Hinchcliff et al., 2010); genetic factors (Weideman et al., 2004); and increased firmness of going (Newton et al., 2005).

Whilst these studies provide useful information about risk factors for epistaxis, further investigation is justifiable for a number of reasons. Firstly, a number of the published studies reported the results of relatively small numbers of horses and did not conduct multivariable analysis, which can make it difficult to interpret the significance of observed associations (Pfaff, 1976; Pascoe et al., 1981; Raphel and Soma, 1982). Secondly, of the studies which took multiple variables into account only one was conducted in GB (Newton et al., 2005). It has been shown that the prevalence of epistaxis varies between countries, so inter-country risk factors may not be comparable. Further, regulations vary between racing jurisdictions potentially affecting study populations, by enforcing withdrawal of susceptible horses from racing. Finally the only similar study from within GB (Newton et al., 2005) examined cases over a two year period and was conducted more than 10 years ago, subsequent to which, the reported prevalence of epistaxis has increased (Egan, 2011). Examination of a larger population of horses over a longer time period, including evaluation of additional risk factors, might allow the identification of other significant risk factors, potentially highlighting novel interventions that may help to minimise the risk of epistaxis in the future.

The aim of this study was to identify risk factors for epistaxis in Thoroughbred Racehorses running in hurdle and steeplechase races in GB. Because previous research identified differences in the incidence of epistaxis between the two types of jump racing (Newton et al., 2005) both were considered separately in this study.

6.2 Materials and Methods

Potential risk factors for epistaxis in hurdle and steeplechase starts in GB were assessed using case-control studies. In order to allow inclusion of horse, race and track as different levels in risk factor analysis, the studies were conducted at the level of race start (a “start” being a horse starting a race) and included 603 case starts and 169,065 control starts in hurdle racing and 550 case starts and 102,344 control starts in steeplechase racing.

6.2.1 Selection of cases and controls

A case start was defined as a start subsequent to which the horse was diagnosed with epistaxis (i.e. blood at one or both nostrils), whilst still at the racecourse. Cases were identified by racecourse veterinary surgeons (private practitioners employed by the racecourse), either from direct observation following the race, or when asked to examine a horse by the owner or trainer post-race and the diagnosis was made based on the findings of physical examination and recorded by attending BHA veterinary officers (veterinarians working for GB racing governing body). Control starts were defined as any start which did not result in the subsequent diagnosis of epistaxis, whilst still at the racecourse.

6.2.2 Risk factors

Potential risk factors were identified as described in Chapter 2. In addition, in order to examine the association between epistaxis and race performance, an additional variable “proportion of field beaten” (POFB) was included in the analysis. This was calculated using the following equation for each start, as described previously (Newton et al., 2005):

POFB = ([number of runners – finish position] / [number of runners – 1]) x 100

Because the odds of developing epistaxis were not significantly different between horses that finished last in a race and those that did not finish the race, when assessed at the univariable level, these horses were grouped together.

A total of 123 variables for each start (32 horse-related variables, 50 prior racing history-related variables, 26 race related variables, 5 trainer-related variables, 5 jockey-related variables and 5 track-related variables) were available for analysis.

6.2.3 Power of the study

Both studies had similar power: At least 80% power to identify odds ratios of 1.5 or more, with 95% confidence, when the prevalence of exposure in the control population was between 8% and 88% (hurdle racing) or 8% and 87% (steeplechase racing).

6.3 Results

Details of the numbers of starts, horses, jockeys, trainers, racecourses, races, race meets and race dates in each race type analysed in the study are shown in Chapter 2.

For the nine years between 2001 and 2009 there were 603 and 550 recorded cases of epistaxis in hurdle and steeplechase racing respectively, making the incidence rate of epistaxis: 3.6/1000 starts in hurdle racing and 5.3/1000 starts in steeplechase racing. Over the same period the incidence rate in flat racing in GB was 1.25/1000 starts.

6.3.1 Repeat epistaxis

The 603 cases of epistaxis in hurdle racing were recorded from 564 horses, whilst the 550 cases in steeplechase racing were recorded from 483 horses. Details of the number of repeat episodes recorded for those horses, the average amount of time between repeat episodes and the percentage of horses that made at least one start after a second or greater episode of epistaxis are shown in Table 6-1.

Table 6-1: Details of horses that had epistaxis and those that suffered from repeat episodes during racing in the study period.

Race Type (starts)	Horses	Repeats	Mean days between episodes	Mean starts between episodes	% started after rpt. episode
Hurdle (603)	564	38 x 1 1 x 2	225 (7-620)	4.2 (0-27)	79 (0-35)
Steeplechase (550)	483	48 x 1 5 x 2 3 x 3	293 (9-1090)	3.7 (0-22)	64 (0-62)

The “Repeats” column records the number of repeat episodes such that 38 x 1 means that 38 horses had one repeat episode of epistaxis during the study period. The “% started after rpt. episode” column reports the percentage of horses that had a repeat episode of epistaxis, that then went on to have at least one more race start.

6.3.2 Univariable analysis

Of the 122 variables screened at the univariable level, 38 were taken forward for consideration in each of the multivariable manual forward stepwise analyses. Details of these variables are shown in Appendix 6.

6.3.3 Multivariable analysis

In the final multivariable models 10 and 12 variables were found to be significantly associated with epistaxis in hurdle and steeplechase racing respectively (Tables 6-2 and 6-3).

6.3.3.1 Hurdle Racing

Variables found to be significantly associated with **increased** odds of epistaxis in hurdle racing were: running on going firmer than “soft” compared to running on softer going (OR 1.46, 95% C.I. 1.19-1.8); starting in the spring compared to starting in any other season (OR 1.26, 95% C.I. 1.06-1.5); starting in the years 2005-2009 compared to starting in the years 2001-2004 (OR 1.61, 95% C.I. 1.35-1.91); increasing horse age at first start (OR per extra year 1.13, 95% C.I. 1.07-1.2); having had a previous episode of epistaxis whilst racing; being a horse with greater than 75% of career starts in flat racing; having had one or two starts in the previous three to six months compared to having had no starts in that time period (OR 1.27, 95% C.I. 1.06-1.53).

Variables found to be significantly associated with **decreased** odds of epistaxis in hurdle racing were: longer race distance (OR per extra km 0.75, 95% C.I. 0.64-0.87); starting late or middle in the run sequence compared to early in the run sequence (OR 0.44 and 0.66, 95% C.I. 0.35-0.54 and 0.54-0.8 respectively); and having beaten a larger proportion of the field (OR per extra proportion beaten 0.96, 95% C.I. 0.96-0.97).

A significant interaction between previous epistaxis and percentage of career on flat was identified and its influence on main effects was included in the final model. The odds of developing epistaxis were considerably higher (OR 43.2, 95% C.I. 9.42-202) for starts made by a horse that had had a previous episode of epistaxis and had spent greater than 75% of its career in flat racing, full details of the relationship between these variables and the outcome are shown in table 6.2.

Table 6-2: Multivariable model showing variables significantly associated with the risk of developing epistaxis in hurdle racing.

	Total (%) n=169668	Cases (%) n=603	Controls (%) n=169065	P-Value	OR	CI
			TRACK RELATED VARIABLES			
Going						
"Heavy" to "Soft"	43135 (25)	116 (19)	43019 (25)		1 (Ref)	
"GTS" to "Firm"	126533 (75)	487 (81)	126046 (75)	**<0.001**	1.46	1.19-1.8
			RACE RELATED VARIABLES			
Race distance (km)				**<0.001**	0.75	0.64-0.87
Race position in run sequence				**<0.001**		
Early	66957 (39)	339 (56)	66618 (39)		1 (Ref)	
Late	55927 (33)	116 (19)	55811 (33)	*<0.001*	0.44	0.35-0.54
Middle	46784 (28)	148 (25)	46636 (28)	*<0.001*	0.66	0.54-0.8
Season						
Summer, Winter, Autumn	118206 (70)	375 (62)	117831 (70)		1 (Ref)	
Spring	51462 (30)	228 (38)	51234 (30)	**0.008**	1.26	1.06-1.5
Year						
2001 to 2004	70914 (42)	188 (31)	70726 (42)		1 (Ref)	
2005 to 2009	98754 (58)	415 (69)	98339 (58)	**<0.001**	1.61	1.35-1.91
			HORSE RELATED VARIABLES			
Age first race (years)				**<0.001**	1.13	1.07-1.2
Proportion beaten				**<0.001**	0.96	0.96-0.97
Horse number of starts in previous 4 to 6 months				**0.0094**		
None	84984 (50)	296 (49)	84688 (50)		1 (Ref)	
1 to 2	48962 (29)	206 (34)	48756 (29)	*0.01*	1.27	1.06-1.53
3 to 18	35722 (21)	101 (17)	35621 (21)	*0.498*	0.92	0.73-1.17
			SIGNIFICANT INTERACTIONS			
Previous epistaxis whilst racing and % of horse's career on flat						
No previous Epistaxis & <75% of career on flat	155263 (91.5)	482 (80)	154781 (91.6)		1 (Ref)	
No Previous Epistaxis & >75% of career on flat	12169 (7.2)	72 (12)	12097 (7.13)	**<0.001**	1.48	1.12-1.94
Previous Epistaxis & <75% of career on flat	2180 (1.27)	42 (7)	2138 (1.24)	**<0.001**	6.10	4.41-8.45
Previous Epistaxis & >75% of career on flat	56 (0.03)	7 (1)	49 (0.03)	**0.001**	43.2	9.42-202

Bolded P-values are likelihood ratio test P-values, whilst italicised P-values are Wald test P-values. OR = Odds Ratio, C.I. = Confidence Interval, Ref = Reference, "GTS" = Good to Soft.

6.3.4 Steeplechase racing

Variables found to be significantly associated with increased odds of epistaxis in steeplechase racing were: running on going firmer than "good to soft" compared to running on softer going; running in a claiming race compared to running in a non-claiming race (OR 5.8, 95% C.I. 1.39-24.3); starting in the winter or spring seasons compared to the summer or autumn (OR 1.63, 95% C.I. 1.31-2.04); starting in the years 2005 to 2009 compared to starting in the years 2001-2004; having had a previous episode of epistaxis whilst racing (OR 6.9, 95% C.I. 5.52-8.63); being a horse with greater than 75% of career starts in flat racing (OR 4.57, 95% C.I. 2.1-9.95); having had more than eight starts in the previous three to six months compared to having had fewer starts in that time period (OR 9.36, 95% C.I. 2.06-42.5).

Variables found to be significantly associated with decreased odds of epistaxis in steeplechase racing were: starting late or middle compared to early in the run sequence (OR 0.46 and 0.8, 95% C.I. 0.36-0.57 and 0.66-0.97 respectively); being ridden by an amateur jockey compared to being ridden by a professional jockey (OR 0.49, 95% C.I. 0.35-0.69); having beaten a larger proportion of the field (OR per extra proportion beaten 0.98, 95% C.I. 0.97-0.98); having more than two starts in the previous three months (OR 0.74, 95% C.I. 0.61-0.9); and increasing number of starts more than one year previously (OR per extra start 0.98, 95% C.I. 0.98-0.99).

Significant interactions between going and year and between season and proportion of field beaten were identified and their influence on the main effects included in the final model. The odds of developing epistaxis were higher (OR 3.04, 95% C.I. 1.02-9.11) for starts which were on going firmer than "good to soft" and were in the years 2005 to 2009, full details of the relationship between these variables and the outcome are shown in Table 3. The difference in odds of developing epistaxis between the season groups, decreased as the proportion of field beaten increased. To investigate this relationship further, a graph of the difference in probability of epistaxis between the two categories of season at a number of different "proportion of field beaten" values was plotted (Figure 6-1). It can be seen from the graph that the season group probability difference varies with changes in values of "proportion of field beaten." It appears that the difference in probabilities for winter and spring compared to summer and autumn is statistically significant between values of "proportion of field beaten" of approximately 0 to 35 and is non-significant elsewhere.

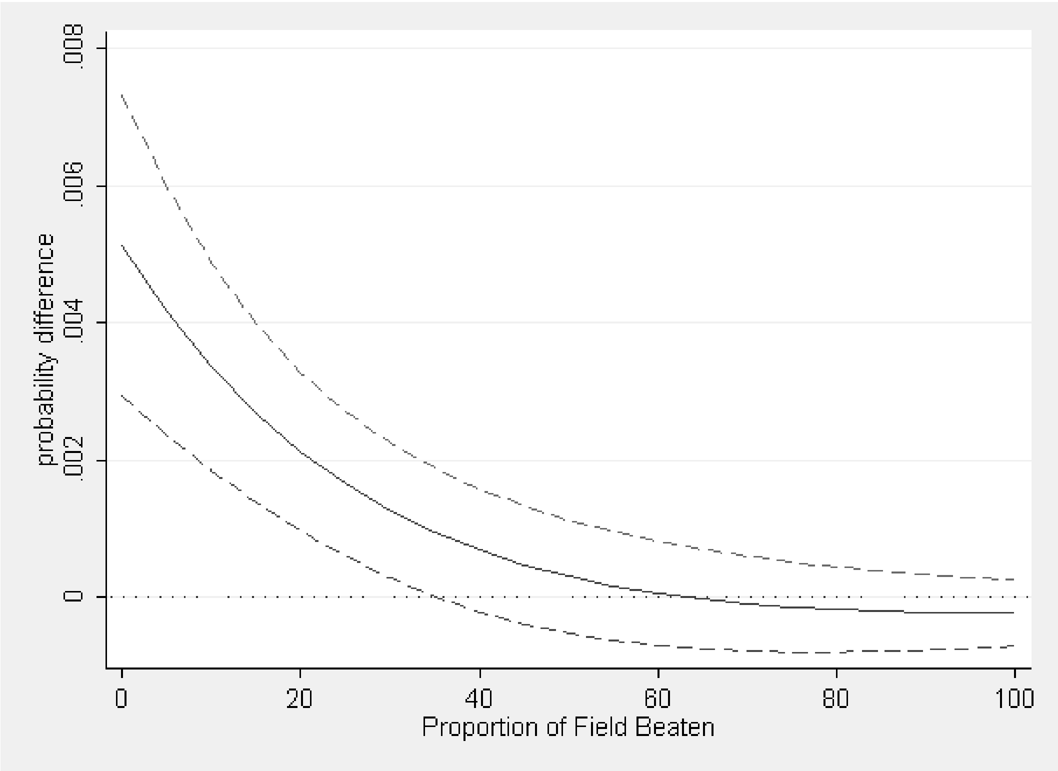


Figure 6-1: Line graph representing the difference in probability of epistaxis between the two categories of season (winter and spring compared to summer and autumn) at a number of different "proportion of field beaten" values. Solid line represents the mean, upper and lower dashed lines represent 95% upper and lower confidence intervals, respectively.

Table 6-3: Multivariable model showing variables significantly associated with the risk of developing epistaxis in steeplechase racing. Horse is included as a random effect.

Epistaxis Steeplechase	Total (%) n=102894	Cases (%) n=550	Controls (%) n=102344	P-Value	OR	CI
RACE RELATED VARIABLES						
Claiming race						
No	102816 (99.9)	548 (99.6)	102268 (99.9)		1 (Ref)	
Yes	78 (0.1)	2 (0.4)	76 (0.1)	**0.001**	5.9	1.39-25.3
Race position in run sequence				**<0.001**		
Early	24790 (24)	191 (35)	24599 (24)		1 (Ref)	
Late	40633 (40)	134 (24)	40499 (40)	*<0.001*	0.46	0.36-0.57
Middle	37471 (36)	225 (41)	37246 (36)	*0.024*	0.8	0.65-0.97
Season						
Summer or Autumn	35360 (34)	167 (30)	35193 (34)		1 (Ref)	
Winter or Spring	67534 (66)	383 (70)	67151 (66)	**<0.001**	1.64	1.31-2.06
JOCKEY RELATED VARIABLES						
Amateur Jockey						
No	89528 (87)	510 (93)	89018 (87)		1 (Ref)	
Yes	13366 (13)	40 (7)	13326 (13)	**<0.001**	0.49	0.35-0.68
HORSE RELATED VARIABLES						
Horse had previous episode of epistaxis whilst racing						
No	99459 (97)	447 (81)	99012 (97)		1 (Ref)	
Yes	3435 (3)	103 (19)	3332 (3)	**<0.001**	6.05	4.4-8.3
Proportion beaten				**<0.001**	0.98	0.97-0.98
Percentage of horse's career starts on flat						
0 to 75	102529 (99.6)	543 (99)	101986 (99.6)		1 (Ref)	
76 to 100	365 (0.4)	7 (1)	358 (0.4)	**<0.001**	4.59	2.1-10.1
Horse number of starts in previous 3 months						
0 to 2	69423 (67)	407 (74)	69016 (67)		1 (Ref)	
3 to 16	33471 (33)	143 (26)	33328 (33)	**<0.001**	0.74	0.61-0.9
Horse number of starts in previous 4 to 6 months						
0 to 8	102851 (99.96)	548 (99.6)	102303 (99.96)		1 (Ref)	
9 to 18	43 (0.04)	2 (0.4)	41 (0.04)	**<0.001**	10	2.13-47
Horse number of starts >1 year previously				**<0.001**	0.98	0.98-0.99
SIGNIFICANT INTERACTIONS						
Going and Year						
Going softer than Good & Year 2001-2004	17538 (17)	42 (8)	17496 (17)		1 (Ref)	
Going softer than Good & Year 2005-2009	28654 (28)	153 (28)	28501 (28)	**<0.001**	2.12	1.49-2.97
Going firmer than GTS & Year 2001-2004	25735 (25)	146 (27)	25589 (25)	**<0.001**	2.69	1.9-3.81
Going firmer than GTS & Year 2005-2009	30967 (30)	209 (38)	30758 (30)	**0.003**	3.04	1.02-9.11
Proportion of field beaten and winter or spring season				**0.020**	*****	

Bolded P-values are likelihood ratio test P-values, whilst italicised P-values are Wald test P-values. OR = Odds Ratio, C.I. = Confidence Interval, Ref = Reference, "GTS" = Good to Soft, * = interaction term for continuous variable, discussed in the results section.

6.3.5 Assessment of clustering

Residual intraclass correlation coefficients (rho) were estimated for horse, horse dam, horse sire, trainer, jockey, course, race and meet for each model and are shown in Table 6-4. With one exception, model coefficients and associated standard errors were altered by less than 20% when any of these random effects were included. The standard error for the odds ratio associated with a previous episode of epistaxis increased by 22.7%, when horse was included as a random effect in the steeplechase model. Based on these findings, horse was retained in the final steeplechase model, whilst no random effect was retained in the hurdle model.

Table 6-4: Residual intraclass correlation estimates for different variables included in the final multivariable models.

	Horse	Dam	Sire	Trainer	Jockey	Course	Race	Meet
Hurdle	<0.001	0.002	0.075	0.031	0.025	0.027	0.15	0.15
Steeplechase	0.16	0.08	0.06	0.026	0.016	0.024	0.13	0.046

6.3.6 Performance of the fixed-effects multivariable models

The final multivariable models were not affected by influential covariate patterns. There were sufficient cases per coefficient to justify the complexity of each model (Bagley et al., 2001). The Hosmer-Lemeshow goodness-of-fit statistic was 7.88 (8 degrees of freedom, P value = 0.45) for the hurdle model and 5.82 (8 degrees of freedom, P value = 0.67) indicating no evidence for lack of fit of either model. The area under the ROC curve was 0.82 for the hurdle model and 0.71 for the steeplechase model, indicating good and moderate predictive ability respectively.

6.4 Discussion

This paper reports the results of a study with the primary goal of identifying risk factors for epistaxis sustained during jump racing in GB. The analysis benefits from access to a large study population. Because of the amount of available data, inclusion of all starts that did not result in epistaxis as controls, may have marginally increased the chance of identifying significant differences between cases and controls, when they did not exist (Type-1 error). This approach was chosen in preference to selecting controls at random, which may have reduced the ability to investigate the effect of clustering; or selecting controls based on inclusion criteria; which had the potential to bias the results. Despite the large amount of data, the study is limited by the reliance on diagnosis and reporting of epistaxis at the racecourse, which is likely to have resulted in under estimation of the true number of cases. Along with this, the previous history of epistaxis is reliant on the horse having had the condition diagnosed at the racecourse and does not take into account any cases whilst in training, or racing outside GB.

6.4.1 Risk factors common to hurdle and steeplechase racing

A number of risk factors common to the hurdle and steeplechase models were identified:

6.4.1.1 Proportion of field beaten

Increasing proportion of field beaten was observed to be associated with decreased likelihood of epistaxis in both hurdle and steeplechase models. A similar association has previously been recognised (Kim et al. 1998; Newton et al. 2005) and could be explained by epistaxis having a negative effect on performance (Mason et al. 1983; Newton et al. 2005). It is considered likely that epistaxis results in worse racing performance, rather than that poor race performance is a risk factor for epistaxis. Given the potential for this to be the case, the models were re-run, excluding POFB. When this was done, there was a minimal effect on the other variables in the models, with none of the other variables dropping out and none of the odds ratios changing by a significant amount.

6.4.1.2 Percentage of previous career in flat racing

In both final multivariable models, starts made by horses which had spent more than 75% of their careers in flat racing had increased odds of developing epistaxis, compared to starts made by horses with proportionately less of their career in flat racing. The odds ratio was considerably higher (4.6, 95% CI 2.1-9.9) in steeplechase racing than in hurdle racing (1.5, 95% CI 1.1-1.9), which might suggest that previous flat racing history has more of an impact for horses racing in this type of racing. It is interesting that these odds ratios suggest an increased risk for these horses because the prevalence of epistaxis has been shown to be much higher in jump than in flat racing (Newton et al., 2005; Egan, 2011). This result may indicate that horses bred for flat racing, which subsequently race over fences, are more prone to epistaxis than horses bred specifically for jumping. Alternatively, to have a high percentage of career flat starts, horses would be likely to be near the beginning of their jump racing careers, so potentially an alternate risk factor associated with this resulted in the observed effect. In the hurdle model, being of increased age at first start was found to be a significant risk factor associated with developing the condition, which tends to concur with this hypothesis. However, because the numbers of starts: 79 (13% of cases) in hurdle and seven (1% of cases) in steeplechase, made by horses with greater than 75% of career flat starts was low, the importance of this finding is questionable.

6.4.1.3 Position of race in the run sequence

The reason for the reduced likelihood of epistaxis in starts that occur middle or late in the run sequence (compared to early), observed in both types of racing is unknown. It could be related to the type of races or horses that are run in each section of the race card, or potentially could be related to track factors associated with alterations in the surface during the race meet. In jump racing in GB, the races for the better horses are often held towards the middle or end of the race meeting (race card), which might partially help to explain this association. However, when “official rating” was included in the models (as a measure of the class/ability of horse), this was found not to be significantly associated with the likelihood of epistaxis in either multivariable.

6.4.1.4 Surface going

Surface “going” graded as “good-to-soft” or firmer was associated with increased risk of epistaxis in hurdle racing, whilst “good” or firmer was associated with increased risk in steeplechase racing. An association between going and risk of epistaxis has been recognised in a previous study (Newton et al., 2005), in which the authors concluded that the firmer ground would result in increased concussive forces, which would tend to support the impact-trauma aetiology of exercise induced pulmonary haemorrhage (EIPH) as proposed by others (Schroter et al., 1998).

6.4.1.5 Previous epistaxis

Horses which had had a previous episode of epistaxis were observed to be at significantly higher risk of developing epistaxis. This increased risk of subsequent episodes has been reported before for epistaxis (Takahashi et al., 2001) and EIPH (Epp et al., 2006) and is the basis for the regulations restricting horses from subsequent races in certain jurisdictions. The high odds ratios (particularly for hurdle racing), suggest that this is a particularly important risk factor and potentially indicates that further regulations should be considered to try and reduce the frequency of the condition in jump racing in GB. However because the prevalence of starts made by horses that had had previous epistaxis is low (1.3% of hurdle starts and 3.3% of steeplechase starts), such an intervention would have minimal effect on the overall prevalence of epistaxis.

6.4.1.6 Year

The incidence rate of epistaxis observed in this study was considerably greater than the prevalence reported by a previous study performed in GB (Newton et al., 2005) and an increased incidence rate of the condition was observed in the later years of this study. Whilst some research suggests that the prevalence of the condition is genuinely increasing (Weideman et al., 2003), an alteration to the computerised injury recording system in GB racecourses was introduced from the end of 2004, which may explain the observed increase in this study. Given the fact that the data from a number of years were included in this study and to adjust for any effect management and other changes over time may have had on risk factors, year was included in both final models.

6.4.1.7 Season

Season was observed to be associated with risk of epistaxis in both hurdle and steeplechase models. Associations between season and risk of epistaxis have been reported (Weideman et al. 2003; Newton et al. 2005). In one study, the association with the spring season was attributed to it being close to the end of the jumping season and potentially the result of increased accumulated racing, which may also partially explain the association observed in this study. However, this association remained significant, when previous racing schedules were taken into account, which might suggest that another explanation exists. Others have reported an increased risk associated with lower ambient temperature (Lapointe et al., 1994; Hinchcliff et al., 2010), which could help to explain these findings, but it is clear that the association with season warrants further investigation.

6.4.1.8 Starts in previous time periods

The numbers of starts made in previous time periods were found to be associated with the likelihood of developing epistaxis in both hurdle and steeplechase racing, although the time periods and number of starts varied between the race types. Similar to tendon injury, it is plausible that the association between epistaxis and previous start history is the result of the balance between horses being healthy enough to run frequently and not having run too frequently to predispose to epistaxis. Because the outcome has the potential to affect the risk factor (i.e. horses with epistaxis are not able to run as frequently) and because the study does not include information about epistaxis that occurred during training, it is more difficult to draw firm conclusions based on the following findings.

Start in the previous three months

In steeplechase racing having made more than two starts in the previous three months resulted in reduced likelihood of epistaxis compared to having made fewer starts. A similar association was observed at the univariable level in hurdle racing with horses that had made more than one start in the previous three months being at significantly reduced likelihood of developing epistaxis (OR 0.76; 95% C.I. 0.65-0.89), although this was not retained in the final multivariable model. Starts greater than three months after the previous start are likely to be: at the beginning of a new season (which could be a risk factor for epistaxis) or, subsequent to a period of rest following injury, which could potentially have been previous epistaxis in training or racing outside GB.

Start in the previous 3 to 6 months

An increased likelihood of epistaxis was observed in horses that had run between one and two times in this period, compared to horses that had not run, in the hurdle model. There was no significant difference between horses that had run more than twice in this period, making this variable less easy to interpret. In steeplechase racing horses that had run greater than eight times in this period were observed to have an increased likelihood of epistaxis, and although this observation was made based on a very small number of starts, it could potentially be related to cumulative fatigue in the lungs, with insufficient recovery time for the pulmonary vasculature.

Starts greater than one year previously

Increasing numbers of starts greater than one year previously were found to be associated with decreased likelihood of epistaxis in steeplechase racing. A similar association was observed at the univariable level in hurdle racing with horses that had made more than 11 starts in this period being at significantly reduced likelihood of developing epistaxis (OR 0.67; 95% C.I. 0.57-0.79), although this was not retained in the final multivariable model. The reason for this association is also likely to be associated with the “healthy horse effect” in that horses without injury/epistaxis (or subclinical injury) are able to run more frequently and over a longer career.

6.4.2 Risk factors identified only in hurdle racing

6.4.2.1 Race distance

The odds of developing epistaxis were observed to *decrease* for each km increase in race distance in hurdle racing. Whilst previous reports have suggested that the prevalence of epistaxis increases in longer races (Cook, 1974; Raphel and Soma, 1982; Kim et al., 1998), these studies did not take race type into account, which might explain this disparity. It has been reported that increasing race speed is associated with increased risk of epistaxis in hurdle and flat races and that increased speed is associated with shorter races (Newton et al., 2005). Unfortunately reliable race speed data were not available for starts made between 2000 and 2004 and, as such, were not included in the analyses in this study. It is therefore possible that the explanation for the association between race distance and risk of epistaxis is related to the speed of the races, with the longer races being run at lower speeds and resulting in reduced pulmonary trauma. However, this is contradicted by the observed increased incidence rate in steeplechase racing, in which races are run at a slower pace than hurdle races.

6.4.2.2 Age first race

Whilst increasing horse age has been recognised by others as a risk factor associated with epistaxis (Cook, 1974; Pfaff, 1976; Pascoe et al., 1981; Raphel and Soma, 1982; Kim et al., 1998; Takahashi et al., 2001; Weideman et al., 2003) and was significant in univariable analysis of steeplechase racing, the variable was not found to be significantly associated with the risk of epistaxis in univariable analysis of hurdle racing or in either multivariable model. Increasing horse age at first start (in any race) was found to be associated with an increased risk of epistaxis in hurdle racing, which has not been reported previously. This association is difficult to explain and tends to contradict the reported association with increased accumulated racing. It is possible that the type of horses which start racing later in their careers are genetically predisposed to epistaxis or that, as reported with distal limb fractures (Smith et al. 1999; Parkin et al. 2005; Ely 2010) and SDFT strain injuries, starting training and racing early in a horse’s life conveys a protective effect.

6.4.3 Risk factors identified only in steeplechase racing

6.4.3.1 Amateur jockeys

Starts made by amateur jockeys resulted in a decreased odds of developing epistaxis compared to starts made by professional jockeys in steeplechase races. This could also potentially be associated with race speed, as amateur jockeys tend to ride in lower quality races, at lower speeds. The ability of the horse may also partly explain this association, as amateur jockeys tend to ride lower quality horses, which were also found to be at decreased risk of developing epistaxis, when assessed using “Official rating” at the univariable level.

6.4.3.2 Claiming races

In claiming races, horses are put up for sale or auction following the race and as such, tend to involve lower quality horses. It is possible that the observed association is related to the quality of horses. It is also possible that this association is observed because horses with known previous problems are being entered into this type of race in order to remove them from the training yard / owner.

6.5 Conclusions

Multiple similar risk factors for epistaxis were identified in hurdle and steeplechase racing, many of which have been reported in previous risk factor studies. Determining which risk factors are causative and which are the result of the condition is not straightforward for many of the variables. Whilst the identified risk factors provide some additional information to help postulate on the aetiology of epistaxis, for example the associations with firm ground surface might be explained by the “impact trauma” theory of aetiology (Newton et al., 2005), the cause of the underlying EIPH remains unclear. In addition, whilst certain recommendations can be made to help reduce the incidence of the condition, such as enforced rest or retirement from racing for horses that have had epistaxis, the impact of this is likely to be small and therefore questionably necessary.

Despite its apparent effects on performance, it could be argued that epistaxis is not a major health / welfare issue. In fact considering it is invariably a manifestation of EIPH, which has been shown to be almost ubiquitous amongst racehorses, attempting to eliminate it might be impossible and unnecessary. Proponents of reducing the incidence of epistaxis argue that the condition is an indication that the horse has been pushed too hard and that it might pre-empt a vascular catastrophe. If this is the case, then the condition is undoubtedly of importance, but further research is required to determine whether there is an association between risk of death and epistaxis and how strong that association is. This unfortunately is likely to be difficult to perform, as some post mortem studies have described haemorrhage in the lungs in almost all examined cases (Corsan, 2012), whilst others have reported frequencies varying from 20-100% depending on the racing jurisdiction (Lyle et al., 2011).

Although not all of the observed associations can be readily explained with the data currently available, the multiple risk factors that have been identified provide information that can be used to improve our understanding of the aetiology of epistaxis during racing. The information is also helpful for reviewing current regulations and racecourse management techniques. Further research investigating weather conditions and unmeasured racecourse management factors (such as position of running rails, frequency and volume of watering and dates of fence changes) at racecourses is currently underway. The importance of previous training histories and genetics may also be worth investigating.

7 Accuracy of Distal Limb Fracture Diagnosis at the Racecourse

The availability of post mortem data for animals that died during the study period provided an opportunity to attempt to validate the injury and fatality data included in the "equine welfare database" prior to evaluation of risk factors for limb fracture.

7.1 Introduction

As discussed in Chapter 1, a number of epidemiological studies of fractures in Thoroughbred racehorses have been performed worldwide. Some of these studies have relied on racecourse veterinary reports (Mckee 1995; Williams et al. 2001), whilst others have initiated or used on going post mortem (PM) examinations to ensure accurate injury classification (Vaughan & Mason 1976; Johnson et al. 1994; Parkin et al. 2004e; Boden et al. 2005, 2006). In California all horses that died on the racetrack from 1990 onwards have been subjected to a PM examination. The results of this work have helped to accurately define the occurrence of injuries and better identify risk factors for those injuries (Estberg et al., 1996, 1998b). Unfortunately because of the large differences in track surface, types of racing and climate, the information from this work in California is not directly applicable to GB. Prior to the late 1990s, no study of greater than two years duration had been performed in GB that used both veterinary reports and PM information to accurately identify fractures occurring on the racetrack.

In 1999, a PM analysis of pairs of distal limbs from all horses that were subject to euthanasia on the racecourse due to suspected distal limb fracture was initiated. Preliminary results from this work were published in 2004 (Parkin et al., 2004c). Details of all injuries and deaths that occur on racecourses in GB are recorded by BHA employed VOs who are in attendance at every race meeting. An analysis of the accuracy of reporting was previously conducted for the period February 1999 to January 2001 (Parkin, 2002). This analysis highlighted some potential improvements that could be made to the BHA reporting system. On 1st January 2004 a modification to the computerised recording system "the equine welfare database" was introduced with the intention of improving the quality of data acquisition on horse injuries at the racecourse. With independent PM examinations being conducted over the same time period it is possible to assess the accuracy of the diagnoses made at the racetrack. This information allows validation of the information contained within the BHA equine welfare database and will be important for future studies, which use the database.

The aims of this study were twofold:

1. Describe the anatomical distribution of fatal fractures of the distal limb, affecting Thoroughbreds racing in GB between February 1999 and August 2005, inclusive (the period over which independent PM examinations were conducted).
2. Assess the accuracy (of fractured bone identification) of BHA VO reports from racecourses and examine whether there was an improvement in reporting accuracy following the introduction of a computerised recording system in January 2004.

7.2 Materials and Methods

7.2.1 Post Mortem data

7.2.1.1 Case identification and limb collection

From 1st February 1999 to 31st July 2005, horses with catastrophic fractures distal to radius or tibia resulting in euthanasia were identified by local racecourse veterinary surgeons at each racecourse. At the end of racing the attending BHA VO removed the affected and contralateral limbs at the level of the distal radius or tibia, placed them in sealed packaging and sent them for PM examination at the University of Liverpool. The majority of limbs were delivered within 36 hours of the time of the euthanasia. Each case was accompanied by a pro-forma providing a unique case number, the horse's name, race date, racecourse, race start time and attending veterinary surgeon.

7.2.1.2 Post mortem examination

The majority of PM examinations were conducted by a veterinary surgeon experienced in equine PM examination or by a trained research assistant. The fractures were classified by the bone(s) affected. Fractures of the third metacarpus and third metatarsus were further classified by the site of the fracture within the bone. Dorsal cortical fractures were classified as fractures which emanated from the dorsal cortex of these bones and did not included fracture lines in the distal articular surface. Carpal fractures were defined as fractures that affected one or more of the carpal bones. Post mortem reports were sent to the BHA VO and the local racecourse veterinary surgeon involved in the case (An example form is shown in Appendix 7). Notably, these reports were sent after the upload of the initial on-course diagnoses and the initial diagnoses were not altered in light of PM examinations.

7.2.2 Veterinary Officer Data

7.2.2.1 Background

For the first 4 years and 11 months of the study (between 1st February 1999 and 31st December 2003) the BHA VOs were provided with forms to report their diagnosis of the type of fracture before PM. These forms were submitted to the BHA independently of PM examination results.

In January 2004 the BHA introduced a modified computer recording system to allow VOs to directly input information on all horses sustaining fatal or non-fatal injuries at the racecourse. Report forms were redesigned and the new database provided drop down headings for recording information. Veterinary Officers were given training and an instruction sheet to facilitate completing the database correctly. Within the database, events (injuries) were stratified by: group (e.g. bone injury); type (e.g. fracture); structure (e.g. proximal phalanx); and region (e.g. left fore). Other comments were recorded in a separate field (e.g. protracted recumbency post fall). In addition to this, information was recorded on whether the injury resulted in lameness, the event location (e.g. at a fence) and event outcome (e.g. euthanasia). An example sheet from the database is shown in Appendix 2.

7.2.2.2 Stratification

The reports from the racecourses were separated into two distinct periods to mirror the change to the new computerised recording system:

Reporting period 1 = Old recording system: 1st February 1999 – 31st December 2003
Reporting period 2 = New recording system: 1st January 2004 – 1st August 2005

7.2.3 Race Information

Race information was available from Weatherbys Ltd. as described in Chapter 2.

7.2.4 Data analyses

The incidence rate (and associated 95% confidence intervals) of catastrophic distal limb fracture in each race type was calculated. Chi-squared analyses with Yates correction were performed to calculate relative risk between race types and between reporting periods 1 and 2, significance was set as <0.05.

Racecourse veterinarian diagnoses, in reporting periods 1 and 2, were compared with the PM findings. Because accurate identification of all fractured bones can be difficult via palpation alone, a number of different comparisons (indicating different degrees of consistency between the reporting systems) were performed.

7.3 Results

7.3.1 Case acquisition

Over the six years and six months of distal limb collection 367 pairs of limbs were submitted for PM examination after suspected distal limb fracture at the racecourse. Assessment of the BHA records from the same time period demonstrated the presence of 379 reports of distal limb fractures; indicating that 12 suspected cases were not submitted for PM examination during the period of the study. A flow chart showing the recruitment of cases for the study and details of the fractures diagnosed at PM are shown in Figure 7-1.

7.3.2 Fracture incidence rate

Of 367 cases submitted for PM examination, 23 were found not to have a fracture of any type. For the entire collection period the overall incidence rate of fatal distal limb fracture (confirmed at PM) in all types of race was 0.63 per 1000 starts (344/545,335), with the lowest frequency (0.34 per 1000 starts) in flat racing on turf and the highest frequency (1.56 per 1000 starts) in National Hunt flat (NHF) races. Details of the fatal distal limb fracture incidence rate by type of racing are shown in Table 7-1.

Table 7-1: Incidence rates of fatal distal limb fractures confirmed at PM from 1st February 1999 to 1st August 2005

	Race type					
	Flat (turf)	**Flat (AWT)**	**NHF**	**Hurdle**	**Chase**	**TOTAL**
Starts	264,517	81,766	15,998	112,990	70,064	545,335
Fatal distal limb #s	89	45	25	115	70	344
All PMs #s per 1000 starts	**0.34**	**0.55**	**1.56**	**1.02**	**1.00**	**0.63**

Key: AWT = all-weather turf; NHF = national hunt flat; Chase = steeplechase; # = fracture; PM = post mortem.

7.3.3 Comparison of the risk of catastrophic distal limb fracture in different race types

The relative risk of catastrophic distal limb fracture in NHF racing compared to turf flat racing was 4.7 (C.I. = 2.9-7.4; $P < 0.001$). The relative risk of catastrophic distal limb fracture in flat races run on all-weather tracks compared to flat races run on turf was 1.6 (C.I. = 1.1-2.4; $P = 0.009$). The relative risk of catastrophic distal limb fracture in all national hunt type races (hurdle, steeplechase or NHF), compared to a flat race (turf and all-weather) was 2.7 (C.I. = 2.2-3.4; $P < 0.001$). The relative risk of catastrophic distal limb fracture in a race with obstacles (hurdle and steeplechase races) compared to races without obstacles (flat, all weather or national hunt flat) was 2.3 (C.I. = 1.9-2.9; $P < 0.001$). The relative risk of catastrophic distal limb fracture in NHF racing compared to all other types of racing was 2.6 (C.I. = 1.7-4; $P < 0.001$).

379
BHA recorded

→ **12** →

12 (3.4%) Not sent for PM	
BHA reported fracture site	**Number**
Knee	5
Cannon (fore)	4
Phalanx/Pastern	1
Cannon (hind)	1
Tarsus/Hock	1

↓

367
Cases submitted for PM examination

→ **23** →

23 (6.3%) No Fracture identified at PM	
Post Mortem Diagnosis	**Count**
Suspensory ligament breakdown	7
Fetlock dislocation (+/-) Collateral / Sesamoidean ligament rupture	7
Distal sesamoidean ligament rupture	6
No injury observed	1
SDFT and DDFT laceration	1
Distal Radial Fracture	1

↓

344
Details of PM findings for horses with confirmed distal limb #s

→

Details of PM fracture diagnosis and location

	Limb					
	RF	LF	BF	RH	LH	TOTAL
Single site fractures:	**78**	**68**	**2**	**24**	**18**	**190**
PP	29	27	0	14	8	78
Cortical MC/TIII	12	11	1	2	3	29
M. c. MC/TIII	10	9	1	5	2	27
L. c. MC/TIII	21	18	0	2	5	46
L. c. & M. c. MCIII	3	2	0	1	0	6
Uniaxial Sesamoid	3	1	0	0	0	4
Multiple site fractures:	**56**	**55**	**3**	**20**	**20**	**154**
L. c. MC/TIII & Sesamoid(s)	22	12	0	2	0	36
L. c. MC/TIII & PP & Sesamoid(s)	5	6	0	10	10	31
Carpus	14	19	1	-	-	34
Biaxial sesamoid	10	16	0	0	0	26
L. c. MC/TIII & PP	4	1	1	2	6	14
Tarsus	-	-	-	4	4	8
PP & MP	0	0	0	2	0	2
M. c. MC/TIII & BS	1	0	0	0	0	1
M. c. MC/TIII & Cortical	0	0	1	0	0	1
Cortical and Carpal	0	1	0	-	-	1
Total	**134**	**123**	**5**	**44**	**38**	**344**

Figure 7-1: Flow chart of case recruitment and fracture details from the entire study period.
Key to Figure 7.1: BHA = British Horseracing Authority; PM = post mortem; MC3 = third metacarpal bone; PP = Proximal phalanx; MT3 = third metatarsal bone; # = fracture; SDFT = superficial digital flexor tendon; DDFT = deep digital flexor tendon; RF = right fore; LF = left fore; BF = both forelimbs; RH = right hind; LH = left hind; MCTIII = Third metacarpus/metatarsus; M.c. = Medial condyle; L. c. = Lateral condyle; Sesamoid(s) = uni or biaxial sesamoid fracture; MP = Middle Phalanx; BS = biaxial sesamoid.

7.3.4 Post Mortem confirmed fractures

7.3.4.1 Location of Fractures

Forelimb (FL) fractures (262/344 = 76.2%) were approximately three times more common than hindlimb (HL) fractures (82/344 = 23.8%). The number of fractures affecting the right limbs (183) was slightly higher than the number affecting the left limbs (166).

Forelimb fractures

In 56.5% (148/262) of cases only one bone was fractured. The third metacarpus and proximal phalanx were the most commonly affected bones, accounting for 59.5% (88/148) and 37.8% (56/148) of FL single site cases respectively.

In 43.5% (114/262) of FL cases, more than one bone was fractured. Lateral condylar fractures of the third metacarpal bone in combination with fractures of the proximal sesamoid bones and/or the proximal phalanx were the most frequent multi-site fracture (44.7% [51/114] of multi-site cases), whilst carpal fractures and biaxial proximal sesamoid bone fractures accounted for 29.8% (34) and 22.8% (26) of multi-site cases respectively.

Hindlimb fractures

In 51.2% (42/82) of cases only one bone was fractured. Single site fractures were divided between fractures of the proximal phalanx (22/42) and fractures of the third metatarsal bone (20/42). Forty (48.8%) cases involved more than one bone. Lateral condylar fractures of the third metatarsal bone in combination with fractures of the proximal sesamoid bones and/or the proximal phalanx were the most frequent multi-site fracture (75% (30/40) of multi-site cases).

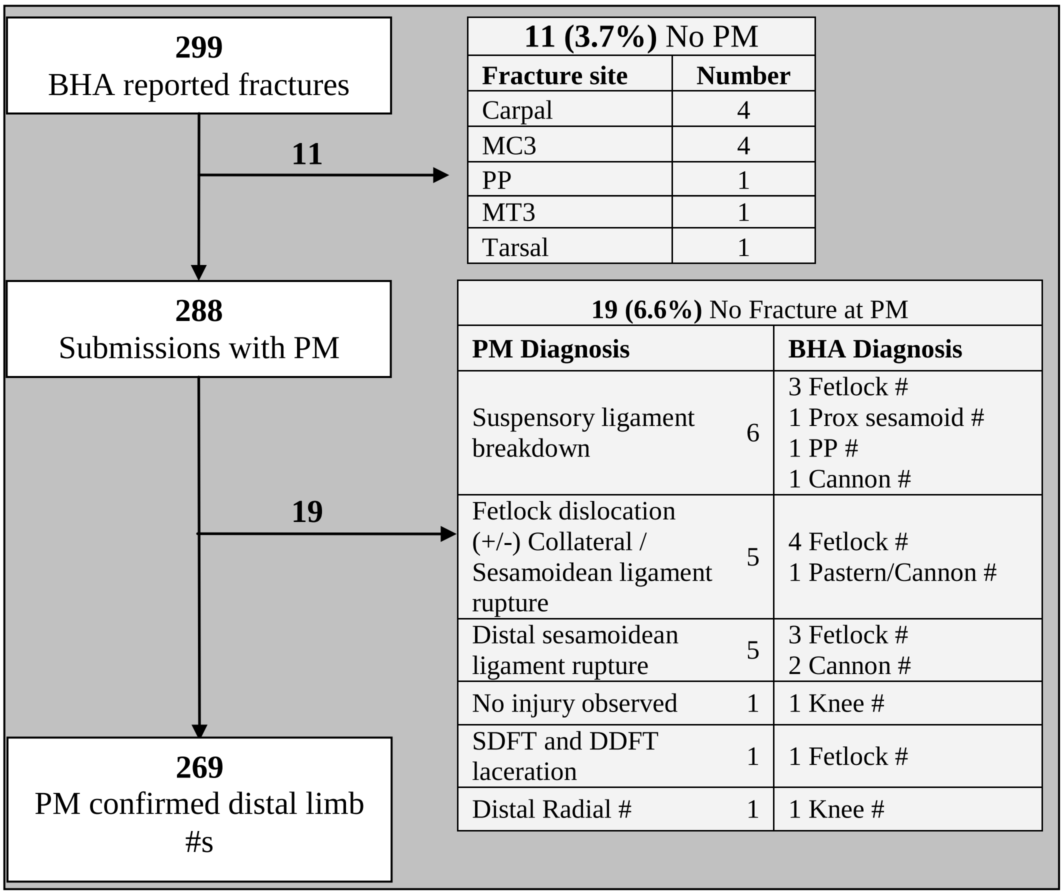
Comparison of fore and hind limbs

When fracture frequencies at the most common anatomical locations identified at PM were compared between FLs and HLs: fractures of the sesamoid bones alone were significantly more frequent in the FLs (4/148 fractures) than the HLs (0/42 fractures); lateral condylar fractures in combination with sesamoid fractures were significantly more frequent in FLs than HLs (relative risk 5.96 [1.5-23.7] p=0.003); whilst lateral condylar fractures in combination with sesamoid and proximal phalangeal fractures were significantly more frequent in the HLs (relative risk 5.18 [2.7-9.8] p=<0.001). There were no significant differences for single site proximal phalangeal fractures (FL 88/148, HL 22/42) or fractures to the lateral (FL 39/148, HL 7/42) or medial condyles (FL 20/148, HL 7/42) of the cannon bones (p=0.52, 0.28 and 0.79 respectively) between the FLs and HLs.

7.3.5 Comparison of Periods 1 and 2

7.3.5.1 Case acquisition in reporting period 1 (02/99-01/04)

The BHA records from 1st February 1999 to 1st January 2004 reported 299 cases of distal limb fracture leading to mortality. Of these, 11 cases were not submitted for PM and 19 (6.4%) were found not to have a distal limb fracture on PM examination. There were therefore 269 confirmed fracture submissions with both BHA and PM reports, for comparison. A flow chart showing details of the cases excluded from the study are shown in Figure 7-2.



11 (3.7%) No PM	
Fracture site	**Number**
Carpal	4
MC3	4
PP	1
MT3	1
Tarsal	1

19 (6.6%) No Fracture at PM		
PM Diagnosis		**BHA Diagnosis**
Suspensory ligament breakdown	6	3 Fetlock # 1 Prox sesamoid # 1 PP # 1 Cannon #
Fetlock dislocation (+/-) Collateral / Sesamoidean ligament rupture	5	4 Fetlock # 1 Pastern/Cannon #
Distal sesamoidean ligament rupture	5	3 Fetlock # 2 Cannon #
No injury observed	1	1 Knee #
SDFT and DDFT laceration	1	1 Fetlock #
Distal Radial #	1	1 Knee #

Figure 7-2: Flow chart demonstrating case inclusion for reporting period 1.
Key: BHA = British Horseracing Authority; PM = post mortem; MC3 = third metacarpal bone; PP = Proximal phalanx; MT3 = third metatarsal bone; # = fracture.

7.3.5.2 Case acquisition in reporting period 2 (01/04-08/05)

Over one year and seven months the BHA records reported 80 cases of distal limb fracture resulting in euthanasia. Of these, one case (reported as having a fracture of the right carpus) was not submitted for PM examination and in four cases no distal limb fracture was identified at PM evaluation (Table 7-2). There were therefore 75 confirmed fracture submissions with both BHA and PM reports, for comparison.

Table 7-2: Details of four cases submitted in reporting period 2 found not to have a distal limb fracture

PM diagnosis	**BHA diagnosis**
Suspensory ligament rupture	Sesamoid fracture
Fetlock dislocation and suspensory rupture	Pastern fracture
Distal sesamoidean ligament rupture	Both sesamoids fractured
Fetlock collateral and sesamoidean ligament rupture	P1 Fracture

7.3.6 Racecourse records for periods 1 and 2

Full details of racecourse veterinary report compared to PM diagnosis are shown in Table 7-3.

Table 7-3: Details of diagnosis recorded at the racecourse compared to diagnosis made at PM for periods 1 and 2:

PM fracture classification	Period 1	Period 1 BHA Report	Period 2	Period 2 BHA report
Single Site Fractures:	**151**		**39**	
PP	62	26 Phalanx/Pastern 21 Pastern 4 Fetlock 4 P1 3 Cannon 1 Fetlock/Cannon 1 Foot/P3 1 Pedal/Coffin 1 Sesamoid both	16	7 Pastern 4 P1 3 P1 Comminuted 1 MC3 1 MT3 Condylar
Cortical MC/TIII	23	22 Cannon 1 None	6	4 Cannon 2 MC3
M. c. MC/TIII	23	19 Cannon 1 Carpus/Cannon 1 Fetlock 1 MC3 1 None	4	2 Cannon 1 MC3 1 MT3
L. c. MC/TIII	39	28 Cannon 6 Fetlock 2 Sesamoid 1 Sesamoid/Fetlock 1 Sesamoid/Cannon 1 Cannon/Sesamoid	7	4 Cannon 2 MC3 1 MC3 Comminuted
L. c. & M. c. MCIII	4	4 Cannon	2	2 MC3
Uniaxial Sesamoid	0	0	4	2 Sesamoid 1 Sesamoid lateral 1 Cannon
Multiple site fractures:	**118**		**36**	
L. c. MC/TIII & Sesamoid(s)	29	16 Cannon 9 Fetlock 1 Pastern 1 Phalanx/Pastern 1 Sesamoid/Cannon 1 Sesamoid lateral	7	3 MC3 Condylar 2 Cannon 1 MC3 1 Sesamoid both
L. c. MC/TIII & PP & Sesamoid(s)	15	7 Cannon 3 Fetlock 2 Pastern/Cannon 1 Pastern 1 Radius/Ulna 1 Ses/Can/Past	16	8 Pastern 3 Cannon 2 P1 1 MC3 1 MC3 condylar comminuted 1 P1 / Lat Sesamoid
Carpus	25	22 Carpus / Knee 3 Cannon	9	9 Carpal / Knee
Biaxial sesamoid	23	10 Sesamoid 8 Fetlock 3 Cannon 1 Phalanx/Pastern 1 SL	3	1 Sesamoid 1 Sesamoid (both) 1 Frog

L. c. MC/TIII & PP	14	4 Phalanx/Pastern 3 Cannon 3 Fetlock 3 Fet/Phal/Past/Can 1 Can/Phal/Past	0	
Tarsus	7	5 Tarsus 1 Hock 1 Tarsus/Hock	1	Hock
PP & MP	2	2 Pastern	0	0
M. c. MC/TIII & PP				
M. c. MC/TIII & BS	1	1 Cannon	0	0
M. c. MC/TIII & Cortical	1	1 Cannon	0	0
Cortical and Carpal	1	1 Cannon	0	0
Total	**269**		**75**	

Key for Table 7.3: PM = post mortem; BHA = British Horseracing Authority; PP = Proximal phalanx; DP = Distal phalanx; MC3 = third metacarpal bone; MT3 = third metatarsal bone; MP = Middle phalanx; MC/TIII = Third metacarpus/metatarsus; M.c. = Medial condyle; L. c. = Lateral condyle; Sesamoid(s) = uni or biaxial sesamoid fracture; Ses = Sesamoid; Fet=fetlock; Phal=phalanx, Past=pastern; Can=cannon.

7.3.7 Comparison of BHA and PM reporting for periods 1 and 2:

Comparisons between the diagnoses recorded at the racecourse and the PM diagnoses are shown in Table 7-4. The diagnosis of "fetlock fracture" was not made during period 2 as this had been removed as a diagnostic option from the data recording sheets at the start of that period. The percentage of cases reported correctly was higher in period 2 for all categories (although the differences in percentages between the periods were not significant for any but the correct reporting of at least one fractured bone). There was a low level of accuracy in reporting all fractured bones in both period 1 (52.1%) and period 2 (54.4%).

Table 7-4: Table comparing the reporting from each period

BHA report compared to PM findings	**Period 1** (n=288) (n)	**Period 2** (n=79) (n)	**RR** 2 v 1 (C.I.s)	**p-value** (Yates corrected)
Correctly reported the presence of "a fracture" (irrespective of bone and leg)	**93.4 %** (269)	**94.9 %** (75)	**1.02** (0.96-1.08)	**0.81**
Correctly reported all fractured bones in the correct leg	**52.1 %** (150)	**54.4 %** (43)	**1.05** (0.83-1.32)	**0.81**
Correctly reported the injured leg	**81.9 %** (236)	**82.3 %** (65)	**1.00** (0.89-1.13)	**0.92**
Correctly reported at least one of the fractured bones in the correct leg (including fetlock as a possible site)	**76 %** (219)	**77.2 %** (61)	**1.02** (0.89-1.16)	**0.95**
Correctly reported at least one of the fractured bones in the correct leg (excluding fetlock as a possible site)	**64.9 %** (187)	**77.2 %** (61)	**1.19** (1.03-1.38)	**0.05**
Correctly reported at least one of the fractured bones (irrespective of leg) (including fetlock as a possible site)	**86.5 %** (249)	**89.9 %** (71)	**1.04** (0.95-1.13)	**0.54**
Correctly reported at least one of the fractured bones (irrespective of leg) (excluding fetlock as a possible site)	**73.3 %** (211)	**89.9 %** (71)	**1.23** (1.11-1.36)	**0.003***

Key: PM = post mortem; RR = relative risk; including fetlock = included fetlock as a correct diagnosis when referring to bones of the metacarpophalangeal or metatarsophalangeal joints; excluding fetlock = excluded fetlock as a correct diagnosis. * = significant at <0.05.

7.4 Discussion

This study reports on the PM findings from the largest number of distal limb fractures sustained whilst racing, so far investigated in GB. The recruitment of PM cases was considered excellent, with just 3.4% of BHA reported fracture cases not being sent for PM. The major reason for these failures to submit cases was refusal by the owner or trainer to allow a PM to be carried out. A limitation of this study was that the calculated racetrack fracture incidence rate was based on cases of suspect fracture, which were subjected to euthanasia at the racetrack and does not include horses that obtained a fracture whilst racing, but were subjected to euthanasia away from the track (i.e. following further investigation/treatment). The estimates of the frequency of fracture sustained while racing that result in euthanasia are therefore likely to be slight underestimates. It is also likely that there will be some bias in the type of horse that are removed from the racecourse before euthanasia as treatment is more likely to be attempted in horses considered worth salvaging (young horses, good horses or horses with breeding potential) and in horses with fractures considered to be treatable. This bias should be considered in future studies that attempt to identify risk factors for fatality on the racecourse.

Compared to previous studies, the incidence of fatal distal limb fractures in racing in GB has remained relatively unaltered: between 1987 and 1993 there were 0.33 fractures/1000 starts in flat racing, 1.4/1000 starts in hurdle racing and 2.3/1000 starts in steeplechase racing (Mckee, 1995), whilst between 1999 and 2001 there were 0.38/1000 starts in flat racing on turf, 0.93/1000 starts in hurdle racing and 1.37/1000 starts in steeplechase racing (Parkin et al., 2004c). This lack of significant reduction in fractures may be viewed as disappointing, as safety issues are constantly reviewed by the BHA and measures to improve safety such the introduction of shorter NHF races have been introduced in order to try and reduce the incidence of racecourse fatalities.

The risk of fatal distal limb fractures varied between race type: National hunt flat races demonstrated the highest incidence, as previously observed (Mckee, 1995; Parkin et al., 2004c). The risk of catastrophic distal limb fracture was just over five times higher in NHF races than that for flat turf races and nearly three times higher than for all other types or races combined. The cause of this increased risk is uncertain. However, NHF races are used as an introduction to racing for horses before the start of a jump career and are typically run by horses between three and five years old. Previous research has shown that horses in their first year of racing had the highest risk of fatal distal limb fracture (Parkin et al., 2004d) and that increased age at first start is positively associated with the risk of lateral condylar fracture (Parkin et al., 2004b). Other work has shown that starting training at an early age is protective against distal limb injury (Wood et al., 2000), which these horses may not have done in comparison to horses that ran in flat races prior to starting a jump racing career.

A significant difference in the incidence rate of fractures between flat racing surfaces was also observed, with the all-weather tracks resulting in a higher (1.6 times) risk of a fatal distal limb fracture than turf. This might suggest that turf is a safer surface than all-weather. However potential confounding variables exist: racing populations differ between turf and all-weather, with different prize funds and horse quality between the surfaces. Also, all-weather surfaces permit racing all year round and as such the weather conditions vary between the two race types. Further investigation, using multivariable epidemiological techniques, of the reasons for this difference is required.

Racing over obstacles was found to be associated with a 2.3 times increased risk for fatal distal limb fracture than racing on the flat. This increased risk has been recognised before and has been attributed to the increased prevalence of horses falling in jump racing and the increased forces applied to the limbs at take-off and landing (Parkin et al., 2004c). The significantly higher risk in this popular type of racing is the focus of this PhD study.

Forelimb fractures of the third metacarpus and proximal phalanx were most commonly observed and fractures affecting multiple sites were slightly more common than those affecting single sites. The majority of fractures were of structures near the metacarpophalangeal joint (MCPJ), with carpal fractures being less frequent and fractures of the middle and distal phalanges being very infrequent. Potential explanations for this include, the increased lever arm (and subsequent force) acting on the MCPJ and the relative reduction in weight bearing surface and number of bones available in this area to disperse forces compared to the carpus. The compact size and shape of the two distal phalanges, in combination with the shock absorbing effect of the MCPJ, may make them less prone to fracture than the bones in the MCPJ.

Fractures of the HL were less frequent than those of the FL, as previously reported (Johnson et al., 1994; Parkin et al., 2004a). Fractures of the proximal phalanx and third metatarsal bone were most common, as in the FLs. Single site fractures of the medial condyle were more common than those of the lateral condyle, which differed from the FL.

It is hypothesised that the lower number of fractures observed in the HLs is because of the reduced amount of force experienced by these limbs during locomotion (Witte et al., 2004).

The significant differences between certain fracture sites between the FLs and HLs were of interest: fractures of the proximal sesamoid bones without involvement of other bones were not observed in the HLs, but were relatively frequent in the FLs; lateral condylar fractures in combination with proximal sesamoid bone fractures were more common in the FLs than the HLs, whilst lateral condylar fractures in combination with fractures of proximal sesamoid bones and the proximal phalanx were more common in the HLs than the FLs. It is probable that these differences are as a result of differing forces acting through the "fetlock region" between FLs and HLs, potentially associated with the difference in angulation of these joints. Future analysis of a larger number of fracture cases would be interesting, as although significant differences were observed, the number of cases are relatively small and the error bars are wide.

The introduction of a new computerised recording system in 2004, resulted in a non-significant improvement in the proportion of submissions with no distal limb fracture at PM (6.5% [19/288] in period 1 and 5.1% [4/79] in period 2). The most common finding at PM for cases without a fracture was suspensory ligament rupture or sesamoidean ligament damage, in both reporting periods, suggesting that these injuries clinically resemble fractures of the distal limb, specifically around the metacarpo/tarsophalangeal joint. The most common diagnosis made by the racecourse veterinarians for these conditions being fractures around the MCPJ, in both reporting periods. Misdiagnosis of a fracture is undesirable as it might result in unnecessary euthanasia, however for the majority of cases in this study, the severity of the alternate injuries diagnosed at PM would have warranted euthanasia. In one case no injury could be identified at PM. It is possible that this case was related to an error in recording or limb collection; for example FLs may have inadvertently been submitted for PM instead of HLs. Indeed misclassification of the affected leg was observed in 18.1% (52/288) of submissions in reporting period 1 and 17.7% (14/79) of submissions in reporting period 2. This is considered a high percentage of misclassification, when it is likely that the majority of horses with distal limb fractures would demonstrate significant lameness. It is possible that a percentage of this limb misclassification could be as a result of recording error, which could have occurred at the racetrack or during PM. The recording system relies on racecourse veterinarians reporting to the BHA veterinary officers (who may not have seen the horse), who then input the information into the database. On top of this, some of the PM specimens were collected at abattoirs/knacker’s yards, which would also provide a potential source of error.

When the details of racecourse reports were compared to the PM diagnosis, the agreement was lower. Diagnosis of all fractured bones in the correct leg was identified in only 52.1% and 54.4% of reports from Period 1 and 2, respectively. This would suggest that the diagnoses being made at the racetrack could be significantly improved. Racetrack diagnoses are made without the aid of radiographs and are therefore reliant on a local racecourse veterinarian’s physical examination of the limb. Alterations in anatomy caused by catastrophic fractures are also likely to make accurate diagnosis more difficult. However, simple on-track PM examinations could be implemented to aid in the correct identification of fracture limbs, for example, with respect to metacarpo/tarsophalangeal joint centred fractures, simply opening the joint would enable evaluation of articular surfaces to help identify fractures of the third metacarpus/tarsus, the proximal phalanx and the proximal sesamoid bones.

When limb misclassification was disregarded and the diagnosis of “fetlock fracture” was excluded as a viable diagnosis, identification of at least one of the fractured bones in BHA reports was significantly improved in reporting period 2 compared to reporting period 1 (P=0.003). Whilst “fetlock fracture” does encompass the majority of the fractures observed, it provides less information for planning interventions to try and reduce risk e.g. of biaxial proximal sesamoid, condylar or proximal phalangeal fracture. The significant improvement in the recording in period 2 suggests that the new system is helpful and that this is at least partly due to the inability to identify “fetlock” as a fracture location in the new system. However, as shown in table 5, there are still flaws in the system, which should be considered when the “Equine Welfare Database” is reviewed.

7.4 Conclusion:

The incidence of fatal distal limb fractures sustained whilst racing over jumps in GB has not significantly altered since the 1970s. Overall the recording of correct fracture diagnoses to the BHA database from the racetrack veterinarians has not significantly improved despite the introduction of a novel computerised recording system. Further training of local racecourse veterinarians, to enable them to identify exactly which bones have been fractured by careful palpation, or provision of facilities for distal limb radiography on the racecourse should be considered.

8 Risk Factors for Hind Limb Fractures

8.1 Introduction

Whilst previous studies have identified risk factors for limb fractures in racehorses (see Chapter 1), some of which have included hindlimb fractures (HLF), none have focussed solely on fractures of the hindlimbs. It is possible that risk factors for HLF differ significantly from those for forelimb fractures.

Having identified the frequency of HLF occurrence, along with the relative lack of previous research into them, the BHA identified HLF as an area worthy of further investigation. It was decided that fractures of the pelvis should be examined separately.

The aims of this part of the study were to identify risk factors associated with sustaining a HLF in Thoroughbred racehorses running in hurdle and steeplechase races in GB and to also compare the risk factors identified between the two disciplines.

8.2 Materials and Methods

Potential risk factors for HLF in hurdle and steeplechase starts in GB were assessed using cohort studies. In order to allow inclusion of horse, race and track as different levels in risk factor analysis, the study was conducted at the start level (a “start” being a horse starting a race) and included 99 case starts and 169,569 control starts in the hurdle study and 90 cases starts and 102,804 control starts in the steeplechase study.

8.2.1 Selection of cases and controls

A case start was defined as a start in a race, subsequent to which the horse was diagnosed with a fracture of a bone in the hindlimb (distal to and including the femur), whilst still at the racecourse. Cases were identified by racecourse veterinary surgeons based on the findings of physical examination and recorded by attending BHA VOs. Control starts were defined as any start in a race, which did not result in the subsequent diagnosis of a fracture of a bone in the hindlimb (distal to and including the femur), whilst still at the racecourse.

8.2.2 Risk factors

A total of 122 variables for each start (32 horse-related variables, 50 prior racing history-related variables, 25 race related variables, 5 trainer-related variables, 5 jockey-related variables and 5 track-related variables) were available for analysis.

8.2.3 Power of the study

The hurdle model had at least 80% power to identify odds ratios of 2 or more, with 95% confidence, when the prevalence of exposure in the control population was between 16% and 67%. The steeplechase model had at least 80% power to identify odds ratios of 2 or more, with 95% confidence, when the prevalence of exposure in the control population was between 19% and 63%.

8.3 Results

Details of the numbers of starts, horses, jockeys, trainers, racecourses, races, race meets and race dates in each race type analysed in the study are shown in Chapter 2.

For the nine years between 2001 and 2009 there were 99 and 90 recorded cases of HLF in hurdle and steeplechase racing, respectively. The incidence rates of HLF were:

- 0.58/1000 starts in hurdle racing
- 0.87/1000 starts in steeplechase racing

8.3.1 Fracture sites

Details of fracture sites and frequencies, as well as percentage of cases that died as a result of the fracture are shown in Table 8-1.

Table 8-1: Number and distribution of hind limb fractures in hurdle and steeplechase racing during the study period, as well as percentage that resulted in fatality.

Fracture Site	Hurdle (% Fatal)	Steeplechase (% Fatal)
Third Metatarsal	37 (92)	27 (89)
Tibia/Fibula	29 (97)	22 (91)
Proximal Phalanx	22 (91)	21 (81)
Femur	7 (100)	6 (100)
Tarsus	3 (67)	9 (56)
Proximal Sesamoid bone(s)	1 (0)	1 (0)
Tuber Calcis	0 (0)	1 (100)
Middle Phalanx	0 (0)	2 (100)
Distal Phalanx	0 (0)	1 (0)

8.3.2 Univariable analysis

Of the 122 variables screened at the univariable level, 35 were taken forward for consideration in each of the multivariable manual forward stepwise analyses. Details of these variables are shown in Appendix 6.

8.3.3 Multivariable analysis

In the final multivariable models, five variables were found to be significantly associated with HLF in both hurdle and steeplechase racing (Tables 8-2 and 8-3).

8.3.3.1 Hurdle Racing

Variables found to be significantly associated with **increased** likelihood of HLF in hurdle racing were: being a horse with greater than 50% of career starts in flat racing compared to having had none (Odds Ratio [OR] 2.08, 95% C.I. 1.21-3.58); starting in the years 2002-2003 or 2006-2009 compared to running in 2001 (OR 14.47, 95% C.I. 1.97-106.12 and OR 10.92, 95% C.I. 1.51-78.91, respectively); and carrying an increased weight (OR for each additional pound 1.05, 95% C.I. 1.02-1.08).

Variables found to be significantly associated with **decreased** likelihood of HLF in hurdle racing were: horse age, with horses older than six years old being at reduced likelihood than younger horses (although this did not remain significant once the interaction term with starts more than one year previously was included); and number of starts more than one year previously (OR per extra year 0.89, 95% C.I. 0.84-0.94).

A significant interaction between horse age and number of starts more than one year previously was identified and its influence on the main effects was included in the final model. Figure 8-1 represents how the **difference in probability** of HLF varied between the two age groups: 2-6 years and >6 years, across numbers of starts greater than one year previously. It can be observed that the two age groups were only significantly different from each other when the numbers of starts made greater than one year previously were between approximately 20 and 65.

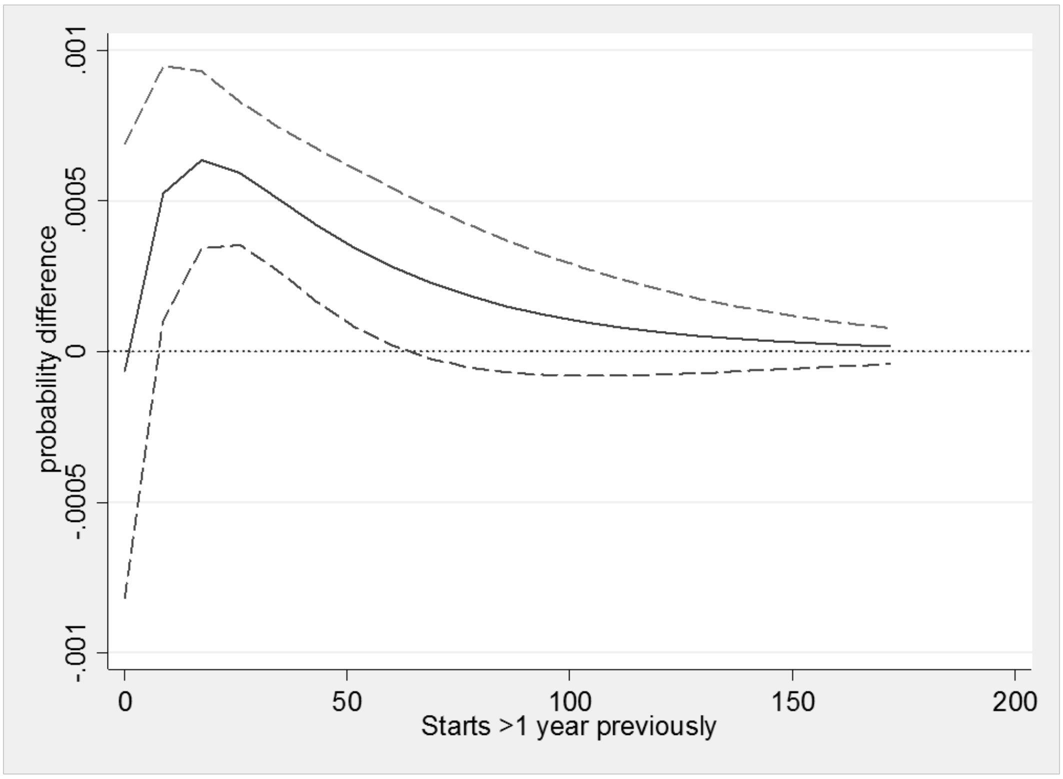


Figure 8-1: Line graph representing the difference in probability of hind limb fracture between the two categories of "age" groups: "2-6 years" and ">6 years", at a number of different "starts greater than one year previously" values. Solid line represents the mean, upper and lower dashed lines represent 95% upper and lower confidence intervals respectively

Table 8-2: Multivariable model showing variables significantly associated with the risk of hind limb fracture in hurdle racing.

Variable	TOTAL (%) n=169668	Cases (%) n=99	Controls (%) n=169569	P-value	Odds Ratio (OR)	95% Confidence Interval
% Of Career on Flat						
0	79466 (46.84)	61 (61.62)	79405 (46.83)	**<0.001**	1 (Ref)	
1 to 50	53916 (31.78)	13 (13.13)	53903 (31.79)	*0.088*	0.57	0.3-1.09
51 to 100	36286 (21.39)	25 (25.25)	36261 (21.38)	*0.008*	2.08	1.21-3.58
Year						
2001	16660 (9.82)	1 (1.01)	16659 (9.82)	**<0.001**	1 (Ref)	
2002 to 2003	34656 (20.43)	30 (30.3)	34626 (20.42)	*0.009*	14.47	1.97-106.12
2004 to 2005	39487 (23.27)	12 (12.12)	39475 (23.28)	*0.118*	5.09	0.66-39.16
2006 to 2009	78865 (46.48)	56 (56.57)	78809 (46.48)	*0.018*	10.92	1.51-78.91
Weight Carried (lbs)				**<0.001**	1.05	1.02-1.08
Age (years)						
2 to 6	109368 (64.46)	56 (56.57)	109312 (64.46)		1 (Ref)	
>6 (7 to 16)	60300 (35.54)	43 (43.43)	60257 (35.54)	*0.869*	0.95	0.52-1.73
Starts >1 year previously				**<0.001**	0.89	0.84-0.94
Interaction						
Age & Starts >1 year previously				*0.001*	1.10	1.04-1.16

Bolded P-values are likelihood ratio test P-values, whilst italicised P-values are Wald test P-values

8.3.3.2 Steeplechase Racing

Variables found to be significantly associated with **increased** likelihood of HLF in steeplechase racing were: being a horse with more than 60% of career starts in flat racing compared to having a lower percentage (OR 14.46, 95% C.I. 3.48-59.9); running in the summer season compared to any of the other seasons (OR 2.54, 95% C.I. 1.5-4.4); having made the first race start in hurdle racing rather than in another type of racing (OR 1.68, 95% C.I. 1.03-2.75).

Variables found to be significantly associated with **decreased** likelihood of HLF in steeplechase racing were: having more than nine runners in a race compared to having fewer (OR 0.64, 95% C.I. 0.41-0.99); and running at a racecourse which held more than 2,222 starts (i.e. was within the top three quartiles of tracks for this variable) during the whole study period (OR 0.6, 95% C.I. 0.38-0.95).

Table 8-3: Multivariable model showing variables significantly associated with the risk of hind limb fracture in steeplechase racing. Horse is included as a random effect.

Variable	TOTAL (%) n=102894	Cases (%) n=90	Controls (%) n=102804	P-value	Odds Ratio (OR)	95% CI
% Previous Career on Flat						
0-60	102529 (99.65)	87 (96.67)	102442 (99.65)		1 (Ref)	
61-100	365 (0.35)	3 (3.33)	362 (0.35)	**0.003**	14.46	3.48-59.9
Summer Season						
No	90739 (88.19)	70 (77.78)	90669 (88.2)		1 (Ref)	
Yes	12155 (11.81)	20 (22.22)	12135 (11.8)	**0.002**	2.54	1.5-4.4
Number of Runners						
1 to 9	52416 (50.94)	56 (62.22)	52360 (50.93)		1 (Ref)	
10 to 40	50478 (49.06)	34 (37.78)	50444 (49.07)	**0.042**	0.64	0.41-0.99
Course Number of St Starts						
1 to 2222	26931 (26.17)	32 (35.56)	26899 (26.17)		1 (Ref)	
2223 to 7766	75963 (73.83)	58 (64.44)	75905 (73.83)	**0.028**	0.6	0.38-0.95
First Race Type						
Flat, St, NHF	49751 (48.35)	36 (40)	49715 (48.36)		1 (Ref)	
Hurdle	53143 (51.65)	54 (60)	53089 (51.64)	**0.039**	1.68	1.03-2.75

Bolded P-values are likelihood ratio test P-values. Key: CI=confidence interval; St=Steeplechase; NHF=national hunt flat.

8.3.4 Assessment of clustering

Residual intraclass correlation coefficients (rho) were estimated for horse, horse dam, horse sire, trainer, jockey, course, race and meet for each model and are shown in Table 8-4. Coefficients and standard errors associated with variables included in the single level multivariable models were altered by less than 10% when any of these random effects were included, except for the odds ratio and standard error for “percentage of previous career on flat” (23% and 47% changes, respectively) and the standard error for summer season (14% change) when horse was included as a random effect in the steeplechase model. As a result horse was retained as a random effect in the steeplechase model.

Table 8-4: Residual intraclass correlation estimates for different variables included in the final multivariable models.

	Horse	Dam	Sire	Trainer	Jockey	Course	Race	Meet
Hurdle	<0.001	<0.001	<0.001	0.09	<0.001	<0.001	<0.001	0.08
Steeplechase	0.57	<0.001	0.06	0.006	<0.001	<0.001	0.24	0.003

8.3.5 Performance of the fixed-effects multivariable models

The final multivariable models were not affected by influential covariate patterns. There were sufficient cases per coefficient to justify the complexity of each model (Bagley et al., 2001). The Hosmer-Lemeshow goodness-of-fit statistic was 14.56 (8 degrees of freedom, P value = 0.07) for the hurdle model and was 6.72 (8 degrees of freedom, P-value = 0.46) for the steeplechase model, indicating no evidence for lack of fit of either model. The area under the ROC curve was 0.75 for the hurdle model and 0.66 for the steeplechase model; indicating moderate predictive ability for both models.

8.4 Discussion

This chapter reports the results of a study with the primary goal of identifying risk factors specific to HLF that occurred during hurdle and steeplechase racing in GB. The numbers of HLF recorded over the nine year study period were fortunately relatively low; meaning that significant risk factor identification becomes more difficult. The study design, using start level data was chosen to facilitate inclusion of horse, race and track as different levels in risk factor analysis. The decision to use all non-case starts as controls was made in attempt to reduce the impact of bias incorporated by control selection, but did result in a large ratio of non-cases to cases, which may have increased the likelihood of Type 1 errors, i.e. concluding that there was a significant relationship when there was not. This should be born in mind when interpreting the results of these analyses.

As noted in studies described in other chapters, the current study is also prone to errors in accuracy of reporting – for example, in the previous chapter it can be seen that diagnosis of fracture of the correct leg occurred in only approximately 82% of cases, whilst correct reporting of all fractured bones in the correct leg occurred in just over 50% of cases. It is also possible that some fractures were undiagnosed until the horse left the racecourse and so are excluded from this study.

The distribution of HLF was similar between the two racing disciplines, with the predominant HLF type being the third metatarsal, followed by tibia/fibula and proximal phalanx in both disciplines. The fatality rate for all three of these fracture types was relatively high, which is of interest considering third metatarsal and proximal phalangeal fractures are frequently repairable surgically. This may be a reflection of the severity of these fractures, the population of horses, the decisions of the racecourse veterinary surgeons or alternatively, of the attitude of the owners/trainers of these particular injured horses to surgical fracture repair.

To facilitate interpretation, the discussion section has been divided into sections for risk factors common to hurdle and steeplechase racing and for those specific to hurdle and steeplechase racing individually.

8.4.1 Risk factors common to hurdle and steeplechase racing

8.4.1.1 Percentage of previous career in flat racing

Increased percentages of previous careers in flat racing (greater than 50% and greater than 60% in hurdle and steeplechase, respectively) were observed to be associated with increased likelihood of HLF. The odds ratio was observed to be much higher for this variable in steeplechase racing than hurdle racing. This might suggest the variable has more importance in steeplechase racing, i.e. horses that have run a lot of races in flat racing might be particularly prone to HLF in steeplechase racing. However the confidence intervals around this were wide, indicating a higher level of uncertainty in this finding. Potential explanations for the association between increased previous career in flat and fatality were discussed in Chapter 4 and include, cumulative pathological bone changes, stage of racing career and type of horse, which could all potentially explain the association with HLF observed in this part of the study.

8.4.2 Risk factors specific to hurdle racing

8.4.2.1 Year

Year was found to be associated with likelihood of HLF in the final multivariable model for hurdle racing. Six of the years in the study were observed to be associated with significantly greater likelihood of HLF than the year 2001. Whilst it is possible that this association was observed because year 2001 had a particularly low number of HLF, years 2004 and 2005 did not differ significantly from that year, which would tend to suggest that this was not the case. An alternative would have been to identify the year with the average number of HLF (from all nine years) and compare all the other years to this, i.e. examine whether these years differed significantly from the average. Because data were collected over a prolonged period, it was considered important that year should be included in the analyses. If, as in this case, likelihood of outcome varied significantly between years it was included as a variable in the final model, so that the effect of year on the other risk factors could be observed. Significant differences between years are also potentially interesting, when considering further investigation of risk factors, because it might be that some factor changed in a particular year that predisposed the outcome, for example a change in regulations, or method to record injuries.

8.4.2.2 Weight carried

Increasing weight carried was found to be associated with increased likelihood of HLF in hurdle racing. A similar association was observed in the study of superficial digital flexor tendinitis. It is possible that the additional weight might result in increased horse fatigue, which in turn might predispose to falling or abnormal limb loading, specifically of the hind limb during take-off. Weight carried is related to horse performance, because additional weights are carried in handicap races by horses deemed to be better. As such, it is possible that horse ability is also related to likelihood of HLF in hurdle races, i.e. better horses are more likely to suffer the injury. However, investigation of ratings (scores based on horse performance) at the uni- and the multi-variable levels failed to identify a significant association with likelihood of HLF.

8.4.2.3 Horse age

Horses older than six years were associated with reduced likelihood of HLF compared to younger horses. It is possible that the association is observed because of the “healthy horse effect”, as discussed in Chapter 5, in that horses that avoid sustaining a HLF in their first years of racing are less prone to subsequently develop such an injury. However multiple previous studies have demonstrated that increasing horse age is a risk factor for musculoskeletal injury (Mohammed et al. 1991; Bailey et al. 1997; Bailey et al. 1998; Estberg et al. 1998; Perkins et al. 2005a). Notably the association between age and likelihood of HLF became non-significant when the interaction term between age and starts greater than one year previously was included in the model, which might tend to suggest that age itself is a less important risk factor for HLF.

8.4.2.4 Starts greater than one year previously

Increased number of starts, greater than one year previously was associated with a decreased likelihood of HLF in the hurdle model. As discussed previously (Chapter 4) and in the preceding paragraph, the reason for this association could be associated with the “healthy horse effect” in that horses without injury (or subclinical injury) are able to run more frequently, over longer careers and are less likely to subsequently fracture their hind limbs during racing.

8.4.2.5 Interaction between horse age and number of starts greater than one year previously

An interaction term between horse age and number of starts is unsurprising, because older horses will have had more time to accumulate a larger number of starts more than one year previously, than younger horses. The largest difference in the probability of HLF occurred between age groups (2-6 years vs >6 years) for starts made in which there had been approximately 20 starts more than one year previously. It is difficult to explain why this difference in probability varies between numbers of starts more than one year previously, but it could potentially be related to the balance between making too many starts (leading to bone overload) and being healthy enough to make some starts (a reflection of the "healthy horse effect").

8.4.3 Risk factors specific to steeplechase racing

8.4.3.1 Season

Starts in the summer season were found to be associated with increased likelihood of HLF compared to starts in other seasons, which could be related to the harder summer ground (if not accounted for fully by the measure of going) and possibly potentiated by increased horse fatigue in hot weather. A similar association with summer season was not observed in the hurdle analyses. Firmness of ground (going) was not found to be significant in either final multivariable model, but has been reported as an important risk factor for limb fracture and fatality in Thoroughbred racing (Parkin et al., 2004a, 2004b, 2004d; Boden et al., 2007a). This lack of association may be associated with the lack of power in the study because of the small number of cases, although it could also be because other risk factors for this outcome are more important.

8.4.3.2 First start type

The finding that horses which had made their first start in a hurdle race were at increased risk of a HLF in steeplechase racing compared to horses that had made their first starts in any of the other race types is difficult to explain. Potentially, this is a reflection of the type of horses that undertake this racing career path prior to ending up in steeplechase racing. It would tend to suggest that horses bred for jump racing are at higher risk of HLF, than horses bred for flat racing, whilst one might intuitively expect the opposite. The finding that increased previous career on flat is also associated with increased HLF risk might suggest that first race type is an important risk factor, as well as the amount of time spent in that race type.

8.4.3.3 Number of runners

Starts in races with more than nine runners were at reduced likelihood of HLF compared to starts made in races with fewer runners. This was similar to the finding in the hurdle superficial digital flexor tendinopathy study (Chapter 5) and could be the result of similar reasons, which include: an unmeasured factor such as the quality of horses in these races, or the speed of the race; as it is plausible that horses in larger fields may be forced to start at a slower speed.

8.4.3.4 Running at a racecourse which held more than 2,222 starts (in the top three quartiles of tracks for this variable) during the study period

As described previously, during the period of this study an attempt was made to account for how busy the racecourses were. In this study starts made on the tracks that were in the top three quarters of busy steeplechase racecourses were at significantly lower likelihood of HLF than starts on less busy courses. This could be the result of differences in the racecourses (such as: the amount of investment in: maintenance / safety measures / quality of steeplechase fences / quality of racing surfaces and availability of new/fresh ground), or be related to differences in the type of horses that run (with differences in quality / jumping ability) at the different racecourses or the type of races that are held at the quieter courses.

8.5 Conclusions

Risk factors for HLF differ between hurdle and steeplechase racing. Similar risk factors to those reported by others for musculoskeletal injury have been recognised as being important. Because of the relatively low number of outcomes it is possible that both Type I and Type II errors occurred in the analysis and further analysis of more cases might be warranted. However, based on the findings of this work it would seem that previous racing history, weight carried and horse age are important risk factors for HLF in hurdle racing; whilst previous racing history, season, number of runners and busyness of racecourse are important risk factors for HLF in steeplechase racing.

Considering the potential differences in aetiology of different HLF, further analysis of risk factors for specific HLF types would be warranted if sufficient cases became available over time.

9 Risk Factors for Pelvis Fractures

9.1 Introduction

Fractures of the pelvis are recognised as a common injury of Thoroughbred racehorses and can be complete or incomplete (i.e. stress fractures). The occurrence of pelvic fractures in racing has been reported from post-mortem studies in California; one study reported that pelvic fractures made up 4% (18/432) of fatal fractures that occurred (Johnson et al., 1994), whilst in another study, of 36 Thoroughbred racehorses that died of unrelated injuries, 28% had concomitant pelvis stress fractures (Haussler and Stover, 1998). It is probable that these different prevalences are related to the denominator used for defining prevalence, as well as differences in the type of fractures, the first study likely reporting complete fractures, as compared to stress fractures in the second study. In a study of fatal injuries in racing in GB between 1987 and 1993, pelvic fractures made up 8.2%, 1.9%, 2.9% and 2.6% of fatal fractures in flat, hurdle, steeplechase and national hunt flat racing, respectively (Mckee, 1995). In a study of national hunt (jump) racing in GB, pelvic fractures occurred with a prevalence of 0.44-0.48 per 1000 starts (Williams et al. 2001). Studies of horses in training in GB have also recognised relatively high frequencies of pelvic fractures. One study of a cohort of horses in race training reported that 15.5% (23/148) of fractures were of the pelvis (Verheyen and Wood, 2004), whilst a similar study of a different cohort of horses in race training in GB recognised pelvic stress fractures as the equal most common fracture type (19/111, 17%) that occurred, along with fractures of the third metacarpal bone (Ely et al., 2009).

A study of risk factors for fatal complete pelvic fractures in racehorses in USA reported female sex, older age and number of lay-ups (rest periods) to be risk factors (Carrier et al., 1998). Whilst a study of risk factors for pelvic stress fractures in racehorses in training in GB reported canter distance, type of exercise surface and trainer to be significant risk factors (Verheyen et al. 2006). Whilst these studies provide potentially useful information about risk factors for pelvic fractures, the study of complete fractures did not use multivariable techniques and the study of horses in training only evaluated a limited number of potential risk factors. No previous studies have performed multivariable analysis of risk factors for pelvic fracture during racing in GB.

The aims of this part of the study were to identify risk factors associated with sustaining a pelvic fracture in Thoroughbred racehorses running in hurdle, steeplechase or national hunt flat races in GB.

9.2 Materials and Methods

Potential risk factors for pelvic fracture in hurdle, steeplechase and national hunt flat starts in GB were assessed using a cohort study. The three race types were analysed together because the likelihood of pelvic fracture did not differ significantly between them, and the number of cases in each race type would not have provided sufficient statistical power. In order to allow inclusion of horse, race and track as different levels in risk factor analysis, the study was conducted at the start level (a “start” being a horse starting a race) and included 86 case starts and 298,209 control starts.

9.2.1 Selection of cases and controls

A case start was defined as a start in a race, subsequent to which the horse was diagnosed with a fracture of the pelvis, whilst still at the racecourse. Cases were identified by racecourse veterinary surgeons based on the findings of physical examination and recorded by attending BHA VOs. Cases recorded as “possible fracture” of the pelvis were not included as cases. Control starts were defined as any start in a race, which did not result in the subsequent diagnosis of a fracture of the pelvis, whilst still at the racecourse.

9.2.2 Risk factors

A total of 122 variables for each start (32 horse-related variables, 50 prior racing history-related variables, 25 race related variables, 5 trainer-related variables, 5 jockey-related variables and 5 track-related variables) were available for analysis.

9.2.3 Power of the study

The study had at least 80% power to identify odds ratios of 2 or more, with 95% confidence, when the prevalence of exposure in the control population was between 21% and 60%.

9.3 Results

Details of the numbers of starts, horses, jockeys, trainers, racecourses, races, race meets and race dates in each race type analysed in the study are shown in Chapter 2.

For the nine years between 2001 and 2009 there were 43, 35 and 8 recorded cases of pelvic fracture in hurdle, steeplechase and national hunt flat racing, respectively. The incidence rates of pelvic fracture were:

- 0.25/1000 starts in hurdle racing
- 0.34/1000 starts in steeplechase racing
- 0.31/1000 starts in national hunt flat racing

9.3.1 Univariable analysis

Of the 122 variables screened at the univariable level, 35 were taken forward for consideration in each of the multivariable manual forward stepwise analyses. Details of these variables are shown in Appendix 6.

9.3.2 Multivariable analysis

In the final multivariable model, nine variables were found to be significantly associated with pelvic fracture (Table 9-1).

Variables found to be significantly associated with **increased** likelihood of pelvic fracture were: being a horse with more than 75% of previous career starts in flat racing compared to having a lower percentage (OR 6.03, 95% C.I. 3.06-11.87); starts in the winter or spring compared to those in the summer or autumn (OR 2.03, 95% C.I. 1.2-3.41); race distances of more than 4.4km compared to shorter racing distances (OR 2.05, 95% C.I. 1.29-3.28); races held in the middle of the run sequence compared to those held early or late in the sequence (OR 1.93, 95% C.I. 1.24-2.99); starts made under trainers with greater than 36% of their starts resulting in a placed (1^{st}-3^{rd} place) finish compared to trainers with lower percentages of placed finishes (OR 1.81, 95% C.I. 1.14-2.86); and increased number of runners in the race (OR 1.05, 95% C.I. 1.01-1.1).

Variables found to be significantly associated with **decreased** likelihood of pelvic fracture were: starts made under jockeys with any first place finishes in the study period compared to starts made under jockeys with no first place finishes (OR 0.31, 95% C.I. 0.12-0.79);

having made any starts in the previous three months compared to having made none (OR 0.54, 95% C.I. 0.35-0.85); and increased number of starts greater than one year previously.

Table 9-1: Multivariable model showing variables significantly associated with the risk of pelvic fracture.

Variables	TOTAL (%) n=298295	Cases (%) n=86	Controls (%) n=298209	**P-value**	Odds Ratio (OR)	95% CI
% Career on Flat						
0 to 75	285522 (95.72)	75 (87.21)	285447 (95.72)		1 (Ref)	
>75	12773 (4.28)	11 (12.79)	12762 (4.28)	**<0.001**	6.03	3.06-11.87
Season						
Summer and Autumn	111087 (37.24)	19 (22.09)	111068 (37.25)		1 (Ref)	
Winter and Spring	187208 (62.76)	67 (77.91)	187141 (62.75)	**0.005**	2.03	1.2-3.41
Race Distance (km)						
2.4 to 4.4	231090 (77.47)	56 (65.12)	231034 (77.47)		1 (Ref)	
>4.4	67205 (22.53)	30 (34.88)	67175 (22.53)	**0.004**	2.05	1.29-3.28
Race Position in run sequence						
Early or Late	213909 (71.71)	51 (59.3)	213858 (71.71)		1 (Ref)	
Middle	84386 (28.29)	35 (40.7)	84351 (28.29)	**0.004**	1.93	1.24-2.99
Jockey % of finishes in 1st place						
None	4683 (1.57)	5 (5.81)	4678 (1.57)		1 (Ref)	
Any	293612 (98.43)	81 (94.19)	293531 (98.43)	**0.035**	0.31	0.12-0.79
Trainer % of finishes in 1-3						
0 to 36	234422 (78.59)	58 (67.44)	234364 (78.59)		1 (Ref)	
>36	63873 (21.41)	28 (32.56)	63845 (21.41)	**0.015**	1.81	1.14-2.86
Starts in previous 3 months						
None	75952 (25.46)	32 (37.21)	75920 (25.46)		1 (Ref)	
Greater than none	222343 (74.54)	54 (62.79)	222289 (74.54)	**0.01**	0.54	0.35-0.85
Number of starts >1 year previously				**0.005**		
0 to 5	82948 (27.81)	35 (40.7)	82913 (27.8)		1 (Ref)	
6 to 12	73729 (24.72)	15 (17.44)	73714 (24.72)	*0.007*	0.43	0.23-0.79
13 to 23	69671 (23.36)	21 (24.42)	69650 (23.36)	*0.058*	0.59	0.34-1.02
24 to 172	71947 (24.12)	15 (17.44)	71932 (24.12)	*0.002*	0.38	0.2-0.7
Number of runners in race				**0.03**	1.05	1.01-1.1

Bolded P-values are likelihood ratio test P-values, whilst italicised P-values are Wald test P-values

9.3.3 Assessment of clustering

Residual intraclass correlation coefficients (rho) were estimated for horse, horse dam, horse sire, trainer, jockey, course, race and meet for each model and are shown in Table 9-2. Coefficients and standard errors associated with variables included in the single level multivariable models were altered by less than 1% when any of these random effects were included. None of the higher levels were included as random effects in the final multivariable model.

Table 9-2: Residual intraclass correlation estimates for different variables included in the final multivariable model.

Variable	Horse	Dam	Sire	Trainer	Jockey	Course	Race	Meet
	0.004	<0.001	0.04	<0.001	<0.001	<0.001	<0.001	0.14

9.3.4 Performance of the fixed-effects multivariable models

The final multivariable models were not affected by influential covariate patterns. There were sufficient cases per coefficient to justify the complexity of each model (Bagley et al., 2001). The Hosmer-Lemeshow goodness-of-fit statistic was 7.77 (8 degrees of freedom, P value = 0.46) indicating no evidence for lack of fit for the model and the area under the ROC curve was 0.74, indicating moderate predictive ability.

9.4 Discussion

This chapter reports the results of a study with the primary goal of identifying risk factors specific for pelvic fractures that occurred as a result of hurdle, steeplechase and national hunt flat racing in GB. The numbers of pelvic fractures recorded over the nine year study period were fortunately relatively low. However, this means that significant risk factor identification becomes more difficult. The study design, using start level data was chosen to facilitate inclusion of horse, race and track as different levels in risk factor analysis. The decision to use all non-case starts as controls was made in attempt to reduce the impact of bias incorporated by control selection, but did result in a large ratio of non-cases to cases, which may have increased the likelihood of Type 1 errors, i.e. concluding that there was a significant relationship when there wasn't. This should be borne in mind when interpreting the results of these analyses.

As noted in studies reported in the other chapters, the current study is also prone to errors in accuracy of reporting – for example, in Chapter 7 it was shown that diagnosis of the correct leg occurred in only approximately 82% of cases. Pelvic fractures (especially incomplete ones) can be difficult to clinically diagnose at the racecourse, without the aid of ultrasound or other imaging modalities, and so it is possible (even likely) that some of the racecourse clinical diagnoses were incorrect and that some pelvic fractures were missed or undiagnosed until the horses left the racecourse. The relatively high fatality rate associated with the pelvic fractures in this study 64% (55/86), provides some idea of the severity of the recorded fractures, potentially indicating that these fractures were complete; because horses are more likely to die from complete pelvic fractures and euthanasia is more likely to be performed when a confident diagnosis has been made (diagnosis is normally more straightforward when crepitus can be palpated with a complete fracture).

The recording system allowed recording of "possible pelvic fractures", which were excluded from this analysis to try and improve the reliability of the diagnoses, however by including the cases of "possible pelvic fractures" as controls (n=52), it is possible that the associations between the risk factors and the outcome may have been affected. It was considered that the low number of "possible" fracture cases would be very unlikely to have a major impact, but it was considered prudent to consider this factor. Because if "possible fractures" were actual fractures carrying the same risk factors, then including them as controls would have been likely to reduce the strength of the observed relationships between risk factors and outcome. To evaluate this, the final multivariable model was re-run excluding “possible pelvic fractures” from the control population (results are shown in Appendix 8). When this was done, the odds ratios and standard errors for all variables changed by less than 0.03% and remained significant, indicating that these “possible fracture” cases had very little effect on the final model.

The decision to combine all three race types (hurdle, steeplechase and national hunt flat) in the analysis of pelvic fractures was based on the fact that the likelihood of pelvic fracture did not differ significantly between them. This approach was also preferred because the number of pelvic fractures recorded during the study period was relatively low (n=86). Following completion of the final multivariable model, the effect of including “race type” to the model was examined. This resulted in changes in odds ratios and standard errors by less than 20% and all variables remained significant, as a result “race-type” was left out of the final model, as it was not a significant risk factor in its own right, possibly because of the small number of cases in each race type.

9.4.1 Risk Factors for Pelvic Fracture

9.4.1.1 Percentage of previous career in flat racing

A horse having greater than 75% of previous career starts in flat racing was found to be associated with increased likelihood of pelvic fracture. Potential explanations for the association between increased previous career in flat and fatality were discussed in Chapters 4 and 8 and include, cumulative pathological changes, stage of racing career and type of horse, which could all potentially explain the association with pelvic fracture observed in this part of the study.

9.4.1.2 Season

Starts in the winter and spring were found to be associated with increased likelihood of pelvic fracture compared to starts in summer or autumn. This could be the result of differences in ground conditions, or between types of races or horses that undertake races in those seasons. This finding differs from those in the steeplechase hind limb fracture risk factor model (Chapter 8) which found the summer season to be associated with increased likelihood of fracture. The reason for this difference in findings is unknown, but suggests that there is a difference in aetiology of the different fracture types and highlights the need to perform risk factor analysis separately for different types of injury (when sufficient case numbers are available).

9.4.1.3 Race distance

Race distances of more than 4.4km were associated with an increased likelihood of pelvic fractures compared to shorter races. This could be because horses spend longer time at risk in longer races, or because longer races result in increased horse fatigue. It is also possible that longer races are associated with specific race types that carry increased risk of injury for another reason such as more demanding fences (such as in the Grand National). Increased race distance was observed as a risk factor for tendon injury in Chapter 5 and previous studies have also identified an association between increased race distance and risk of injury (Takahashi et al., 2004; Parkin et al., 2009) and are discussed in Chapter 5.

9.4.1.4 Race position in run sequence

Starts made in the middle of the run sequence had a higher likelihood of pelvic fracture than those early or late in the sequence. The reason for this finding is unclear, although it could be related to an unmeasured track related variable. Alternatively, this could be related to the class of horses, with potentially different quality horses running at different stages of the race card. Associations between the likelihood of tendon injury and epistaxis with position in run sequence were also recognised (reported in Chapters 5 and 6), which suggests that this variable might be worthy of additional investigation.

9.4.1.5 Percentage of Jockey finishes in 1st place

Starts made under jockeys that had had at least one win over the 10 year study period were found to be associated with a decreased likelihood of pelvic fracture than starts made by jockeys that had never won a race. This suggests that horses ridden by less successful and or less experienced jockeys are more likely to sustain a pelvic fracture. An explanation for this might be that inexperienced jockeys are less able to identify when a horse should be pulled up because of lameness, as previously suggested (Parkin et al., 2004b), but could equally be related to the type of horses ridden or races ridden in (i.e. likely lower quality) by less experienced jockeys. Notably, the percentage of starts made under jockeys that had not previously won a race was very low (1.57% of all starts), so manipulation of this risk factor would likely have very little impact on the overall incidence of pelvic fractures.

9.4.1.6 Percentage of trainer finishes in first to third place

Starts made by horses trained by trainers that had more than 36% of their starts resulting in a placed (1st-3rd) finish were found to be associated with an increased likelihood of pelvic fracture than starts made by trainers with a lower percentage of places. This suggests that starts made under more successful trainers were more likely to result in pelvic fracture. Trainer success was also recognised to be associated with likelihood of fatality and tendon injury in the hurdle models (Chapters 4 and 5). Similar reasons could be proposed for the association observed here, with differences in the training regimens, or in the quality or health of the horses trained at different training yards. There appears to be a three way relationship between training hard, success in racing and risk of injury; such that you need to train horses hard for them to be successful, but this is associated with increased risk of injury. This is an area that needs careful discussion with trainers, particularly because the balance is very likely to vary between animals.

9.4.1.7 Starts in the previous three months

Starts made by horses that had made any starts in the preceding three months were at reduced likelihood of pelvic fracture than starts made by horses which had not run in that time period. Starts more than three months after the previous start are likely to be: at the beginning of a new season (which could be a risk factor for pelvic fracture) or, subsequent to a period of rest following injury, which could potentially have been related to underlying pelvic pathology, or alternatively to limb pathology, which placed greater compensatory strain on the pelvis.

9.4.1.8 Starts greater than one year previously

The relationship between number of starts more than one year previously and the likelihood of pelvic fracture was not linear, but there was a general trend for increased number of starts to be associated with a decreased likelihood of pelvic fracture. As discussed previously (Chapters 4 and 8), the reason for this association could be associated with the “healthy horse effect” in that horses without injury (or subclinical injury) are able to run more frequently, over longer careers and are less likely to subsequently fracture their hind limbs during racing.

9.4.1.9 Number of runners

Increased numbers of runners was associated with increased likelihood of pelvic fracture. Potential reasons for this include increased likelihood of falling with increased runners, or this could be related to the types of races or the horses involved in races with increased numbers of runners (in general, increased field sizes are normally observed in higher value/better races). It is interesting that converse associations with numbers of runners were made in the steeplechase hind limb fracture model (Chapter 8) and the hurdle tendon study, in which increased numbers of runners were associated with decreased likelihood of injury. Once again the reason for this difference is unknown, although notably the strength of the association is not large, with an odds ratio of 1.05 per extra runner and a lower 95% confidence interval that was very close to one. It is difficult to make recommendations to reduce the number of runners, as although it may appear to reduce the risk of pelvic fractures, it has the potential to increase the risk of another deleterious outcome. However, it is plausible that reducing the number of runners will result in alterations to the speed of the race for example, which could have knock-on effects for the risk of different injuries.

9.5 Conclusions

A number of different risk factors for pelvic fracture were identified in this study. As mentioned in the previous chapter, the relatively low number of outcomes makes the work more prone to the effects of Type I and II errors and this study may benefit from further analysis of more cases. Significant risk factors were identified. However, manipulation of these risk factors is likely to be challenging, especially considering the low incidence rate of the outcome.

Further evaluation of the reason for the associations with season, race distance and position in run sequence might be warranted, but are currently hard to base recommendations on, because of converse findings for other more common injury types. Using the information relating to jockey and trainer success, would be particularly difficult, as based on these findings - less successful trainers and more successful jockeys carry the lower risk of pelvic fractures; but it would not be possible to dictate which jockeys and trainers are permitted to continue to take part in racing. Manipulation of horses' previous run histories is also not possible. It is likely that the most beneficial use for the risk factors identified will be to identify / predict which horses are at increased risk of pelvic fracture, such that trainers and veterinarians can identify animals that fit some of the high risk categories and then try to avoid entering them into races that predispose to this disorder. For example it might be prudent not to enter horses that had high risk previous run histories (e.g. not having run in the preceding 3 months or more than one year ago and having a high percentage of previous starts on the flat) into high risk races (e.g. long race distances, in the middle of the run sequence, with lots of other runners). This approach to using the identified risk factors is discussed further in Chapter 11

10 Risk Factors for Proximal Forelimb Fractures

10.1 Introduction

Fractures of the equine forelimb proximal to the carpus frequently result in fatality. These fractures, although not as commonly sustained as fractures to the distal forelimb, do occur in Thoroughbred horses during racing. Investigation of risk factors for this type of injury could result in a reduction in the number of racehorse fatalities.

Previous studies have recognised the importance of proximal forelimb (PF) fractures. A study of fatal musculoskeletal injuries of horses racing in GB between 1990 and 1999 reported that upper limb injuries made up 19%, 18% and 27% of those sustained during flat, hurdle and steeplechase racing, respectively (Wood et al., 2000). A study of PM findings from racetrack fatalities in California between 1991 and 2006, reported that humeral and scapular fractures made up 9% and 2% of the fatal musculoskeletal injuries sustained by Thoroughbreds respectively (Stover and Murray, 2008). A study of injuries sustained whilst racing in GB between 1996 and 1998 reported a marked difference in prevalence of PF fractures between racing disciplines: flat racing 0.14/1000 starts; hurdle racing 0.75/1000 starts; steeplechase racing 1.84/1000 starts (Williams et al. 2001), suggesting that jump racing, steeplechase in particular, carries an increased risk for PF fracture.

Risk factors for scapular fractures in Thoroughbred horses have been identified in Californian studies as: horse age (2 or ≥5 years), sex (male), limb distribution (right forelimb), race type (maiden claiming races), fewer career races and shorter race distances (Vallance et al., 2011). Risk factors for humeral fractures during racing and training have been identified in a further Californian study as: horse age (3 years old), sex (male) and return to exercise from a period of rest (especially within 10 to 21 days) (Carrier et al., 1998). Whilst the findings from these studies help to identify possible associations, both studies were conducted in flat racing and neither study used multivariable analyses to help determine the significance of the risk factors in relation to others. No previous examination for risk factors associated with radius or ulna fractures in Thoroughbred racehorses appear to have been performed. Whilst prevalence studies have been performed in GB, no examinations of risk factors for PF fracture have been carried out for any racing discipline in GB.

The aim of this study was to identify risk factors for PF fracture in Thoroughbred Racehorses running in hurdle and steeplechase races in GB. Because the majority of PF fractures occur as a result of the same instigating factors (external trauma) and because there were relatively few fractures of individual PF bones, it was decided to examine all PF bone fractures together. Because previous research identified differences in the prevalence of PF fracture between the types of jump racing (Williams et al. 2001) the two disciplines were considered separately in this study.

10.2 Materials and Methods

Potential risk factors for PF fracture in hurdle and steeplechase starts in GB were assessed using cohort studies. In order to allow inclusion of horse, race and track as different levels in risk factor analysis, the study was conducted at the level of race start (a "start" being a horse starting a race) and included 97 cases from 169,668 starts in hurdle racing and 122 cases from 102,894 starts in steeplechase racing.

10.2.1 Selection of cases and controls

A case start was defined as a start in a race, subsequent to which the horse was diagnosed with a fracture of a fore limb proximal to the carpus, whilst still at the racecourse. Cases were identified by racecourse veterinary surgeons based on the findings of physical examination and recorded by attending veterinary officers. Control starts were defined as any start in a race, which did not result in the subsequent diagnosis of a PF fracture, whilst the horse was still at the racecourse.

10.2.2 Risk factors

A total of 122 variables for each start (32 horse-related variables, 50 prior racing history-related variables, 25 race related variables, 5 trainer-related variables, 5 jockey-related variables and 5 track-related variables) were available for analysis.

10.2.3 Power of the study

Both studies had reasonable power (steeplechase higher than hurdle): at least 80% power to identify odds ratios of 2 or more, with 95% confidence, when the prevalence of exposure in the control population was between 17% and 66% (hurdle racing) or 12% and 74% (steeplechase racing).

10.3 Results

Details of the numbers of starts, horses, jockeys, trainers, racecourses, races, race meets and race dates in each race type analysed in the study are shown in Chapter 2.

For the nine years between 2001 and 2009 there were 97 and 122 recorded cases of PF fractures in hurdle and steeplechase racing, respectively. Over the study period the incidence rates of PF fracture were:

- 0.57/1000 starts in hurdle racing
- 1.19/1000 starts in steeplechase racing.

Details of specific fracture sites and outcomes are shown in Table 10-1. The majority (88%-100%) of PF fractures in both hurdle and steeplechase racing resulted in fatality/euthanasia at the racecourse. A higher proportion of humeral fractures were observed in steeplechase than hurdle racing, whilst there were similar numbers of fractures of the scapula, humerus and radius/ulna.

Table 10-1: Details of fracture sites and outcomes for cases in the study

	Hurdle		**Steeplechase**	
Fracture Site	Number (%)	NF (%)	Number (%)	NF (%)
Scapula	**34** (35)	2 (6)	**33** (27)	4 (12)
Humerus	**31** (32)	1 (3)	**54** (44)	0
Radius/Ulna	**32** (33)	1 (3)	**35** (29)	2 (6)

Key: NF = non-fatal at racecourse.

10.3.1 Univariable analysis

Univariable analysis

Of the 122 variables screened at the univariable level, 35 were taken forward for consideration in each of the multivariable manual forward stepwise analyses. Details of these variables are shown in Appendix 6.

10.3.2 Multivariable analysis

In the final multivariable models, five and four variables were found to be significantly associated with PF fracture in hurdle and steeplechase racing, respectively (Tables 10-2 and 10-3).

10.3.2.1 Hurdle Racing

Variables found to be significantly associated with increased likelihood of PF fracture in hurdle racing were: running on going firmer than “good” compared to running on softer going (OR 2.46, 95% C.I. 1.64-3.68); increasing percentage of previous race starts on the flat (OR 1.02, 95% C.I. 1.02-1.03); male sex compared to female (OR 2.09, 95% C.I. 1.08-4.04); increasing number of months since horse’s previous start (OR per extra month 1.045 (95% C.I. 1.08-1.07); and horse career length of greater than four years compared to shorter (OR 1.6, 95% C.I. 1.02-2.49).

Table 10-2: Multivariable model showing variables significantly associated with the risk of proximal forelimb fracture in hurdle racing.

	Total n=169668	Cases (%) n=97	Controls (%) n=169571	P-value	Odds Ratio	95% Confidence Interval
Going						
Heavy to Good	134375	56 (58)	134319 (79)	1 (Ref)		
GTF - Firm	35293	41 (42)	35252 (21)	**<0.001**	2.46	1.64-3.68
% Career flat				**<0.001**	1.02	1.02-1.03
Sex						
Female	35908	10 (10)	35898 (21)	1 (Ref)		
Male	133760	87 (90)	133673 (79)	**0.017**	2.09	1.08-4.04
Months since previous start				**0.005**	1.045	1.02-1.07
Horse's racing career length (years)						
0 to 4	143744	68 (70)	143676 (85)	1 (Ref)		
5 to 13	25924	29 (30)	25895 (15)	**0.047**	1.6	1.02-2.49

Bold P-values are likelihood ratio test P-values; Ref = Reference; “GTF” = Good to Firm.

10.3.2.2 Steeplechase Racing

Variables found to be significantly associated with **increased** odds of PF fracture in steeplechase racing were: running in a novice race compared to any other type of steeplechase race (OR 1.76, 95% C.I. 1.22-2.53); being ridden by an amateur rather than a professional jockey (OR 1.81, 95% C.I. 1.16-2.83); and being a horse with more than 38% of previous race starts in flat racing (OR 2.12, 95% C.I. 1.26-3.56).

The only variable found to be significantly associated with **decreased** odds of PF fracture in steeplechase racing was: horse having had between one and six starts in the previous nine to 12 months compared to having had none (OR 0.63, 95% C.I. 0.44-0.91).

Table 10-3: Multivariable model showing variables significantly associated with the risk of proximal forelimb fracture in steeplechase racing.

	Total n=102894	Cases (%) n=122	Controls (%) n=102772	P-value	Odds Ratio	95% C.I.
Novice race						
No	67214	62 (51)	62 (65)	1 (Ref)		
Yes	35680	60 (49)	60 (35)	**0.003**	1.76	1.22-2.53
Amateur jockey						
No	89528	97 (80)	97 (87)	1 (Ref)		
Yes	13366	25 (20)	25 (13)	**0.014**	1.81	1.16-2.83
% Career flat						
0 to 38	96107	105 (86)	105 (93)	1 (Ref)		
39 to 100	6787	17 (14)	17 (7)	**0.009**	2.12	1.26-3.56
Horses' number of starts in previous 10 to 12 months				**0.043**		
0	43666	68 (56)	68 (42)	1 (Ref)		
1 to 6	58467	53 (43)	53 (57)	*0.012*	0.63	0.44-0.91
7 to 16	761	1 (1)	1 (1)	*0.876*	0.85	0.12-6.19

Bolded P-values are likelihood ratio test P-values, whilst italicised P-values are Wald test P-values.

C.I.=confidence interval; Ref = Reference.

10.3.3 Assessment of clustering

Residual intraclass correlation coefficients (rho) were estimated for horse, horse dam, horse sire, trainer, jockey, course, race and meet for each model and are shown in Table 10-4. Coefficients and standard errors associated with variables included in both single level multivariable models were altered by less than 2% when any of these random effects were included, therefore none were included as random effects.

Table 10-4: Residual intra-class correlation estimates for different variables included in the final multivariable model.

	Horse	Dam	Sire	Trainer	Jockey	Course	Race	Meet
Hurdle	0.024	<0.001	<0.001	0.02	0.01	0.002	<0.001	<0.001
Steeplechase	0.06	<0.001	0.05	<0.001	<0.001	0.01	0.08	0.2

10.3.4 Performance of the fixed-effects multivariable models

The final multivariable models were not affected by influential covariate patterns. There were sufficient cases per coefficient to justify the complexity of the model (Bagley et al., 2001). The Hosmer-Lemeshow goodness-of-fit statistic was 3.45 (8 degrees of freedom, P value = 0.90) for the hurdle model and 1.11 (8 degrees of freedom, P value = 0.95) for the steeplechase model, indicating no evidence for lack of fit of either model. The area under the ROC curve was 0.77 for the hurdle model and 0.64 for the steeplechase model, indicating moderate and fair predictive ability, respectively.

10.4 Discussion

This chapter reports the results of a study with the primary goal of identifying risk factors for PF fracture sustained during the major types of jump racing in GB. The analysis benefits from access to a large study population, but is limited by the reliance on diagnosis of PF fracture at the racecourse, which having been based on physical examination only, may have resulted in some inaccuracies in fracture localisation and even in diagnosis of fracture. The grouping of radius and ulna fractures as a distinct diagnosis highlights this inaccuracy; as fractures of these two different bones usually carry very different long term prognoses – poor and good, respectively. The decision to group all PF fractures together because of assumed similar aetiology and also because of low numbers of individual fracture types has the limitation of making the assumption that these fractures were associated with similar risk factors, which previous work does not necessarily support (Carrier et al., 1998; Vallance et al., 2012).

The incidence rate of PF fracture observed in this study was lower in both disciplines than the prevalence reported by a previous study performed in GB (Williams et al. 2001). This reduced incidence rate could be the result of improved safety in jump racing, or alternatively could be the result of an anomalous increase in cases during the two years evaluated in the previous study. No significant differences in the likelihood of PF fracture were observed between the years evaluated in this study.

10.4.1 Risk factors common to hurdle and steeplechase racing

10.4.1.1 Percentage of previous career in flat racing

The percentage of a horse’s previous starts that had been on the flat was found to be significant in both final multivariable models. Whilst the format of the variable differed between racing disciplines (continuous in hurdle and categorical in steeplechase), it was observed in both models that larger percentages of career spent on the flat were associated with increased likelihood of PF fracture. This result may indicate that horses bred for flat racing, which subsequently race over fences, are more prone to PF fracture than horses bred specifically for jumping. Alternatively, to have a high percentage of career flat starts, horses would be likely to be near the beginning of their jump racing careers, so this may be a proxy measure of being early in their jump career. However, this association does not appear to be straightforward because other variables used to examine this relationship such as: first jump race; first race of that type; and race of different type to the previous race, were not found to be significant in either model.

10.4.1.2 Starts in previous time periods

Previous racing history was found to be associated with the likelihood of PF fracture in both racing disciplines. In hurdle racing, increasing number of months since a horse's previous start was associated with increased likelihood of sustaining a PF fracture, whilst in steeplechase racing horses which had raced between one and six times in the previous 10 to 12 months demonstrated a decreased likelihood of PF fracture than those which had not raced at all over the same period. Increased time between races could be horse related (e.g. enforced rest because of a medical problem) or season related (e.g. the time in between jump racing seasons) and it is plausible that the increased likelihood of PF fracture occurs as a result of either of these factors. Horses are rested when suffering from injuries or lameness and it is possible that when they are returned to racing they are at increased risk of injury. It is also possible that rest from racing between jump seasons adversely affects musculoskeletal physiology, (such as alterations to bone density as a result of a change in the balance of osteoclast and osteoblast activity), making horses more prone to fractures on return to racing or that horses take a while to regain race fitness/experience. It is also possible that a feature of the races early in the jump racing season carry an increased risk for PF fracture, although season was not found to be significantly associated with the likelihood of PF fracture in either jump discipline.

10.4.2 Risk factors specific to hurdle racing

10.4.2.1 Going

In the hurdle model running on ground with going classed as firmer than "good" compared to running on softer going was associated with an increased risk of sustaining a PF fracture. Associations between increased track firmness and other musculoskeletal injuries, such as fractures and tendinopathy, have been made in a number of studies (Parkin et al., 2004a; Henley et al., 2006; Boden et al., 2007a) and in the study reported in Chapter 5 of this thesis. This association has been hypothesised to be the result of the increased racing speed and reduced shock absorbance caused by firm ground. Unfortunately reliable race speed data were not available for starts made between 2000 and 2004 and as such was not included in the analyses.

10.4.2.2 Career length

Horses with a racing career length of more than four years were at increased risk of sustaining a PF fracture in hurdle racing compared to those with shorter career lengths. This could be related to "time at risk", with horses racing for longer periods being at increased risk of sustaining a fracture, or potentially related to increased cumulative skeletal pathological changes over a longer career. It might be reasonable to suggest that horse age could explain the observed association. However, although there was a trend for increasing age being associated with increasing likelihood of PF fracture, this was not found to be statistically significant in either univariable or multivariable analyses.

10.4.2.3 Sex

Male horses were found to have an increased likelihood of suffering PF fractures than female horses. Previous research in California has also reported that male horses are at increased risk of sustaining scapular and humeral fractures (Carrier et al. 1998; Vallance et al. 2011), whilst others have reported the same association with other fatal fractures in racing Thoroughbreds (Estberg et al. 1996; Estberg et al. 1998; Hernandez et al. 2001; Boden et al. 2007a). These differences in outcomes between sexes, might be related to: increased willingness of owners to try and salvage female horses for breeding (Perkins et al., 2005b), which they could not do for castrated males; males having more protracted racing careers (Bailey et al., 1999); or because of the effect of sex hormones on bone density, body weight and equine behaviour (Boden et al., 2007a). It is plausible that all of these explanations have some influence on the observed result.

10.4.3 Risk factors specific to steeplechase racing

10.4.3.1 Novice races

Horses running in novice steeplechase races were observed to have increased likelihood of suffering a PF fracture than horses running in any other type of steeplechase race. Novice races are for horses that start the season having not previously won a steeplechase race. It is possible therefore that the increased likelihood of PF fracture in these races is related to the reduced ability of many of the horses that run in this type of race, or an underlying injury that has prevented these horses from winning previously. It is also possible that the association is related to the fact that these horses are likely to be in the early part of their steeplechase careers. Interestingly, an association between maiden claiming races and increased likelihood of scapular fractures has been observed by others (Vallance et al., 2011).

10.4.3.2 Amateur jockeys

Horses ridden in steeplechase races by amateur jockeys had increased likelihood of PF fracture than those ridden by professional jockeys. This could be related to jockey ability and/or experience, if less experienced jockeys have increased numbers of falls or collisions. Alternatively it could be because amateur jockeys are more likely to ride the less talented / experienced horses, which may be more prone to injury, or that they are less able to recognise when a horse has sustained an injury causing lameness.

10.5 Conclusions

Multiple associations have been identified for the development of PF fractures, which differ between racing disciplines. Not all of these associations can be readily explained by the data currently available, but these new findings will hopefully help improve our understanding of the aetiology of PF fractures sustained during racing. This information should also be helpful in reviewing current regulations and racecourse management techniques for NH racing in GB. Further research investigating weather conditions and unmeasured racecourse management factors (such as position of running rails, frequency and volume of course watering and dates of fence movements) at racecourses is currently underway. The importance of previous training histories, genetics and medical histories may also be worth investigating in future investigation of PF fractures.

11 Model Validation

11.1 Introduction

In addition to providing information about important risk factors for disease, multivariable models can also be used to help form accurate prognoses for the likelihood of an outcome. They are most frequently used in human medicine to help provide prognoses for outcomes of disease, or to predict the likelihood of diseases such as heart disease or cancer. Three consecutive phases in applying multivariable prognostic research have been defined (Moons et al., 2009):

1. Development – in which multivariable prognostic models are produced and refined.
2. Validation – in which the predictive performance of the developed multivariable model is tested on a new set of data.
3. Impact – in which the effects of using a model are assessed, for example: did the frequency of outcome decrease as a result of applying the model?

The main ways to validate the performance of prognostic model on an alternate data set have been defined as: "calibration" in which the observed and predicted event rates are compared between groups of patients; and "discrimination" in which the model's ability to distinguish between patients who do or do not experience the event of interest is assessed (Altman et al., 2009). The data used to validate a model is important, as validation based on the same data as the one used to produce the model will clearly result in overly optimistic results. Approaches to selecting data for validation include: "Internal", in which the data available for model production is subdivided into a model production and model validation group; "Temporal", in which a new data set is acquired from a different time period (normally more recent and hence prospective data); and "External", in which data is collected from a different population (for example, another country).

This chapter reports on the methods and results of applying validation techniques (phase 2) to some of the multivariable models developed (phase 1) in the preceding chapters. A set of data were available from jump racing in GB from a year (2010) subsequent to those used to produce the models and as such the validation techniques selected in this study would be classified as "Temporal". Notably, "External" validation would be particularly difficult as application of the models to other populations of racehorses (i.e. in other countries) is unlikely to be a useful means of predicting outcome due to the variability between racing populations, race types and environments. Specifically with respect to the unique nature of jump racing in GB, data from Ireland (and perhaps France) would be comparable.

11.2 Overview of approach to validation

Data were available for all jump races that took place in the year 2010, such that all previously examined risk factors could be analysed in that year. In order to attempt to validate the risk factors identified from the 2001 to 2009 data, two approaches were taken:

1. To assess whether identified risk factors were also significant in the 2010 data set, multivariable models using the risk factors identified from the 2001 to 2009 data were developed using the 2010 data.
2. The covariate patterns identified as being associated with the highest probability of outcome from the 2001-2009 data were identified. The frequency of outcome associated with these covariate patterns were then evaluated in the 2010 data set.

These approaches were taken for the outcomes: fatality, superficial digital flexor (SDF) tendinopathy and epistaxis only, because the number of cases identified in one year (2010) was considered likely to be too low to allow meaningful comparison for the other outcomes evaluated in the study.

11.3 Part 1: Evaluating 2001-2009 identified risk factors in the 2010 data

11.3.1 Methods

Variables in the 2010 data were categorised to match the variables in the 2001-2009 models, for example: if season had been categorised as summer compared to all other seasons for one of the models, this same categorisation was performed on the 2010 data. Having done this, multivariable logistic regression models were run for each outcome, using the "logistic" command in Stata12. The risk factor "year" could not be included in the analysis of the 2010 data. If random effects had been included in the final 2001-2009 models, these were also included in the 2010 models.

Following model production, post-hoc analysis using the Hosmer-Lemeshow goodness-of-fit test ("estat gof, group(10)table" command in Stata12) was performed. Receiver operator curves were also produced ("lroc" command in Stata12) to generate a *c* index as a measure of model discrimination.

11.3.2 Results of multivariable models with 2010 data

The results of multivariable logistic regression analysis performed on the 2010 data set using the models for fatality, superficial digital flexor (SDF) tendinopathy and epistaxis in hurdle and steeplechase racing developed from the 2001-2009 data are shown in Tables 11-1 through 11-6, respectively, alongside the results from the 2001 to 2009 data.

Results of the Hosmer-Lemeshow goodness-of-fit tests and receiver operator curves for all models are shown in Table 11-7.

11.3.3 Fatality:

11.3.3.1 Hurdle racing

It can be observed in Table 11-1 that eight of the original 11 risk factors (73%) were not statistically significantly associated with the outcome in the 2010 model. However, the odds ratios for all eight were similar and in the same direction as those from the 2001-2009 data. Variables that were significantly associated with likelihood of fatality in hurdle racing from the 2010 data were: Starts in a maiden or novice race; Horse age; and Number of starts made by that horse greater than one year previously. The interaction terms between “Starts greater than one year previously” and “Percentage of previous starts on flat” and “Horse age” also remained significant in the 2010 model.

11.3.3.2 Steeplechase racing

It can be observed in Table 11-2, that six of the original eight risk factors (75%) were not statistically significantly associated with the outcome in the 2010 model. Odds ratios similar to those from the 2001-2009 model were identified for four of the six non-significant variables, the other two: “Going” and “Change race type from previous race” demonstrated non-significant odds ratios in the opposite direction (reduced likelihood compared to increased likelihood) from those observed in the 2001-2009 data. Variables that were significantly associated with likelihood of fatality in steeplechase racing from the 2010 data were: Percentage of previous starts on flat and Starts in the previous 10 to 12 months. The interaction terms were not observed to be significant in the 2010 data set.

Table 11-1: Comparison of the Fatality in hurdle racing model from 2001-2009 data with the 2010 data. Non-significant P-Values are in grey cells.

	2001-2009 Data					2010 Data				
	OR	**CI**	**P-Value**	**Control**	**Case**	**OR**	**CI**	**P-Value**	**Control**	**Case**
Going										
"Heavy" to "GTS"	**Ref**			76568	228	**Ref**			7811	31
"Good" to "Firm"	**1.69**	1.44-1.99	**<0.001**	92348	524	**1.5**	0.86-2.62	**0.156**	9666	65
Summer Season										
No	**Ref**			151729	647	**Ref**			14567	73
Yes	**1.3**	1.08-1.56	**0.007**	17187	105	**1.79**	0.3-1.39	**0.265**	2910	23
Race Distance (Km)	**1.28**	1.12-1.46	**<0.001**	168916	752	**1.34**	0.84-2.14	**0.217**	17477	96
Maiden or Novice Race										
No	**Ref**			78056	375	**Ref**			9098	56
Yes	**0.71**	0.6-0.84	**<0.001**	90860	377	**0.39**	0.22-0.72	**0.002**	8379	40
Starts at that racecourse										
178 to 5824	**Ref**			129781	526	**Ref**			8427	42
> 5824 (5825-7766)	**1.2**	1.02-1.42	**0.027**	39135	226	**1.47**	0.83-2.6	**0.181**	2977	18
Trainer % of 1st places (per 10%)	**1.39**	1.21-1.61	**<0.001**	168916	752	**1.37**	0.84-2.24	**0.203**	17477	96
% of previous starts on flat (per 10%)	**1.24**	1.2-1.29	**<0.001**	168916	752	**1.004**	0.85-1.18	**0.957**	17477	96
Age (years)	**1.26**	1.19-1.33	**<0.001**	168916	752	**1.27**	1.03-1.57	**0.028**	17477	96
Change race type since previous race										
No	**Ref**			133129	604	**Ref**			13717	83
Yes	**0.76**	0.63-0.92	**0.004**	35787	148	**0.65**	0.3-1.39	**0.265**	3760	13
Starts in previous 10-12 months										
None	**Ref**			86404	428	**Ref**			8965	61
>0 (1-16)	**0.81**	0.7-0.94	**0.007**	82512	324	**0.77**	0.45-1.32	**0.346**	8512	35
Starts >1 year previously	**0.88**	0.87-0.9	**<0.001**	168916	752	**0.83**	0.75-0.91	**<0.001**	17477	96
INTERACTION										
Starts >1 yr prev & % of prev flat starts (10%)	**1**	1-1.01	**<0.001**			**1.009**	1.002-1.02	**0.012**		
Starts >1 year previously & horse age (years)	**1.01**	1-1.01	**<0.001**			**1.01**	1-1.02	**0.032**		

Key: OR=odds ratio; CI=Confidence Interval; Control=number of control starts in that category, Case=number of case starts in that category; GTS=good to soft; Ref=Reference category.

Table 11-2: Comparison of the Fatality in steeplechase racing model from 2001-2009 data with the 2010 data. Horse was included as a random effect in both models. Non-significant P-Values are in grey cells.

	2001-2009 Data					2010 Data				
	OR	**CI**	**P-Value**	**Control**	**Case**	**OR**	**CI**	**P-Value**	**Control**	**Case**
Going										
Heavy	**Ref**			7047	20	**Ref**			786	7
Soft to GTF	**2.08**	1.32-3.27	**0.002**	94407	576	**0.65**	0.29-1.45	**0.29**	9698	60
Firm	**4.02**	1.83-8.86	**0.001**	834	10				0	0
Race Distance (Km)										
3.2 to 4.8	**Ref**			79612	448	**Ref**			8423	52
>4.8 (5.0-7.2)	**1.29**	1.05-1.57	**0.012**	22676	158	**1.1**	0.6-2	**0.747**	2061	15
Summer Season										
No	**Ref**			90231	508	**Ref**			8970	56
Yes	**1.39**	1.11-1.76	**0.004**	12057	98	**1.1**	0.56-2.13	**0.779**	1514	11
Horse Age (Years)	**1.13**	1.06-1.22	**<0.001**	102288	606	**1.04**	0.84-1.3	**0.674**	10484	67
% of previous starts on flat (per 10%)	**1.33**	1.24-1.43	**<0.001**	102288	606	**1.26**	1.03-1.54	**0.02**	10484	67
Change race type since previous race										
No	**Ref**			85113	476	**Ref**			8663	57
Yes	**1.53**	1.2-1.96	**0.001**	17175	130	**0.63**	0.27-1.49	**0.294**	1821	10
Starts in previous 10-12 months										
None	**Ref**			43359	307	**Ref**			4187	39
>0 (1-15)	**0.86**	0.72-1.02	**0.08**	58929	299	**0.52**	0.32-0.86	**0.011**	6297	28
Starts >1 year previously	**0.92**	0.9-0.95	**<0.001**	102288	606	**0.92**	0.85-1	**0.053**	10484	67
INTERACTION										
Change race type & % career on flat	**0.87**	0.79-0.96	**0.007**			**1.1**	0.83-1.46	**0.496**		
Starts >1year ago & Horse age (years)	**1.005**	1.002-1.008	**<0.001**			**1.41**	0.99-0.099	**0.158**		

Key: OR=odds ratio; CI=Confidence Interval; Control=number of control starts in that category, Case=number of case starts in that category; Ref=Reference category; GTF=good to firm.

11.3.4 Superficial digital flexor tendinopathy

11.3.4.1 Hurdle racing

It can be observed in Table 11-3, that 16 of the 19 original risk factors (84%) were not statistically significantly associated with the outcome in the 2010 model. Of these 16, four (Days since last hurdle race at the track; Time of race; Race position in run sequence; and Change in running distance since previous race) were associated with a non-significant odds ratios that indicated an association in the opposite direction to that observed in the 2001-2009 data set. Variables that were significantly associated with likelihood of SDF tendinopathy in hurdle racing from the 2010 data were: Race distance; Previous SDF tendinopathy; First race type and Number of starts in the preceding three months.

11.3.4.2 Steeplechase racing

It can be observed in Table 11-4 that six of the 12 original risk factors (50%) were not statistically significantly associated with the outcome in the 2010 model. Odds ratios similar to those from the 2001-2009 model were identified for four of the six non-significant variables, the other two: “Season” and “Race position in run sequence” demonstrated non-significant odds ratios in the opposite direction from those observed in the 2001-2009 data. Variables that were significantly associated with likelihood of fatality in steeplechase racing from the 2010 data were: Track going; Race distance; Horse age; Previous SDF tendinopathy; Horse official rating; and Horse number of starts greater than one year previously.

Table 11-3: Comparison of the Superficial digital flexor tendinopathy in hurdle racing model from 2001-2009 data with the 2010 data. Non-significant P-Values are in grey cells.

	2001-1009 Data					2010 Data				
	OR	**CI**	**P-Value**	**Control**	**Case**	**OR**	**CI**	**P-Value**	**Control**	**Case**
Track Going										
Heavy	**Ref**			12,795	21	**Ref**			1,187	6
Soft	**1.73**	1.07-2.8	**0.024**	30,233	86	**0.45**	0.15-1.35	**0.156**	2,972	7
Good to Soft	**2.61**	1.65-4.14	**<0.001**	33,521	140	**1.42**	0.58-3.51	**0.442**	3,644	26
Good	**4.1**	2.64-6.37	**<0.001**	57,175	404	**1.36**	0.57-3.25	**0.485**	7,055	53
Good to Firm	**5.44**	3.48-8.51	**<0.001**	33,409	356	**1.33**	0.51-3.48	**0.564**	2,602	21
Firm	**8.39**	4.62-15.2	**<0.001**	1,504	24				0	0
Days since last hurdle race at that track										
0 to 90	**Ref**			155,169	917	**Ref**			16,056	107
≥ 91	**1.41**	1.15-1.73	**0.001**	13,468	114	**0.66**	0.29-1.54	**0.34**	1,404	6
Season										
Spr, Aut or Win	**Ref**			145,026	783	**Ref**			14,556	84
Summer	**1.38**	1.18-1.62	**<0.001**	23,611	248	**1.55**	0.96-2.53	**0.076**	2,904	29
Time of Race										
Afternoon	**Ref**			155,785	952	**Ref**			1,831	13
Mor or Eve	**0.65**	0.51-0.82	**<0.001**	12,852	79	**1.27**	0.69-2.34	**0.447**	15,629	100
Race Position in run sequence										
Early and middle	**Ref**			112,996	745	**Ref**			11,469	72
Late	**0.77**	0.67-0.89	**<0.001**	55,641	286	**1.03**	0.69-1.54	**0.877**	5,991	41
Race Dist (km)	**2.14**	1.92-2.39	**<0.001**	168,637	1031	**1.6**	1.14-2.25	**0.006**	17,460	113
Number of runners in race										
1 to 12	**Ref**			84,892	565	**Ref**			10,914	72
13 to 30	**0.84**	0.74-0.96	**0.008**	83,745	466	**0.93**	0.63-1.38	**0.721**	6,546	41
Sell/Claim Race										
No	**Ref**			148,645	836	**Ref**			16,293	103
Yes	**1.53**	1.29-1.82	**<0.001**	19,992	195	**1.42**	0.72-2.83	**0.313**	1,167	10
Trainer Score	**0.9**	0.87-0.93	**<0.001**	168,637	1031	**0.92**	0.82-1.03	**0.163**	17,460	113
Age at 1st Race	**1.21**	1.14-1.29	**<0.001**	168,637	1031	**1.18**	0.98-1.43	**0.085**	17,460	113
Previous start not Hurdle										
No	**Ref**			132,868	865	**Ref**			13,709	91
Yes	**0.65**	0.55-0.77	**<0.001**	35,769	166	**0.83**	0.51-1.34	**0.439**	3,751	22
Horse had previous SDF tendinopathy										
No	**Ref**			168,448	999	**Ref**			17,349	108
Yes	**20.84**	13.9-31.1	**<0.001**	189	32	**4.46**	1.69-11.76	**0.002**	111	5
% Career Flat	**1.02**	1.01-1.02	**<0.001**	168,637	1031	**1**	0.99-1.02	**0.387**	17,460	113
First Race Type										
Fl, St, Hu	**Ref**			110,092	604	**Ref**			13,795	76
NHF	**1.73**	1.48-2.03	**<0.001**	58,545	427	**1.82**	1.16-2.83	**0.008**	3,665	37
Change in running distance since last race										
-800 to +2200m	**Ref**			162,950	988	**Ref**			16,888	111
-2400 to -1000m	**1.57**	1.14-2.15	**0.005**	5,687	43	**0.6**	0.14-2.47	**0.476**	572	2
Weight carried										
130 to 160lbs	**Ref**			149,250	900	**Ref**			15,012	95
161 to 186lbs	**1.28**	1.06-1.55	**0.011**	19,387	131	**1.17**	0.7-1.97	**0.544**	2,448	18
Horse completed racing year	**1.05**	1.02-1.09	**0.003**	168,637	1031	**1.1**	0.99-1.23	**0.078**	17,460	113
Horse number of starts in previous three months										
0 and 8 to 16	**Ref**			37,222	278	**Ref**			4,093	36
1 to 7	**0.7**	0.61-0.81	**<0.001**	131,415	753	**0.64**	0.42-0.96	**0.032**	13,367	77
Horse starts in prev 10 to 12 m	**0.86**	0.83-0.9	**<0.001**	168,637	1031	**0.9**	0.79-1.03	**0.127**	17,460	113

Key: OR=odds ratio; CI=Confidence Interval; Control=number of control starts in that category, Case=number of case starts in that category; Ref=Reference category; Spr=Spring; Aut=Autumn; Win=Winter; Mor=Morning; Eve=Evening; Dist=Distance; Fl=Flat; St=Steeeplechase; Hu=Hurdle; NHF=National Hunt Flat.

Table 11-4: Comparison of the Superficial digital flexor tendinopathy in steeplechase racing model from 2001-2009 data with the 2010 data. Non-significant P-Values are in grey cells.

	2001-1009 Data					2010 Data				
	OR	**CI**	**P-Value**	**Control**	**Case**	**OR**	**CI**	**P-Value**	**Control**	**Case**
Track Going										
Heavy and Soft	**Ref**			25,709	66	**Ref**			2,637	6
Good to Soft	**1.98**	1.45-2.7	**<0.001**	20,315	102	**2.3**	0.81-6.53	**0.118**	2,223	9
Good	**2.77**	2.11-3.63	**<0.001**	36,575	277	**2.39**	0.94-6.03	**0.066**	4,217	20
Good to Firm	**3.42**	2.55-4.58	**<0.001**	18,812	194	**4.2**	1.4-12.61	**0.01**	1,429	10
Firm	**3.53**	1.74-7.14	**<0.001**	835	9				0	0
Race Dist (km)	**1.37**	1.23-1.53	**<0.001**	102,246	648	**1.66**	1.1-2.5	**0.016**	10,506	45
Season										
Spr, Aut, Win	**Ref**			90,222	517	**Ref**			8,987	39
Summer	**1.42**	1.16-1.75	**0.001**	12,024	131	**0.63**	0.25-1.6	**0.33**	1,519	6
Time of race										
Afternoon	**Ref**			92,490	571	**Ref**			9,214	41
Mor or Eve	**0.74**	0.58-0.95	**0.017**	9,756	77	**0.39**	0.13-1.14	**0.086**	1,292	4
Race position in run sequence										
Early	**Ref**			24,611	179	**Ref**			2,281	7
Mid or Late	**0.83**	0.69-0.99	**0.037**	77,635	469	**1.3**	0.57-2.97	**0.538**	8,225	38
Age (years)	**1.19**	1.14-1.25	**<0.001**	102,246	648	**1.24**	1.04-1.48	**0.017**	10,506	45
Previous SDF Tendinopathy										
No	**Ref**			101,593	606	**Ref**			10,380	42
Yes	**8.51**	6.1-11.88	**<0.001**	653	42	**3.79**	1.12-12.9	**0.033**	126	3
Horse Official Rating										
0-115	**Ref**			78,380	567	**Ref**			6,903	37
>115	**0.65**	0.51-0.83	**0.001**	23,866	81	**0.44**	0.2-0.98	**0.044**	3,603	8
% of career flat (10%)	**1.22**	1.16-1.28	**<0.001**	102,246	648	**1.16**	0.94-1.43	**0.177**	10,506	45
Horse number of starts in previous 3 months										
0 to 1	**Ref**			23,089	169	**Ref**			2,517	15
2 to 4	**0.77**	0.63-0.93	**0.008**	50,208	285	**0.74**	0.38-1.45	**0.384**	5,084	22
>4	**0.84**	0.68-1.03	**0.1**	28,949	194	**0.43**	0.18-1.03	**0.059**	2,905	8
Horse number of starts in previous 10 to 12 months										
0	**Ref**			43,273	393	**Ref**			4,200	26
1 to 7	**0.61**	0.52-0.72	**<0.001**	58,726	251	**0.61**	0.33-1.13	**0.114**	6,279	19
>7	**2.03**	0.75-5.53	**0.166**	247	4				27	0
Horse number of starts greater than 1 year previously										
0 to 15	**Ref**			51,925	394	**Ref**			4,457	24
>15	**0.42**	0.34-0.51	**<0.001**	50,321	254	**0.42**	0.2-0.87	**0.019**	6,049	21

Key: OR=odds ratio; CI=Confidence Interval; Control=number of control starts in that category, Case=number of case starts in that category; Ref=Reference category; Dist=Distance; Spr=Spring; Aut=Autumn; Win=Winter; Mor=Morning; Eve=Evening; Fl=Flat; St=Steeeplechase; Hu=Hurdle; NHF=National Hunt Flat.

11.3.5 Epistaxis

11.3.5.1 Hurdle racing

It can be observed in Table 11-5, that three of the six original risk factors (50%) were not statistically significantly associated with the outcome in the 2010 model, although the odds ratios for all three were similar and in the same direction as those from the 2001-2009 data. Variables that were significantly associated with likelihood of epistaxis in hurdle racing from the 2010 data were: Age at first race; Proportion of field beaten; and Horse number of starts in the previous four to six months. There were no cases of epistaxis in the 2010 data set that matched the combined categories of previous epistaxis and percentage of career flat with the highest odds ratio, making it impossible to accurately assess the interaction term.

11.3.5.2 Steeplechase racing

It can be observed in Table 11-6 that seven of the 11 original risk factors (63.6%) were not statistically significantly associated with the outcome in the 2010 model. Odds ratios similar to those from the 2001-2009 model were identified for six of the seven non-significant variables, the other one “Number of starts in the previous 4 to 6 months” was associated with a non-significant odds ratio in the opposite direction to that identified in the 2001-2009 data. Variables that were significantly associated with likelihood of epistaxis in steeplechase racing from the 2010 data were: Race position in run sequence; Horse had previous epistaxis; Proportion of field beaten; and Number of starts made greater than one year previously.

Table 11-5: Comparison of the Epistaxis in hurdle racing model from 2001-2009 data with the 2010 data. Non-significant P-Values are in grey cells.

Hurdle Epistaxis	2001-1009 Data					2010 Data				
	OR	CI	P-Value	Control	Case	OR	CI	P-Value	Control	Case
Going										
"Heavy" to "Soft"	**Ref**			43,019	116	**Ref**			2,973	6
"GTS" to "Firm"	**1.44**	1.17-1.77	**0.001**	126,046	487	**1.79**	0.76-4.18	**0.18**	14,537	57
Race Dist (km)	**0.75**	0.64-0.87	**<0.001**	169,065	603	**0.81**	0.5-1.3	**0.378**	17,510	63
Race positing in run sequence										
Early	**Ref**			66,618	339	**Ref**			6,719	31
Late	**0.43**	0.35-0.54	**<0.001**	55,811	116	**0.67**	0.37-1.21	**0.185**	6,013	19
Middle	**0.65**	0.54-0.8	**<0.001**	46,636	148	**0.53**	0.27-1.03	**0.06**	4,778	13
Season										
Sum, Win, Aut	**Ref**			117,831	375	**Ref**			11,265	35
Spring	**1.27**	1.07-1.51	**0.006**	51,234	228	**1.13**	0.68-1.89	**0.64**	6,245	28
Age 1st Race (yrs)	**1.12**	1.06-1.19	**<0.001**	169,065	603	**1.25**	1.03-1.5	**0.021**	17,510	63
Proportion beaten	**0.96**	0.96-0.97	**<0.001**	169,065	603	**0.96**	0.95-0.97	**<0.001**	17,510	63
Horse number of starts in prev 4 to 6 months										
None	**Ref**			84,688	296	**Ref**			8,409	22
1 to 2	**1.28**	1.07-1.54	**0.008**	48,756	206	**2.24**	1.26-3.98	**0.006**	5,902	29
(>2) 3 to 18	**0.93**	0.73-1.17	**0.522**	35,621	101	**1.81**	0.86-3.8	**0.117**	3,199	12
INTERACTIONS										
No prev Epi & <75% career flat	**Ref**			154781	482	**Ref**			15735	44
No pre Epi & >75% career flat	**1.47**	1.11-1.93	**0.006**	12097	72	**1.67**	0.68-4.1	**0.258**	1351	7
Prev Epi & <75% career flat	**6.51**	4.7-8.9	**<0.001**	2138	42	**13.16**	6.67-25.9	**<0.001**	393	12
Prev Epi & >75% career flat	**40.6**	8.8-187.5	**0.002**	49	7				31	0

Key: OR=odds ratio; CI=Confidence Interval; Control=number of control starts in that category, Case=number of case starts in that category; Ref=Reference category; GTS=good to soft; Dist=Distance; Sum=Summer; Win=Winter; Aut=Autumn; yrs=years

Table 11-6: Comparison of the Epistaxis in steeplechase racing model from 2001-2009 data with the 2010 data. Horse was included as a random effect in both models. Non-significant P-Values are in grey cells.

Steeple Epistaxis	2001-1009 Data					2010 Data				
	OR	CI	P-Value	Control	Case	OR	CI	P-Value	Control	Case
Claiming Race										
No	**Ref**			102,268	548	**Ref**			10,452	87
Yes	**6.8**	1.6-28.9	**0.009**	76	2	**8.36**	0.9-75.95	**0.059**	11	1
Race position in run sequence										
Early	**Ref**			24,599	191	**Ref**			2,259	29
Late	**0.46**	0.37-0.58	**<0.001**	40,499	134	**0.58**	0.34-0.99	**0.045**	4,275	29
Middle	**0.8**	0.66-0.98	**0.03**	37,246	225	**0.62**	0.37-1.05	**0.074**	3,929	30
Season										
Sum or Aut	**Ref**			35,193	167	**Ref**			4,078	32
Win or Spring	**1.62**	1.3-2.03	**<0.001**	67,151	383	**1.13**	0.66-1.92	**0.655**	6,385	56
Amateur Jockey										
No	**Ref**			89,018	510	**Ref**			8,928	78
Yes	**0.48**	0.35-0.67	**<0.001**	13,326	40	**0.65**	0.32-1.33	**0.234**	1,535	10
Horse had previous episode of epistaxis whilst racing										
No	**Ref**			99,012	447	**Ref**			9,913	78
Yes	**6.54**	4.82-8.87	**<0.001**	3,332	103	**2.78**	1.39-5.55	**0.004**	550	10
Proportion of field beaten	**0.98**	0.97-0.98	**<0.001**	102,344	550	**0.97**	0.96-0.98	**<0.001**	10,463	88
Percentage of horse's starts on flat										
0 to 75	**Ref**			101,986	543	**Ref**			10,444	87
>75	**4.52**	2.06-9.91	**<0.001**	358	7	**7.73**	0.84-71.08	**0.071**	19	1
Horse number of starts in previous 3 months										
0 to 2	**Ref**			69,016	407	**Ref**			7,372	69
>2 (3-16)	**0.74**	0.61-0.91	**0.003**	33,328	143	**0.81**	0.48-1.37	**0.432**	3,091	19
Horse number of starts in previous 4 to 6 months										
0 to 8	**Ref**			102,303	548	**Ref**			5,209	44
>8 (9-18)	**10.53**	2.25-49.3	**0.003**	41	2	**0.93**	0.59-1.46	**0.753**	5,254	44
Horse number of starts >1 yr ago	**0.98**	0.98-0.99	**<0.001**	102,344	550	**0.96**	0.94-0.98	**<0.001**	10,463	88
Going										
Heavy to "GTS"	**Ref**			45,997	195	**Ref**			4,838	37
"Good" to "Firm"	**1.7**	1.42-2.04	**<0.001**	56,347	355	**1.29**	0.83-2	**0.263**	5,625	51
INTERACTION										
Proportion beaten & season	**0.99**	0.99-1	**0.022**			**1**	0.98-1.02	**0.948**		

Key: OR=odds ratio; CI=Confidence Interval; Control=number of control starts in that category, Case=number of case starts in that category; Ref=Reference category; Sum=Summer; Aut=Autumn; Win=Winter; yr=year; GTS=Good to Soft.

11.3.7 Post-Hoc tests of 2010 model fit

Table 11-7 shows the results of the Hosmer-Lemeshow goodness-of-fit tests and receiver operator curves for each of the models performed on the 2010 data using risk factors identified as being significant in the 2001-2009 data. The P-values for all Chi-squared tests were greater than 0.05 indicating that there was no evidence for lack of fit for any of the models. There was variation in the *c*-indices, which are a measure of model discrimination (or fit) between the models. If we define discrimination based on c-index as: 0.90-1 = excellent; 0.80-0.90 = good; 0.70-0.80 = fair; 0.60-0.70 = poor and 0.50-0.60 = failed, the models could be considered to have from poor to good fit for the data. There were no major differences between the *c*-indices obtained from the 2001-2009 models and those obtained from the 2010 data, the biggest difference being observed in the value for the epistaxis in steeplechase racing model, in which a higher *c*-index was observed from the 2010 data.

Table 11-7: Results of the Hosmer-Lemeshow goodness-of-fit tests and receiver operator curves for each of the models performed on the 2010 data using risk factors identified as being significant in the 2001-2009 data, with c-indices for the 2001-2009 models for comparison.

Model	HL GOF Chi^2 value	HL GOF P-value	*c*-index 2010	*c*-index 01-09
Fatality Hurdle	6.77	0.5619	0.7518	0.71
Fatality Steeplechase	1.52	0.9924	0.6545	0.64
SDF tendinopathy Hurdle	10.06	0.2612	0.718	0.75
SDF tendinopathy Steeplechase	6.16	0.6292	0.7485	0.73
Epistaxis Hurdle	11.22	0.1896	0.8354	0.82
Epistaxis Steeplechase	8.66	0.3717	0.8084	0.71

Key: HL GOF=Hosmer-Lemeshow goodness-of-fit; *c*-index refers to the area under the receiver-operator curve; 01-09=years 2001-2009; SDF=superficial digital flexor.

11.3.8 Power of the 2010 models

Using the same control population exposure prevalence used to calculate statistical power in the 2001-2009 models, the odds ratios that would have been detectable, with 80% power, in the 2010 data were calculated. These are shown in Table 11-8 The detectable odds ratios were considerably higher than those reported in risk factor models (Tables 11-1 to 11-6), which likely explains at least part of the reason for the failure to find statistically significant associations in the 2010 data.

Table 11-8: Table showing the results of power calculations describing the odds ratios detectable using the 2001-2009 and 2010 data, for models of fatality, superficial digital flexor tendinopathy and epistaxis in hurdle and steeplechase racing.

Model	Prevalence of exposure in control population	Odds ratio detectable from 2001-2009 data	Odds ratio detectable from 2010 data
Fatality Hurdle	17-77%	≥1.3	≥2.34
Fatality Steeple	21-69%	≥1.3	≥2.46
SDF tendinopathy Hurdle	12-82%	≥1.3	≥2.44
SDF tendinopathy Steeplechase	11-82%	≥1.4	≥6.4
Epistaxis Hurdle	8-88%	≥1.5	≥7.5
Epistaxis Steeplechase	8-87%	≥1.5	≥3.9

Key: SDF=superficial digital flexor

11.3.9 Discussion of the findings from Chapter 11 Part 1

The risk factors identified from the 2001-2009 data were not all significantly associated with the outcomes in the 2010 data set. In fact, the majority (50% - 84%) of variables were not found to be significant. This lack of significance (and apparent lack of agreement between the two data sets), is potentially related to the smaller sample size analysed from the 2010 data, which is particularly relevant when considering outcomes with low prevalence. Other potential explanations for the lack of significance include: differences in racing in 2010 from the preceding years, leading to altered associations between risk factors; or anomalous identification of risk factors from the 2001-2009 data set.

Whilst the lack of significance in associations between risk factors and outcomes can be readily easily explained, it is perhaps differences in the observed associations that would be more concerning when it comes to making use of the risk factor models. For a number of risk factors, reduced odds of outcome associated with a risk factor were observed in the 2010 data, when increased odds of outcome had been identified in the 2001-2009 data and vice versa. Importantly, in all cases where an opposite direction of association was observed (between 2001-2009 and 2010 data sets) the associations observed in the 2010 data set were not statistically significant, so erroneous recommendations would not have been made based on the later analysis.

The post-hoc tests indicated reasonable calibration and discrimination for all of the models: The results of the Hosmer-Lemeshow goodness of fit tests, demonstrated no evidence of lack of fit for any of the models, although this test has been recognised as having limited power to assess calibration (Altman et al., 2009). Only one (fatality in steeplechase racing) of the models' discriminatory abilities in the 2010 data was considered poor (as defined by the *c*-index). The rest were considered fair to good, indicating reasonable ability to predict outcomes in the 2010 data which would perhaps support their use. When it comes to making use of the risk factors identified in the 2001-2009 data in combination with the results of the above evaluations of the risk factors in the 2010 data, it might be prudent to initially focus on the risk factors observed to be significant in both sets of data (as these could be considered more robust). In order to fully evaluate the risk factors not found to be significant in the 2010 data, further data could be recruited over subsequent years to allow future analysis on a larger data set. It would also be possible to perform multiple validation comparisons, which could include automatically testing each individual year of data against models produced from the other years, or randomly selecting a sample of the data prior to model production. It would then be possible to determine whether identified statistically significant risk factors remained significant and provide evidence for a strengthened association with the outcome.

11.4 Part 2: Evaluation of predictive ability /calibration of the 2001-2009 models

11.4.1 Methods

11.4.1.1 Overview

It is possible to compute predictive probabilities from the multivariable models produced from the 2001-2009 data. These predictive probabilities give an indication of how likely the outcome is from each combination of variables that were evaluated in the logistic regression model.

11.4.1.2 Predictive probability example

If we had a multivariable model with three significant variables, each with two categories such as **Age**: Old (greater than five years old) or Young (less than five years old); **Sex**: Male or Female and **Colour**: Bay or Grey. Then there are eight potential combinations (covariate patterns) of the variables: Bay Old Male; Bay Old Female; Bay Young Male; Bay Young Female; Grey Old Male; Grey Old Female; Grey Young Male; Grey Young Female. By analysing the results of a multivariable logistic regression model it is possible to produce predictive probabilities for each of the combinations of these three variables i.e. to say which combination of the three variables has the strongest association with the outcome and which has the least strong association, as well as ordering them in between. For example, it might be that the most cases of fatality per start occurred in the Grey Old Male horses group, which would give this group the highest predictive probability. Whilst, if the fewest numbers of fatalities per start, occurred in the Bay Young Female horses, this group would have the lowest predictive probability.

When considering the multivariable models that were produced for the 2001-2009 data, there were many more variables (some of which were continuous) and therefore many more potential covariate patterns. Numbers of potential covariate patterns for each model are shown in Table 11-9. The number of potential covariate patterns (when including continuous variables) was very large for all of the models.

Table 11-9: Number of potential covariate patterns for each of the models assessed.

2001-2009 Model	Number of Variables	Number of Continuous Variables	Number of Groups Cat + Cont	Potential Covariate Patterns
Fatality H	11	5	2^(6 + 304)	$3.2x10^{91}$
Fatality St	8	3	2^(6 + 239)	$5.6x10^{73}$
SDF Tend H	19	5	2^(17 + 172)	$7.8x10^{56}$
SDF Tend St	12	3	2^(14 + 128)	$5.6x10^{42}$
Epistaxis H	9	3	2^(8 + 273)	$3.9x10^{84}$
Epistaxis St	11	2	2^(10 + 372)	$9.9x10^{114}$

Key: Cat=Categorical; Cont=Continuous; H=Hurdle; St=Steeplechase; SDF Tend=superficial digital flexor tendinopathy.

In order to assess the predictive ability of the 2001-2009 models, covariate patterns that were associated with the highest likelihood of outcome were identified. Covariate patterns were produced from the 2010 data and compared to predicted probabilities from the 2001-2009 models. If the 2001-2009 models were good at predicting the outcome from the 2010 data, it would be expected that starts in the 2010 data matching the covariate patterns with the highest predictive probabilities, would have a higher proportion of cases than starts that matched covariate patterns with lower predicted probabilities.

11.4.1.3 Production of predicted probabilities

Predicted probabilities were calculated for each covariate pattern in each of the 2001-2009 models. This was done using the “estat gof” function with “table” option in Stata12, which displays a table of the groups used for the Hosmer-Lemeshow goodness-of-fit test with predicted probabilities, observed and expected counts for both outcomes, and totals for each group. The covariate patterns produced from each multivariable model were ordered by predicted probability and ascribed a percentage based on highest (100%) to lowest (0%) predicted probability. From this, subsets of covariate patterns were defined as being within the top: 1, 5, 10, 25 and 50% of the patterns and also grouped into 10% blocks.

11.4.1.4 Matching the 2010 data to the 2001-2009 covariate patterns

Covariate patterns for each start in the 2010 data set were produced using the same coding as used for the 2001-2009 models. Using Microsoft Access™, the covariate patterns from the 2010 data were compared to the covariate patterns from the 2001-2009 models and if matched, were ascribed the percentage predicted probability (as defined above).

11.4.1.5 Evaluation of matched data

In order to assess the accuracy of the probabilities predicted from the 2001-2009 data, the prevalence of outcomes in the 2010 data were examined in relation to the different subsets of probabilities (as defined by the 2001-2009 data). If the 2001-2009 models were good predictors for outcomes in 2010, it was considered likely that the prevalence of outcomes in the groups with high predicted probability would be higher than the prevalence in groups with low predicted probability. In order to assess this, the prevalence of outcome was defined for each subset of predicted probability for each model.

11.4.1.6 Dealing with missing covariate patterns

Because predicted probabilities were only produced for the covariate patterns that existed in the 2001-2009 data set, and there were a very large number of potential patterns for the full models (see Table 11-9), not all of the covariate patterns present in the 2010 data were matched with a pattern assigned a predictive probability from the 2001-2009 model. When covariate patterns were not matched, interpretation of the predictive value of the models was more difficult, because of the unknown significance of the outcomes that occurred with unmatched patterns. For example, it might be that a single change in one of the risk factors resulted in a lack of matching but that otherwise the covariate pattern was very similar to a covariate pattern with a high predicted probability. This would result in apparent poor predictive ability of the models.

In order to reduce the number of potential covariate patterns and hence improve the numbers of 2010 starts that matched the 2001-2009 covariate patterns the following approach was taken:

Firstly, all variables were converted to categorical values, using the techniques described in Chapter 2, by determining the most appropriate from the lowest Akaike Information Criteria and by using biologically plausible categories.

Secondly, if categorisation did not result in matching of all 2010 covariate patterns, variables were removed sequentially from the 2001-2009 multivariable models in order of strength of odds ratio (from lowest to highest) until 100% of 2010 covariate patterns could be matched (for all except the SDF tendinopathy in hurdle race model – see description in 11.4.2.3).

Worked example:

The multivariable logistic regression model for fatality in hurdle racing from the 2001 – 2009 data included 11 variables, five of which were continuous. As shown in Table 11-9, this resulted in a potential $3.2x10^{91}$ covariate patterns. The 2001-2009 data actually yielded 43,121 patterns. When these covariate patterns were compared to the 2010 data, only 1,773 of 17,573 (10%) of starts matched. The 2001-2009 risk factors were then all converted to categorical variables, resulting in 3,238 actual patterns, which matched to many more, i.e. 11,422 of 17,753 (64%) of 2010 starts. Removal of the risk factor with the lowest odds ratio resulting in a 10 variable model resulted in 1,844 covariate patterns and matching of 11,451 of 17,753 (64.5%) 2010 starts. Removal of the risk factor with the next lowest odds ratio, resulting in a nine variable model yielded 985 covariate patterns and matching of 17,569 of 17,753 (98.9%) of 2010 starts. Removal of the risk factor with the next lowest odds ratio, resulting in an eight variable model yielded 516 covariate patterns and matching of 17,753 of 17,753 (100%) of 2010 starts.

Because of the unknown effect of the unaccounted for starts in the unmatched 2010 data, only the results for the models that matched 100% of 2010 starts are presented here (for all except the SDF tendinopathy in hurdle race model – see description in 11.4.2.3).

11.4.2 Results

11.4.2.1 Fatality in Hurdle racing

The 2001-2009 models' covariate patterns that matched 100% of the 2010 data was an eight variable model, with predicted probabilities ranging from: 0.0008 to 0.0345 per start. The outcomes of matching are shown in Table 11-10 and Figure 11-1. No cases were observed in the 2010 starts that matched the Top 1% of predicted probabilities. The overall frequency of cases per 1000 starts in the 2010 data was 5.5. The highest frequency identified by matching was 11.4 per 1000 starts in the Top 5% group, which if used as a tool for examination would have required examination of 88 starts to identify one case. The next highest frequency (9.4) was in the top 50% of probabilities, in which 48 cases (50% of cases) were identified from 5,112 (29% of) starts – more than double the overall frequency of cases per start.

Table 11-10: Results of matching all 2010 starts' covariate patterns with the covariate patterns identified from the multivariable model for fatality in hurdle racing with the 8 variables with the highest odds ratios, from the 2001-2009 data. Of year 2010 starts, 17,573 of 17,573 (100%) were matched. The Top percentages refer to the covariate patterns identified as having the highest predictive probabilities.

% Probability subset	Top 1%		Top 5%		Top 10%		Top 25%		Top 50%		
Matched	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**Total**
Number of Controls	17467	10	17390	87	17187	290	16190	1287	12413	5064	17477
Number of Cases	96	0	95	1	94	2	86	10	48	48	96
Column Total	17563	10	17485	88	17281	292	16276	1297	12461	5112	17573
Cases /1000 Starts	**5.5**	**0**	**5.4**	**11.4**	**5.4**	**6.8**	**5.3**	**7.7**	**3.9**	**9.4**	**5.5**

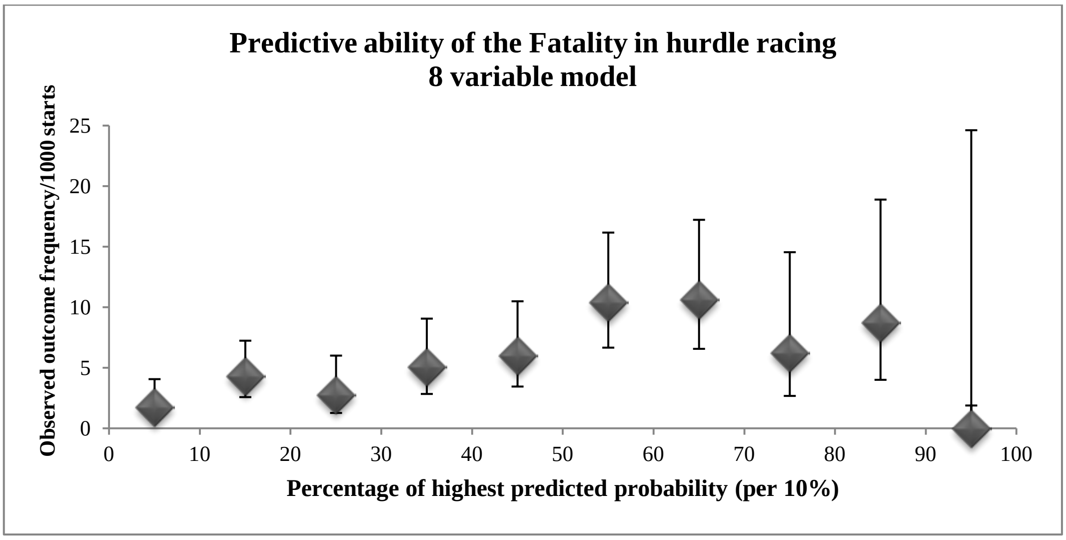


Figure 11-1: Plot of observed frequency of fatality in hurdle racing in 2010, across the range of predicted probabilities (0=0.0008 to 100%=0.0345) from the 2001-2009 model. Diamonds indicate the observed frequency of events per decile of predicted probability, with vertical lines representing 95% confidence intervals, calculated using the Wilson method (Wilson 1927)**.**

11.4.2.2 Fatality in Steeplechase racing

Following categorisation of all variables in the 2001-2009 model, all of the 2010 data covariate patterns were accounted for. The predicted probabilities for the model ranged from: 0.0017 to 0.0314 per start. The outcomes of matching are shown in Table 11-11 and Figure 11-2. The numbers of cases identified were zero for all of the Top percentage probabilities, except the Top 50%, in which 6 (9% of) of cases were identified from 9.7% of 2010 starts. Using this percentage, the frequency of cases per start was lower than the overall frequency (6.4 per 1000 starts), indicating that this model had poor predictive ability in the 2010 data set.

Table 11-11: Results of matching all 2010 starts' covariate patterns with the covariate patterns identified by the full multivariable model for fatality in steeplechase racing with all variables categorised, from the 2001-2009 data. Of year 2010 starts, 10,551 of 10,551 (100%) were matched. The Top percentages refer to the covariate patterns identified as having the highest predictive probabilities.

% Probability subset	Top 1%		Top 5%		Top 10%		Top 25%		Top 50%		
Matched	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Total
Number of Controls	10484	0	10484	0	10484	0	10449	35	9465	1019	10484
Number of Cases	67	0	67	0	67	0	67	0	61	6	67
Column Total	10551	0	10551	0	10551	0	10516	35	9526	1025	10551
Cases /1000 Starts	6.4	0	6.4	0	6.4	0	6.4	0	6.4	5.9	6.4

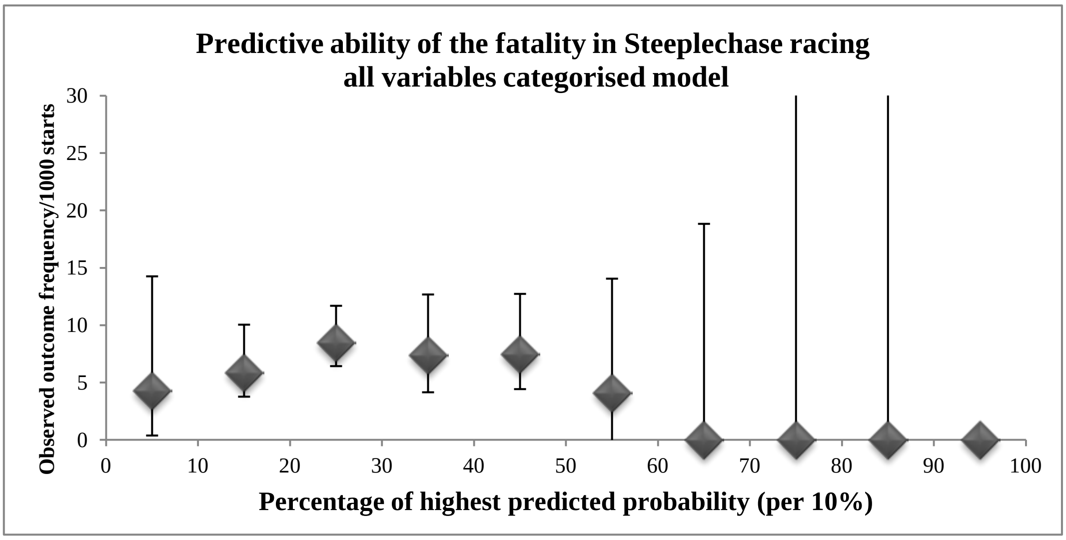


Figure 11-2: Plot of observed frequency of fatality in steeplechase racing in 2010, across the range of predicted probabilities (0=0.0017 to 100%=0.0314) from the 2001-2009 model. Diamonds indicate the observed frequency of events per decile of predicted probability, with vertical lines representing 95% confidence intervals, calculated using the Wilson method (Wilson 1927)**.**

11.4.2.3 Superficial digital flexor tendinopathy in Hurdle racing

Matching of 100% of the 2010 starts' covariate patterns was unsuccessful, even when the number of variables in the 2001-2009 model were reduced to four. Whilst the seven, six and five variable versions of the 2001-2009 model all matched high percentages of 2010 starts (99.8%, 99.8% and 99.9% respectively), one case was included in the missing patterns from the seven and six variable models, whilst none were missed from the five variable model, therefore the results of that model are shown. The predicted probabilities for the five variable model ranged from: 0.0007 to 0.4459 per start. The outcomes of matching are shown in Table 11-12 and Figure 11-3. No cases were observed in the 2010 starts that matched the Top 1% of predicted probabilities. The frequencies of cases per start were higher than the overall frequency (3.6 per 1000 starts) for all subsets of matching with the highest (66.7) being observed in the Top 5% of predicted probabilities, although these frequencies were based on a relatively small number of cases (1-12 or 1.6-19%). The highest number of cases identified (12) included 23.4% of cases from 4.8% of 2010 starts.

Table 11-12: Results of matching all 2010 starts' covariate patterns with the covariate patterns identified from the multivariable model for superficial digital flexor tendinopathy in hurdle racing with the 5 variables with the highest odds ratios, from the 2001-2009 data. Of year 2010 starts, 17,558 of 17,573 (99.9%) were matched. The Top percentages refer to the covariate patterns identified as having the highest predictive probabilities.

% Probability subset	Top 1%		Top 5%		Top 10%		Top 25%		Top 50%		
Matched	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**Total**
Number of Controls	17509	1	17496	14	17476	34	17426	84	16681	829	17510
Number of Cases	63	0	62	1	61	2	58	5	51	12	63
Column Total	17572	1	17558	15	17537	36	17484	89	16732	841	17573
Cases /1000 Starts	**3.6**	**0**	**3.5**	**66.7**	**3.5**	**55.6**	**3.3**	**56.2**	**3**	**14.3**	**3.6**

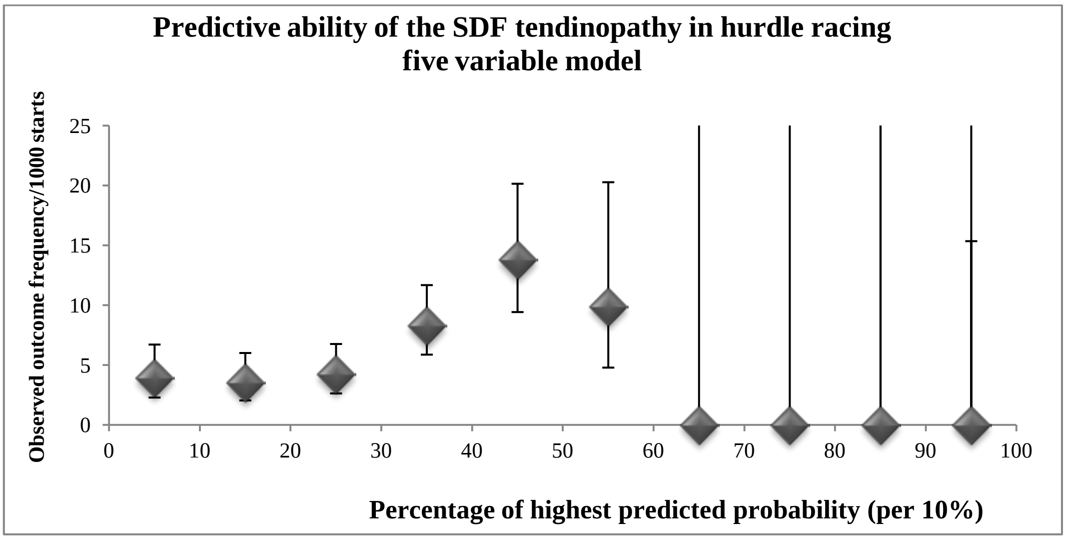


Figure 11-3: Plot of observed frequency of superficial digital flexor (SDF) tendinopathy in hurdle racing in 2010, across the range of predicted probabilities (0=0.0007 to 100%=0.4459) from the 2001-2009 model. Diamonds indicate the observed frequency of events per decile of predicted probability, with vertical lines representing 95% confidence intervals, calculated using the Wilson method (Wilson 1927)**.**

11.4.2.4 Superficial digital flexor tendinopathy in Steeplechase racing

The 2001-2009 models' covariate patterns that matched 100% of the 2010 data was a five variable model with predicted probabilities ranging from: 0.0009 to 0.2105 per start. The outcomes of matching are shown in Table 11-13 and Figure 11-4. No cases were observed in the 2010 starts that matched the Top 1, 5 or 10% of predicted probabilities. A case frequency much higher (46.9 per 1000 starts) than the overall frequency (4.3 per 1000 starts) was observed in the starts matched to the Top 25% of covariate patterns, but only accounted for three of the 64 cases (4.7%). The highest number of cases identified (7) included only 15.5% of cases but were from 4.5% of 2010 starts.

Table 11-13: Results of matching all 2010 starts' covariate patterns with the covariate patterns identified from the multivariable model for superficial digital flexor tendinopathy in steeplechase racing with the 5 variables with the highest odds ratios, from the 2001-2009 data. Of year 2010 starts, 10,551 of 10,551 (100%) were matched. The Top percentages refer to the covariate patterns identified as having the highest predictive probabilities.

% Probability subset	Top 1%		Top 5%		Top 10%		Top 25%		Top 50%		
Matched	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Total
Number of Controls	10503	3	10499	7	10489	17	10445	61	10041	465	10506
Number of Cases	45	0	45	0	45	0	42	3	38	7	45
Column Total	10548	3	10544	7	10534	17	10487	64	10079	472	10551
Cases /1000 Starts	4.3	0	4.3	0	4.3	0	4	46.9	3.8	14.8	4.3

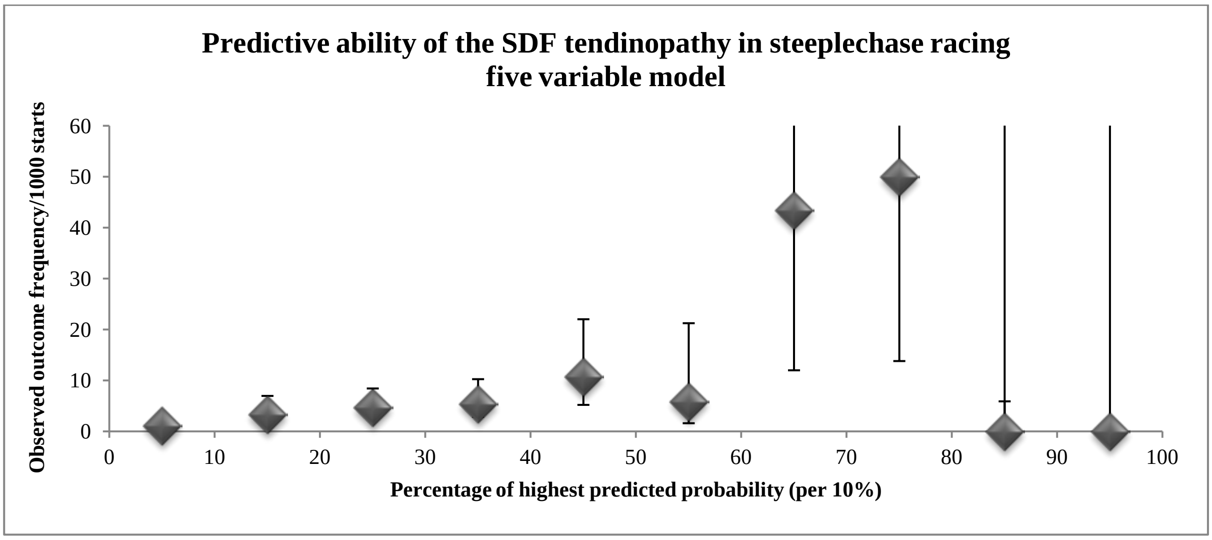


Figure 11-4: Plot of observed frequency of superficial digital flexor (SDF) tendinopathy in steeplechase racing in 2010, across the range of predicted probabilities (0=0.0009 to 100%=0.2105) from the 2001-2009 model. Diamonds indicate the observed frequency of events per decile of predicted probability, with vertical lines representing 95% confidence intervals, calculated using the Wilson method (Wilson 1927)**.**

11.4.2.5 Epistaxis in Hurdle racing

The 2001-2009 models' covariate patterns that matched 100% of the 2010 data was an eight variable model with predicted probabilities ranging from: 0.0004 to 0.1561 per start. The outcomes of matching are shown in Table 11-14 and Figure 11-5. No cases were identified in the starts that matched the Top 1%. Frequencies of outcome higher (ranging from 11.6 to 171 per 1000 starts) than the underlying frequency (3.6 per 1000 starts) were observed with a range of percentage probabilities. The highest frequency was based on less than 10% of cases, whilst the lowest was based on nearly 50% of cases (30/63) having examined less than 15% of 2010 starts, indicating that this model had relatively good predictive potential.

Table 11-14: Results of matching all 2010 starts' covariate patterns with the covariate patterns identified from the multivariable model for epistaxis in hurdle racing with the 8 variables with the highest odds ratios, from the 2001-2009 data. Of year 2010 starts, 17,571 of 17,573 (99.99%) were matched. The Top percentages refer to the covariate patterns identified as having the highest predictive probabilities.

% Probability subset	Top 1%		Top 5%		Top 10%		Top 25%		Top 50%		
Matched	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Total
Number of Controls	17508	2	17495	15	17481	29	16790	720	14961	2549	17510
Number of Cases	63	0	61	2	57	6	48	15	33	30	63
Column Total	17571	2	17556	17	17538	35	16838	735	14994	2579	17573
Cases /1000 Starts	**3.6**	**0**	**3.5**	**118**	**3.3**	**171**	**2.9**	**20.4**	**2.2**	**11.6**	**3.6**

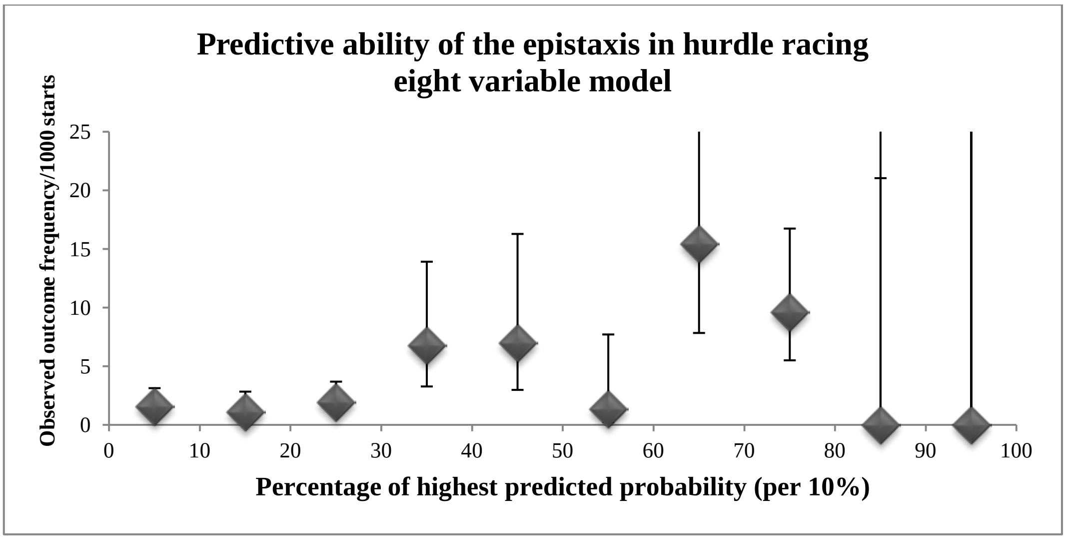


Figure 11-5: Plot of observed frequency of epistaxis in hurdle racing in 2010, across the range of predicted probabilities (0=0.0004 to 100%=0.1561) from the 2001-2009 model. Diamonds indicate the observed frequency of events per decile of predicted probability, with vertical lines representing 95% confidence intervals, calculated using the Wilson method (Wilson 1927)**.**

11.4.2.6 Epistaxis in Steeplechase racing

The 2001-2009 models' covariate patterns that matched 100% of the 2010 data was a six variable model with predicted probabilities ranging from: 0.0005 to 0.2183 per start. The outcomes of matching are shown in Table 11-15 and Figure 11-6. No cases were identified in the Top 1% or Top 5%. The frequencies of cases per start were higher (range 21.3 to 38.1 per 1000 starts) than the underlying frequency (8.3 per 1000 starts), for the top 10, 25 and 50% probability subsets. Use of the top 50% of predicted probabilities would have resulted in identification of 67% of cases from examining only 26% of starts, indicating that this model also had relatively good predictive potential.

Table 11-15: Results of matching all 2010 starts' covariate patterns with the covariate patterns identified from the multivariable model for epistaxis in steeplechase racing with the 6 variables with the highest odds ratios, from the 2001-2009 data. Of year 2010 starts, 10,551 of 10,551 (100%) were matched. The Top percentages refer to the covariate patterns identified as having the highest predictive probabilities.

% Probability subset	Top 1%		Top 5%		Top 10%		Top 25%		Top 50%		
Matched	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Total
Number of Controls	10462	1	10462	1	10398	65	10236	227	7746	2717	10463
Number of Cases	88	0	88	0	86	2	79	9	29	59	88
Column Total	10550	1	10550	1	10484	67	10315	236	7775	2776	10551
Cases/1000 Starts	**8.3**	**0**	**8.3**	**0**	**8.2**	**29.9**	**7.7**	**38.1**	**3.7**	**21.3**	**8.3**

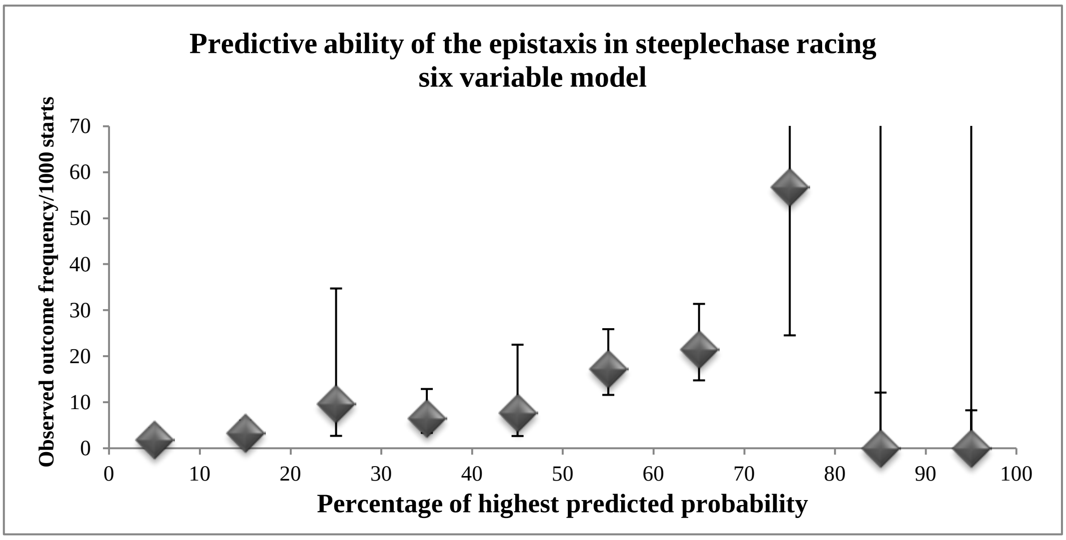


Figure 11-6: Plot of observed frequency of epistaxis in steeplechase racing in 2010, across the range of predicted probabilities (0=0.0005 to 100%=0.2183) from the 2001-2009 model. Diamonds indicate the observed frequency of events per decile of predicted probability, with vertical lines representing 95% confidence intervals, calculated using the Wilson method (Wilson 1927)**.**

11.4.3 Discussion on the findings from Part 2

In an ideal scenario it would be possible to use the 2001-2009 models to identify covariate patterns with significant risk of outcome (injury), which would then allow intervention to help reduce the risk of injury across the population. Importantly, identification of high risk covariate patterns would facilitate focussing attention on a smaller population of animals (highest risk groups) in order to reduce the frequency of outcomes. For example, it might be that additional veterinary checks could be put in place, or that horses could be prevented from running if they had a covariate pattern associated with particularly high frequency of outcome. As an example, if pre-race inspection could predict epistaxis occurrence, then using the top 50% of covariate patterns from the epistaxis in steeplechase model would have enabled identification of 67% (59/88) of cases by examining horses prior to 2,776 starts in 2010. This would have equated to examining approximately: less than 10 starts per day; less than four starts per meet; and less than one start per race, which would not have been unreasonable. Unfortunately pre-race inspection does not allow prediction of epistaxis, so this would not have been a useful exercise, but a similar situation could be envisaged for injuries that are pre-empted by lameness (unfortunately not all fractures are), which may be identified at pre-race inspection.

The success of identifying covariate patterns (from the 2010 data) with increased frequencies of outcome, based on the 2001-2009 models, varied between outcomes. Interestingly the more specific outcomes (e.g. epistaxis in comparison to fatality) were associated with the highest predicted probabilities, despite lower outcome frequencies. Whilst it can be seen from a number of the models that it was possible to markedly increase the frequency of outcomes per start by focussing on high predictive probabilities, when it comes to making use of the models, perhaps more important would be the ability to predict / find a high proportion of cases is probably more important. An ideal predictive model would facilitate identification of the majority of cases from a very small percentage of starts. The ability of the models evaluated here to do this was quite variable, ranging from identification of 9% to 67% of cases from 4.5% to 29% of starts. Obviously, interventions based on these predictions need to be tailored to the outcome and predictive ability. For example, it might be more appropriate to introduce additional veterinary examinations for the 29% of starts matched to the Top 50% of predictive probabilities for fatality than to prevent such a high percentage of starts occurring. Further discussion with the racing authorities on these findings is indicated. It might also be worth investigating the effect of combining the models for multiple outcomes, to see if it is possible to find covariate patterns associated with high predictive probabilities for several outcomes. If these existed, it might be possible to reduce the prevalence of multiple outcomes by targeting a small number of risk factors.

The predicted probabilities varied between the models, with the highest maximum value (0.4459) in the SDF tendinopathy model for hurdle racing and the lowest maximum (0.0314) in the fatality model for steeplechase racing. Because the predictive abilities of the models were not perfect (probability of 1), it would not be expected that the covariate patterns with the highest probabilities would definitely be associated with a case in the 2010 data. Rather, a trend for increased frequency of cases with the higher predicted probabilities was expected and observed in all models (Figures 11-1 through 11-6). In a well calibrated model, a diagonal line running from lower left corner to upper right corner (demonstrating increased outcome frequency with increased expected probability) would be expected and was variably seen for the different models in this study.

One of the difficulties encountered with using the predicted probabilities from the 2001-2009 covariate patterns was that not all potential covariate patterns were accounted for, which meant that not all of the 2010 data (and theoretically not all future data) could be matched. In this study, this was dealt with by reducing the number of risk factors in the model to the lowest number (with the highest odds ratios) until all 2010 covariate patterns were accounted for (although this does not mean that alternative patterns could not occur in future data sets). An alternative approach that was considered was to analyse the covariate patterns in more detail and try to predict the missing values, so that all covariate patterns could be assigned a predicted probability. The difficulty with that approach would be that whilst predicting the effect of changing one category of a variable within a covariate pattern would theoretically be possible, based on other most closely matching patterns, predicting the effects for multiple different categories amongst multiple different risk factors would be extremely difficult, because of the unknown interactions between the variables.

Despite producing models for comparison in which all predicted probabilities were matched, because of the low prevalence of outcome for the models, frequently the top 1% and 5% matched groups included no cases. This meant that it was not possible to assess how useful these patterns would be for identifying potential cases (when theoretically they should be the best). Potentially these patterns could be validated against a larger data set (more years) in the future.

11.5 Conclusion

Validation was performed on a selection of the models produced in earlier chapters, using a novel data set from 2010, utilising calibration and discrimination techniques as recommended by Royston et al. (2009). These techniques demonstrated that the models had differing ability to predict outcomes in the 2010 data, with varying calibration and discrimination. Definition of acceptable model performance, prior to clinical use, is not going to be straightforward and will vary with outcome and resultant measures. It is likely that a less well calibrated or discriminative model would be considered more acceptable when planning minor interventions for a less significant outcome, than it would be for instigating major changes to the rules of racing or when considering an outcome such as fatality. It is clear that further discussion with the racing authorities is required to help define what is acceptable for each outcome. Further work to increase the predictive ability of models, by inclusion of training and health data, could dramatically improve the usefulness of these types of models.

12 Conclusions

12.1 Introduction

The goal of this PhD was to identify risk factors that could be modified to reduce the number of injuries encountered in jump racing in GB. Thoroughbred horse racing is a very popular sport in GB as can be observed from the numbers of horses and starts evaluated in this thesis. It is important to remember that associated with this large population of horses are a very large number of people, including all those involved in breeding, training, veterinary care and racing administration. All of these people have the potential to be affected by changes to racing regulations, especially if those restricted the number of races or the numbers of horses that are allowed to run. As such, it is vitally important that recommendations that are made are based on best available evidence. Despite the years of study planning, data collection and analyses performed in this work, identification of clearly defined recommendations to reduce the risk of injury and fatality has not proven to be straightforward. Whilst this is disappointing, reasonable explanations can be proposed, associated with a number of factors related to the data set and chosen analyses:

1. The outcomes being investigated were all relatively infrequent; ranging from the highest: 7.2 cases of SDF tendinopathy per 1000 steeplechase starts to the lowest: 0.35 cases of hind limb fracture per 1000 hurdle starts. Whilst these low incidences are what everyone involved with racing and horse welfare would want to find, they meant that it was difficult to identify significant risk factors for these events. These low incidences also mean that considerable time is required in order to recruit more cases to increase study power and/or help facilitate model validation (as seen in Chapter 11). To compound this, whilst time can be accounted for in the analyses, multiple changes occur in racing over time including: racing regulations, recording systems, veterinary treatments and training approaches, so recruitment over longer periods may not serve to clarify the significance of risk factors, especially for the less prevalent outcomes.

2. Racing in GB is closely regulated by the BHA, which continually collect data and perform regular audits. In conjunction with this, racecourse staff (clerks and grounds staff in particular) devote their time to preparing and maintaining racecourses and are very aware of injuries that occur at their courses, so factors obviously related to increased risk of injury (tight bends, wrong camber or areas of poor drainage) are usually identified quickly, without need for complex epidemiological analyses. As a result, it is likely that

major risk factors have already been identified and modified over the years. For example it was previously recognised that racing on surface going classified as “hard” was associated with increased numbers of injuries, so racing on this surface categorisation was banned. With this background it is reasonable to expect that the analyses performed in this study were less likely to identify major risk factors that hadn’t been thought of previously, or for which data are not available. Also, whilst a large number of risk factors were investigated in this study, their inclusion was based on *a-priori* hypotheses, i.e. people involve in racing thought they might be important.

3. A very large number of inter-related risk factors are associated with every race start. Although multivariable modelling techniques are able to determine the significance of individual risk factors whilst accounting for the effect of others, because the inter-relation between risk factors is so complex, interpretation of the outcomes can be difficult, especially with high powered studies with many variables in the final model. This challenge is highlighted by the number of significant interaction terms identified in the models. It was also observed during model building, when risk factors observed to be significant at the univariable level were non-significant in the multivariable models and vice versa. Theoretically, inclusion of as many risk factors as possible in the final multivariable model might be beneficial, allowing interpretation of the association between the risk factor and the outcome, whilst accounting for everything else. However because of interaction and confounding between variables, this would be unlikely to have been a useful approach. Instead the strongest associations between risk factors and outcomes were identified and then assessed in conjunction with other risk factors to see if they remained significant. By extrapolation it is likely that those risk factors that remained significantly associated with the outcome once other factors were accounted for truly had a strong association with the outcome.

12.2 Choice of modelling technique

Because of the multiple risk factors being investigated in conjunction with binary outcomes (i.e. injury or no injury), logistic regression modelling was chosen for the analyses. The data being analysed were clustered (Chapter 1 – Figure 1-1) and in order to allow inclusion of horse, race and track as different levels, single level models were produced at the level of race start. Potential effects of clustering at higher levels were examined once the single level multivariable models had been finalised. If this had not been done, separate hierarchical models would have had to be produced for each of the different levels of interest (e.g. horse, racecourse, trainer), the results of which would then have had to been combined prior to interpretation. It can be seen from the low “rhos” identified for each of the random effects in the models, that production of separate models for each would have been unlikely to produce useful additional information and would be unlikely to alter model composition. An alternative would have been to produce multi-hierarchical models, but this has been shown to be difficult with this type of data (Parkin et al., 2009).

The decision to perform case-control analysis, using all non-outcome starts as controls was made because, selection of a subset of non-outcome starts as controls may have resulted in biases during the analysis. For example it is likely that a case to control ratio of 1:4 would have resulted in similar power for the analyses, but would then have meant that four controls had to be selected for each case. These controls could relatively easily have been chosen at random from the data, but this might have reduced the ability to examine the effect of the smaller clusters of random effects (e.g. jockey or dam). Equally, controls could have been selected based on matching cases such as by: race, age, sex, gender, training yard but this would have resulted in inclusion of pre-conceived associations, and so this control selection method was also avoided.

12.3 Choice of risk factors

Multiple risk factors were analysed for each of the outcomes examined in this thesis. These risk factors were determined following discussion with multiple veterinary surgeons and staff associated with racing administration (from the BHA and Weatherbys), as well was from those identified as being important in previous research in this area. As many risk factors as possible were included in the analyses because it was thought that it would be better not to make assumptions about what would be significant. However, by taking this approach (i.e. attempting to investigate very many different risk factors), it was sometimes difficult to completely distinguish risk factors from each other. An example of this would be the examination of: number of races over a previous period; whether the horse had made previous starts in that season or race type; days since previous starts; and horse age, each of which were considered as potentially being related to the outcome, but each also are clearly related to each other.

Whilst the choice of order of submission of variables to the multivariable models could be based on which had the strongest (and most significant) associations with the outcome at the univariable level, submission of variables which represented the same information in slightly different ways clearly needed to be avoided. This was performed by examining the effect of addition and subtraction of each variable to the multivariable model, with and without the other variable(s) that represented the same data, on each association. To make matters more difficult, in many cases the outcome variables under examination showed evidence of lack of linearity or were already categorised (e.g. season), which in turn meant that variable manipulation had to be performed prior to multivariable model building. Whilst this is an accepted step in logistic regression model building, it resulted in the ability to manipulate the data such that varying odds ratios, P-values and AICs could be obtained for almost every variable, which made choice of variable for submission to the multivariable models problematic.

12.4 Univariable analyses

The associations between each proposed risk factor and the outcomes were initially examined using univariable logistic regression. In order to make the models as parsimonious as possible, manipulation of the variables was performed. Numerous approaches to variable categorisation have been proposed, including: biologically plausible categorisation; categorisation based on *a-priori* hypotheses; and a more statistical approach by finding the categorisation that fits the data best. Whilst it was considered important that the categorisation of variables made biological sense (for example it may not have been deemed appropriate to categorise two year olds and 10 year olds together and then compare them to three to nine year olds), it was considered better not to apply *a-priori* hypotheses to the categorisation because of the possibility that this would bias the results, in particular by increasing the chances of missing relevant associations. For example, it is not inconceivable that three to nine year olds were at higher risk than both two year olds and 10 year olds, as it may be that different aetiological / pathophysiological processes result in the latter group being at decreased risk. Instead it was decided that the best approach was to try and categorise variables in such a way that best represented the data, but also made biological sense. The approach chosen for this was to visualise the associations using the “Lintrend” function in Stata, to categorise the data based on the visual appearance and/or subsets of it and to use the AIC as a guide (aiming for the lowest value). Considering the subsequent challenges in making useful recommendations based on the data, there is no question that an alternative approach (to trying to get the best “fit” for the data) may also have been appropriate and might have reduced the amount of time taken for analysis – for example categorising horse age into: young, middle aged and old, rather than examining the data to determine the best categorisation of age groups. However, the approach taken; including multiple categorisations of each variable and repeated submissions to the multi-variable models, would have been more likely to determine significant associations if they truly existed and would have also produced categorisation, such as that suggested, if they were appropriate for the data. For all models, the results of univariable analyses were reported, although interpretation of these should be performed cautiously because of the significant potential for interaction and confounding between variables.

12.5 Multivariable model building

A number of approaches for submission of variables to multivariable logistic regression models have been described, with the two main options being forward or backward addition / subtraction of variables. In the forward approach, variables are added sequentially to the multivariable model. In the backward approach, all variables are included in model to start with and then removed sequentially. In both instances, the common approach is to conclude with a multi-variable model in which all variables are significantly (significance having been pre-defined) associated with the outcome. In the analyses performed in this thesis, a forward stepwise approach was chosen because of the high number of variables being examined. This technique also facilitated the addition of variables in multiple different categorisations (if necessary), to determine which represented the data the best.

Automated approaches to variable submission are also available, but were not adopted here because the software used (Stata) did not facilitate easy categorical variable submission and because it was considered that monitoring of the variables would be improved through manual submission (i.e. it was easier to observe the effect of the addition of each variable in each categorisation, by stepwise building the models manually). As discussed above, a major challenge associated with examining so many variables was that of dealing with the inter-relations between them. For example it might have been that number of starts in the previous three months and days since previous start were both found to be significantly associated with a particular outcome at the univariable level, but (unsurprisingly) then acted as a confounder, or correlated with each other in the multivariable model, such that the odds ratios and P-values changed for both. In this situation the decision was made to remove the variable that was altered significantly in the multivariable model and/or retain the variable that resulted in the multivariable model with the lower AIC. Whilst it was often clear which variables were likely to interact with each other, interaction terms were examined in all models and the same process was repeated for variables with interaction terms above a certain cut-off. This approach meant that variables significantly associated with the outcomes were not always included in the final models, solely because of the inclusion of a different variable. As such, alternative final multivariable models could have been produced, depending on the selection of variables (and their categorisation), which should be considered when interpreting the results. As discussed above, when possible the models were produced in such a way that they represented the data as well as possible. An alternative would have been to only include variables (in categories) thought likely to be associated with the outcome, but considering the ability to manipulate the inclusion of variables, this might have biased the results.

12.6 Available data

The data available in this study came from two main sources: that relating to horse injuries and fatalities came from the BHA, whilst information about the horses themselves, as well as race and training details came from the company in charge of racing administration in GB (Weatherbys Ltd.).

12.6.1 Injury data

Information about injuries sustained during racing was only available from events recorded at racecourses. Information was not available about the progression of cases, or about cases that were subsequently diagnosed with a condition that had been caused by the race itself (e.g. a tendon injury that was not clinically apparent until the day after racing). As such, the results of this research are not exhaustive for conditions that occurred during racing. This has implications when it comes to interpreting the results, because certain conditions may have been more prevalent than has been reported here. In addition, horses that had injuries which were not diagnosed until after they had left the racecourse, would have inadvertently been included as controls, which may have affected the outcomes for the models. This was considered to be more likely for injuries such as tendinopathy than for fractures (which generally present acutely and are very apparent clinically), but rarely could have included smaller stress fractures, where the horse did not show signs at the racecourse. It is likely that the above situation (of conditions being subsequently diagnosed) would not have occurred frequently and would have been less likely for moderate to severe injuries (as these would likely have been observed at the racecourse). In addition, the conditions that were undiagnosed at the racecourses would have had a more significant adverse effect on the results of the models for outcomes of low incidence. Because tendinopathy was a relatively frequent outcome, this concern was thought less likely to have had a major impact on the results.

In addition to the lack of follow-up data for horses injured at the racecourses, there was also no information available about injuries that occurred in training subsequent to racing or indeed injuries that had occurred prior to racing. For example it is possible that subclinical injury sustained whilst racing pre-empted an injury during training, shortly afterwards. As discussed previously, pre-existing (possibly sub-clinical) injury has been recognised as a likely risk factor in the subsequent development of catastrophic injury during racing by others (Parkin et al. 2006; Stover 2012) and injuries frequently occur during training (Verheyen and Wood, 2004; Ely et al., 2009). Consequently, to fully understand the aetiology of (and risk factors for) injury during racing, ideally previous training and medical histories should be fully evaluated in addition to factors associated with the race and previous racing history. Because of the number of different trainers involved in jump racing in GB, this would be very difficult to achieve, even if provision of information was made mandatory by the BHA. Individual training risk factors, have been examined previously, and would likely have to be tailored to each training yard as length, slopes and surfaces of training gallops vary between yards, as does the definition of horse speed. A situation in which trainers and treating veterinary surgeons were obliged to report information about horse injuries sustained during training could be envisaged, but there is considerable potential for bias and/or lack of reporting for fear of racing bans or other restriction. This is potentially an area worth discussing with the BHA.

As discussed in Chapter 2, information about injuries and fatalities was collected from veterinary surgeons attending horses at the racecourses and as such was prone to specific errors and biases relating to variability in diagnoses and recording. In association with this, there was some variation in the categorisation of injuries, such as mild/moderate/severe tendon injuries, that required a subjective decision to be made by the veterinary surgeon attending the case. On top of this, injuries were diagnosed by racecourse veterinarians, whilst a separate veterinarian (from the BHA) was then responsible for transferring the details onto the computerised database, which resulted in some errors of recording (as observed in Chapter 7). Although there was variability in the racecourse veterinarians and their experience, all of these had a minimum of four years equine veterinary experience and all had attended a racecourse veterinary surgeons training course that are pre-requisites to work at the racecourse. As such all diagnoses made in the study were by “experienced” equine veterinary surgeons. Whilst it may have been better to have a single very experienced veterinary surgeon making all the diagnoses and collecting the information about every injury that occurred, to reduce variability in diagnosis and errors in recording, this would clearly not have been plausible when collecting information from multiple different racecourses on the same day.

The injury diagnoses recorded from the racecourses included certain categorisations that required some interpretation prior to analysis. For example: “possible fractures” or “mild” tendon injuries were reported. To facilitate ease of interpretation, it was decided that only definitive diagnoses were chosen for the analyses, such that cases of “possible fracture” were excluded. Because the majority of diagnoses were made based solely on clinical examination, this approach could be questioned: certain fractures, particularly those that are minimally displaced and surrounded in muscle (e.g. pelvic and cervical fractures) can be hard to confirm by clinical examination alone. It is surprising to this author that more of these types of fracture were not recorded as “possible” because without imaging it can be very difficult to confirm or dispute the presence of fractures. Potentially then, there is an argument that “possible fractures” should have been included in the analyses for some of the outcomes, however it is likely that the impact of doing so would have been minimal.

12.6.2 Horse and race data

The information from Weatherbys Ltd. was also prone to errors of recording, but generally related to less subjective information than injury diagnoses, such as horse sex or age, and so may be considered more reliable. However, some problems were still encountered when using their data as certain variables were based on subjective recordings. A prime example of this was that of surface going, which was found to be significantly related to outcome in multiple models. Whilst the inclusion of a mechanical measure to help standardise going measurements may have improved the objectivity, following discussion with the clerks and grounds men at a number of courses, it was clear that some variability in interpretation of the results remained. In addition to this, because going measurements vary around the length and across the width of the track, there is some contention about the suitability of using a single summary measure of surface going. Other techniques for measuring surface firmness have been employed in other parts of the world, such as a tractor pulled device that takes multiple ground surface measures across the width of the track, however these have not been validated in GB and are used mostly for non-turf surfaces. In addition, following discussion with grounds-men, it is thought likely that the surface firmness at take-off and landing sites around jumps is very important and may be more closely associated with injuries than a single measure of surface firmness for the whole track. Based on the findings in this study, this is clearly an area that warrants further research.

Another variable that was missing from the data available from Weatherbys was that of “race speed”. Accurate race speed data was only available from the year 2004 onwards. A decision was made not to include this variable in the analyses, partly because it would have meant exclusion of three years of data, but mainly because it was considered that race speed was not a variable that could be manipulated to reduce injury rates, i.e. concluding that horses should be encouraged to run more slowly would not be a recommendation that would readily be adopted by any trainer. Potentially though, racetracks could be manipulated such that races are run at a slower pace.

12.7 Risk Factor Model Results

Summary tables of the risk factors found to be significantly associated with the different outcomes examined in the thesis, ordered by frequency of inclusion in the different models (highest to lowest) are shown in Tables 12-1 to 12-5. To facilitate interpretation, the risk factors are summarised such that an overall description for each one was included. For example, going was recognised as an important risk factor in a number of the models, but categorisation varied: in the fatality in hurdle racing multivariable model, going rated as firmer than “good-to-soft” was recognised as being associated with increased likelihood, whilst in the SDF tendinopathy in hurdle racing model each category of going was included individually. In both instances, firmer going was recognised as being associated with increased likelihood of outcome (Table 12-1). The purpose of these tables is to allow examination of the potential implications of interventions, the question being: if we made an intervention to reduce the likelihood of one outcome, how would that impact on other outcomes?

12.7.1 Race related variables (Table 12-1)

Limiting the permissible seasons in which national hunt (NH) racing can occur would be relatively easy. A major question prior to instigation of this project was whether NH racing should be allowed to continue in the summer season. It can be seen that NH racing in the summer does result in an increase likelihood of fatality and tendon injury, so this should be considered. However, the numbers of races run in the summer season are relatively low (14% and 12% of total hurdle and steeplechase starts, respectively) limiting the impact of this intervention. Also, although of less concern, stopping summer NH racing might result in additional horses running in the winter or spring seasons, both of which were observed to be associated with increased likelihood of epistaxis and pelvic fracture.

Increased firmness of surface going was significantly associated with a number of the outcomes, such that it is clear that efforts should be made to run NH races on ground that is as soft as possible. This information needs to be conveyed to racecourse grounds men and clerks and will be in the policy advice document produced as a result of this research. On a practical note, a balance clearly has to be struck between obtaining soft ground and suitably maintaining the surface to allow multiple races to be run, as soft ground tends to get damaged from horse hoof impact more quickly.

It was interesting that ground surface was not associated with most of the fracture types investigated in this study, which could be the result of relatively low numbers of outcomes in those analyses, but could also be an indication that proximal limb fractures have a different aetiology to the distal limb fractures, as reported previously (Parkin et al., 2004a, 2004b, 2004d). This disparity between proximal and distal limb fractures could potentially be explained by the hypothesis that proximal limb fractures are more the result of pre-existing stress (hence the predilection stress-fracture sites of the humerus, femur, tibia and pelvis, in the proximal limbs), rather than the result of acute concussion (+/- pre-existing stress) which could be the cause of the distal limb fractures. It is also possible that proximal limb fractures are more often associated with a fall at a fence, than distal limb fractures.

Limiting race distance would potentially be beneficial in reducing the frequency of a number of outcomes. Reasonable hypotheses can be proposed for these associations such as: time at risk, horse fatigue and type of race and ideally these should be examined in more detail before this decision is made. It is also possible for example, that shorter races would be run at a faster pace, which could equally result in more injuries.

Whilst it is important to include multiple variables in the models, certain variables cannot be directly altered to help reduce outcome frequency. Instead the results of these can be used to help better understand the aetiology of conditions or to help identify horses that are at increased risk. For example, year was included in the analyses to take into account the effect of changes with time, and whilst it is important to consider explanations for the high incidence of some injuries in certain years (as was done in the specific chapters), the year of race can clearly not be altered to reduce outcome frequency. Other variables observed to be associated with outcomes: race position in the run sequence, maiden/novice races; selling or claiming races and race time, could also be considered of interest when considering aetiology, but not alterable to reduce outcome frequency. As an example, whenever there are more than two races on a card, there will always be a race in the middle of the run sequence, so this is not alterable. Having determined that starts made in the middle of the run sequence are more likely to result in injury, it is not appropriate to reduce all race cards to two races. It is much more appropriate to identify reasons for this finding. For example, more competitive races run at greater speed are nearly always in the middle of the race card. This is a good example of the importance of trying to determine the causal link between a risk factor and the outcome before interventions are implemented.

The final race related variable found to have an association with outcomes was: increased numbers of runners, which was observed to be associated with decreased likelihood of SDF tendinopathy in hurdle racing and hind limb fracture in steeplechase racing, but to be associated with increased likelihood of pelvic fracture. It is of interest that reducing the number of runners in a race (to reduce the number of pelvic fractures) might actually result in increased numbers of tendon injuries and hind limb fractures. Without an explanation of the causal link between this risk factor and these outcomes it is difficult to determine the most appropriate course of action concerning race numbers. Whilst it would be easy to conclude that reducing the number of runners in a race would be erroneous because SDF tendinopathy is more prevalent than pelvic fractures, it might actually be the case that number of runners is a reflection of something else (e.g. quality of the race), which could be analysed and/or modified to result in a reduction in all three outcomes.

Table 12-1: Summary of race related variables found to be significantly associated with likelihood of outcome from all of the different models in this thesis.

Outcome / Risk factors	Fatal H	Fatal St	Ten Inj H	Ten Inj St	Epi H	Epi St	HL # H	HL # St	Plv # NH	PFL # H	PFL # St
Season(s) with incr. likelihood	Sum	Sum	Sum	Sum	Spr	Win or Spr		Sum	Win or Spr		
Increased firmness of Going	↑	↑	↑	↑	↑	↑				↑	
Increased race distance	↑	↑	↑	↑	↓				↑		
Year(s) with increased likelihood	2003	2009	2003 or 2005		2005 to 2009	2005 to 2009	2002 to 2009				
Position(s) in run sequence with incr. likelihood			Early & Mid	Early	Early	Early			Mid		
Increased number of runners			↓					↓	↑		
Maiden or Novice race	↓										↑
Race time(s) with incr. likelihood			Aft	Aft							
Selling or claiming race			↑			↑					

Key: Fatal=Fatality; H=Hurdle; St=Steeplechase; Ten Inj=superficial digital flexor tendinopathy; Epi=Epistaxis; HL = Hind limb; # = Fracture; Plv=Pelvis; NH = National Hunt; PFL = Proximal forelimb; incr.=increased; Sum=Summer; Spr=Spring; Win=Winter; ↑ = increase in the risk factor associated with **increased** likelihood of outcome; ↓ = increase in the risk factor associated with **decreased** likelihood of outcome; Mid=Middle; Aft=Afternoon.

12.7.2 Racecourse related variables (Table 12-2)

Only two risk factors related to racecourse factors were retained amongst the final multivariable models. The reason for the lack of significant associations is hard to explain, but tends to suggest that variables associated with the racecourses are of less importance when considering likelihood of injury, than horse or race related factors. It is also possible that the lack of significant associations was related to the inclusion of relatively few racecourse related variables in the analyses.

Racecourses with high numbers of race starts (compared to other racecourses) over the study period were found to be associated with an increased likelihood of fatality in hurdle racing but a decreased likelihood of hind limb fracture in steeplechase racing, whilst increased days since last race at the track was found to be associated with increased likelihood of SDF tendinopathy in hurdle racing. Possible explanations for the associations were discussed in the individual chapters, but reasons for the discrepancy between the outcomes are unclear. Whilst it would be relatively straightforward to control the number of starts per course over a set period, it is highly plausible that these associations are a reflection of a further unmeasured risk factor, for example differences in the quality of horses or races on the busier tracks compared to the quieter ones, and at different times in the racing seasons. If legislation altering the permissible number of starts or periods between races were to be considered, further investigation would be required to try and determine causal links. Based on the findings of these studies, with low numbers of relatively infrequent outcomes, this is unlikely to be worth pursuing. However it might be worth pursuing more detailed information about racecourse level factors such as course maintenance and management, to see if these are related to likelihood of injury.

Table 12-2: Summary of racecourse related variables found to be significantly associated with likelihood of outcome from all of the different models in this thesis.

Outcome / Risk factors	Fatal H	Fatal St	Ten Inj H	Ten Inj St	Epi H	Epi St	HL # H	HL # St	Plv # NH	PFL # H	PFL # St
Increased starts at that racecourse	↑							↓			
Increased days since last race at track			↑								

Key: Fatal=Fatality; H=Hurdle; St=Steeplechase; Ten Inj=superficial digital flexor tendinopathy; Epi=Epistaxis; HL = Hind limb; # = Fracture; Plv=Pelvis; NH = National Hunt; PFL = Proximal forelimb; ↑ = increase in the risk factor associated with **increased** likelihood of outcome; ↓ = increase in the risk factor associated with **decreased** likelihood of outcome.

12.7.3 Trainer and Jockey related variables (Table 12-3):

Multiple different measures of trainer and jockey performance were analysed in this theses, all based on the success of horses trained or ridden by them over the period under scrutiny. Based on these measures, more successful trainers (with increased percentage of first or placed finishes, or increased finish position score values) were associated with increased likelihood of fatality in hurdle racing, or pelvic fractures, but decreased likelihood of tendon injury in hurdle racing. More successful jockeys (with increased percentage of first place finishes) were associated with decreased likelihood of pelvic fractures. Amateur jockeys were found to be associated with decreased likelihood of epistaxis but increased likelihood of proximal forelimb fracture in steeplechase racing. Reasons for these associations were discussed in individual chapters and once again discrepancies between the outcomes are hard to explain. Importantly, the significant associations observed serve to provide additional information that might aid in recognising the aetiology of conditions, rather than necessarily produce alterable factors to reduce the frequency of outcomes.

Table 12-3: Summary of Trainer and Jockey related variables found to be significantly associated with likelihood of outcome from all of the different models in this thesis.

Outcome / Risk factors	Fatal H	Fatal St	Ten Inj H	Ten Inj St	Epi H	Epi St	HL # H	HL # St	Plv # NH	PFL # H	PFL # St
Trainer increased % of 1st places	↑										
Trainer increased % placed finishes									↑		
Increased Trainer FPS score			↓								
Amateur jockey						↓					↑
Jockey increased % 1st place finishes									↓		

Key: Fatal=Fatality; H=Hurdle; St=Steeplechase; Ten Inj=superficial digital flexor tendinopathy; Epi=Epistaxis; HL = Hind limb; # = Fracture; Plv=Pelvis; NH = National Hunt; PFL = Proximal forelimb; ↑ = increase in the risk factor associated with **increased** likelihood of outcome; ↓ = increase in the risk factor associated with **decreased** likelihood of outcome; FPS = Finish position score.

12.7.4 Horse related variables (Tables 12-4 and 12-5):

Multiple variables relating to the horse were observed to be associated with the outcomes. For ease of discussion, these have been separated into those relating to the animal itself (Table 12-4) and those relating to previous racing histories (Table 12-5).

Horses that had previously had a SDF tendinopathy or epistaxis diagnosed at the racecourse were at increased risk of developing those conditions again. A similar association was not observed for any of the fractures evaluated, which is likely related to the severity of those outcomes and the relative few animals that actually raced again after those injuries. To reduce the frequency of SDF tendinopathy and epistaxis in jump racing, it would be possible to impose restrictions relating to previous injury, as is done for epistaxis in many other jurisdictions (including Australia, Hong Kong, New Zealand, South Africa, USA) and has been for tendinopathy in one jurisdiction (Hong Kong). A major challenge with this in GB would be the fact that these conditions can and do occur during training, so basing restrictions just on observed occurrence during racing may not necessarily have a significant impact on the overall frequency of these conditions. Also, it could be considered unfair to penalise animals in which injury/clinical sign is observed during racing, whilst horses that have the same disorder during training are not penalised. Imposition of strict restrictions can also result in attempts to hide the occurrence of outcomes during racing and training, as was observed by groom’s use of red cloths to wipe away blood at horse’s nostrils post-race in one jurisdiction, once legislation relating to epistaxis was introduced. As discussed in the chapters relating to epistaxis and tendinopathy; whilst both conditions obviously have connotations relating to horse welfare, the alternative – a ban from racing, might actually result in a worse outcome, if the horse is forced to retire from racing. Further work is required to accurately define the subsequent careers / outcomes of horses that leave racing, but there is no doubt that a proportion of horses are deemed unsuitable for other purpose and end up being euthanased.

Older horse age and increased number of years in racing were found to be associated with an increased likelihood of a number of conditions: fatality, SDF tendinopathy, hind limb and pelvic fracture. The frequency of these outcomes potentially could be reduced by defining an upper age limit and restricting the number of years that horses are allowed to race. Once again, this would have to be balanced against the consideration as to what these older racehorses would end up doing if not racing.

Increased horse age at first race was observed to be significantly associated with an increased likelihood of tendon injury and epistaxis in hurdle racing. As discussed in the respective chapters, this association is thought likely to be related to the importance of physical development and suggests that racing/training at an early age might be of benefit in reducing the likelihood of subsequent racing-related disorders. If this is the case, then it could be suggested that the BHA should recommend that training should start from an early age for all horses destined for racing. Importantly though, the causal path for this association is not necessarily straightforward, as horses of increased age at first race are likely to be representative of a certain population, for example: horses that had started their careers in national hunt racing, which could in itself have had an impact on the likelihood of outcome. Equally, it is possible that the population of horses that started racing at an earlier age and continued to race, were representative of a healthy population, such that horses prone to injuries, would have sustained them previously and so been excluded from the analyses.

The “proportion of field beaten” variable was only included in the analysis of epistaxis because there was some question as to the impact of epistaxis on racing performance, in contrast to all other outcomes which have predictable negative effects on performance. Epistaxis was observed to have a significant association with poorer finish position, which could be used to promote the importance of the condition to those interested in performance, i.e. trainers. Sex and official rating were observed to be significant in two outcomes, however neither could be considered modifiable, as a means of reducing likelihood of outcome.

Table 12-4: Summary of Horse related variables found to be significantly associated with likelihood of outcome from all of the different models in this thesis.

Outcome / Risk factors	Fatal H	Fatal St	Ten Inj H	Ten Inj St	Epi H	Epi St	HL # H	HL # St	Plv # NH	PFL # H	PFL # St
Horse had outcome previously	**N/A**	**N/A**	↑	↑	↑	↑					
Increased horse age	↑	↑		↑			↑ (dotted)				
Increased age at first race			↑		↑						
Increased weight carried			↑				↑				
Horse years completed in racing			↑							↑	
Increased proportion of field beaten					↓	↓					
Sex associated with incr. likelihood										**Male**	
Increased horse official rating				↓							

Key: Fatal=Fatality; H=Hurdle; St=Steeplechase; Ten Inj=superficial digital flexor tendinopathy; Epi=Epistaxis; HL = Hind limb; # = Fracture; Plv=Pelvis; NH = National Hunt; PFL = Proximal forelimb; N/A=Not applicable; ↑ = increase in the risk factor associated with **increased** likelihood of outcome; ↓ = increase in the risk factor associated with **decreased** likelihood of outcome. Dotted arrow represents unclear association; incr.=increased.

12.7.5 Horse previous start history (Table 12-5)

The percentage of previous career in flat racing was the only risk factor examined and found to be significantly associated with all examined outcomes. It was observed that having had a larger percentage of previous career in flat racing was associated with an increased likelihood of each of the outcomes (although the categorisation of previous career flat percentages varied between outcomes). Potential reasons for the association with previous career flat racing history were discussed in individual chapters. It is apparent that either: having not had many previous jump starts, or having had a large number of previous flat starts was associated with increased likelihood of injury. Once again, whilst the risk factor itself is unlikely to have been causal, this finding is of potential importance in directing focus to populations of at risk animals. Based on the finding, it might be of benefit to target pre-race examinations at horses that are early in their jump racing careers having run in flat racing, or horses that have run in a large number of flat races prior to coming to jump racing. As mentioned, the categorisation varied between models, but greater than 75% previous career in flat racing was included in a large number of models, so it might be worth calculating: "percentage of previous career runs in flat racing" for each horse prior to each jump race and to then include additional veterinary checks (as suggested for horses with previous injuries) on animals that were in the highest risk group. Of course, there is no guarantee that additional veterinary checks would reduce the likelihood of outcome, but this is something that could potentially be introduced and then audited.

The numbers of starts made in previous time periods were found to be associated with almost all of the outcomes evaluated. Selection of time periods for these variables has been discussed in individual chapters. Increasing numbers of starts (particularly those made a long time prior to the current start) were generally associated with reduced likelihood of outcomes, which is hypothesised to be related to a "healthy horse" effect and as such could not be considered causal, rather, it is simply an indicator of horse health and soundness. The number of starts in the previous four to six month period was the only risk factor observed to be associated with an increased likelihood of outcome (epistaxis), which is difficult to explain. It had been hoped that time period analysis would allow conclusions to be made about safe frequencies of racing and that recommendations could be produced to help reduce injury frequency by adjusting the frequency of racing. However, based on the observed results, this would not be easy because generally the more a horse raced, the less likely it was to have an injury. Increased time since previous race was observed to be significantly associated with increased likelihood of one outcome (proximal forelimb fracture in hurdle racing), in which no other time period variable was significantly associated. If the injury / outcome was deemed of sufficient importance by the BHA, this would warrant further examination. Currently animals that have not raced for a protracted period (365 days, or 250 days for certain specific races) undergo an additional BHA veterinary check prior to racing. This is because the BHA consider that prolonged periods away from racing are frequently because of horse injury, so additional clinical examination prior to racing to help identify continued problems are undertaken. Indeed, this is potentially why this variable was not observed to be of significance in these analyses; horses that could have become injured, may have been prevented from racing by pre-race veterinary examination. Notably it would be almost impossible to confirm the efficacy of the pre-race checks, because once a horse is stopped from racing, it is not possible to know if it would have sustained an injury. It would be interesting to see how many horses sustained an injury despite having had a pre-race check and to see how horses performed / if they sustained an injury, having been prevented from running on the basis of a pre-race check at a previous race meeting.

The significant associations with: first race type, change in race type and/or race distance provide potential further areas that could be investigated to help reduce the likelihood of injuries. However, these risk factors were observed to be associated with relatively few outcomes and for “changed race type” were associated with increased likelihood of one outcome but decreased likelihood of another. Therefore analyses of these risk factors may be of limited benefit in producing useful recommendations to reduce the likelihood of outcomes.

Table 12-5: Summary of Horse previous start history related variables found to be significantly associated with likelihood of outcome from all of the different models in this thesis.

Risk factors \ Outcome	Fatal H	Fatal St	Ten Inj H	Ten Inj St	Epi H	Epi St	HL # H	HL # St	Plv # NH	PFL # H	PFL # St
Increased % prev starts on flat	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Increased starts >1 year previously	↓	↓		↓		↓	↓		↓		
Increased starts in prev 10-12 m	↓	↓	↓	↓							↓
Increased starts in prev 3m			⇣	↓		↓			↓		
Increased starts in prev 4-6 m					⇡	↑					
Changed race type from prev race	↓	↑	↓								
First race type(s) with increased likelihood			NHF					H			
Reduced race dist since prev race			↑								
Increased time since prev start										↑	

Key: Fatal=Fatality; H=Hurdle; St=Steeplechase; Ten Inj=superficial digital flexor tendinopathy; Epi=Epistaxis; HL = Hind limb; # = Fracture; Plv=Pelvis; NH = National Hunt; PFL = Proximal forelimb; prev=previous; ↑ = increase in the risk factor associated with **increased** likelihood of outcome; ↓ = increase in the risk factor associated with **decreased** likelihood of outcome; NHF=National Hunt Flat. Dotted arrows represent unclear associations.

12.8 Risk factor model validation results

Evaluation of the performance of the multivariable models when assessed on a novel data set (from 2010), demonstrated variable predictive ability, which were discussed in Chapter 11. It is important that this limited predictive ability should be taken into account when making decisions based on the models. Further investigation of risk factors found to be significant in the final multivariable models, but not in the novel data set, might be a waste of time. However it may be that the year 2010 was somehow “different” to the years used to produce the models and that for example, validating the 2001-2009 models against 2011 data could have produced a different validation result, hence the need for multiple validation against different years, or through the use of an alternate method. Certainly, making regulation changes based on variables with the above differences between models should be avoided, at very least until further research has confirmed their relationship with the outcomes. It would seem prudent to focus initially on risk factors that were found to be significant in both the original and the validation models.

12.9 Conclusions from risk factor models

Making recommendations to the BHA to help reduce the frequency of the outcomes evaluated in this study is not straightforward. Despite identification of multiple significant risk factors, many of them only apply to a small number of outcomes and/or are contradictory, such that reduction in one outcome might result in increased likelihood of another. In addition to this, for those outcomes that were evaluated against a novel data set, not all risk factors remained significant, or had equivalent effects on the outcomes.

Effect size also needs to be considered; taking into account the strength of the relationship between the risk factors and the outcomes, as well as the underlying frequency of the outcome. When examining the results from all of the final multivariable models, there were a considerable number of significant associations between risk factors and outcomes in which small (+/- <0.5) or very small (+/- <0.05) odds ratios were identified. These small odds ratios indicate that manipulating the risk factor will have a small effect on the outcome. This is particularly important when considering how infrequent most of the outcomes examined in this thesis were, because making changes (in policy, or rules of racing) that have a small impact on the likelihood of an infrequent outcome is unlikely to be worthwhile. It is also important to note that the severity of the outcome should be considered, as manipulating risk factors recognised to have a small effect size on an outcome of high importance (such as fatality), is likely more justifiable than doing the same for less severe outcomes (such as epistaxis).

Based on these findings, further analysis of: Season; Surface going; Race distance; Horses with previous injuries; Horse age; Previous flat racing start histories; and Number of previous starts, may all be worthwhile in helping to reduce the occurrence of the conditions examined.

To determine the potential effects of making adjustments to these risk factors, population attributable fractions (PAFs) were calculated. These can be defined as: the proportion of disease cases over a specified time that would be prevented following elimination of the exposures, assuming the exposures are causal. Using odds ratios as approximations for relative risk in order to minimise the effects of confounding, PAFs were calculated using methods described (Dohoo et al., 2010) using the following formula:

PAF = pd(aOR-1/aOR)

Where:

pd = proportion of cases exposed to the risk factor

aOR = adjusted odds ratio

As an example, the workings used for calculation of the PAF for summer season from the fatality in hurdle model are shown as follows:

pd = 162/752 = 0.215

aOR-1/aOR = (1.3-1) = 0.3 / 1.3) = 0.231

PAF = 0.215 x 0.231 = 0.049 = **4.9%**

Where multiple categories existed within the risk factor the following equation was used:

$$\mathbf{PAF = 1 - \sum(pd_i/aOR_i)}$$

Where:

pd_i = proportion of cases in the $_i$th exposure level

aOR_i = adjusted odds ratio comparing the $_i$th exposure level to the unexposed group

As an example, the workings used for calculation of the PAF for Going from the fatality in steeplechase model are shown as follows:

Group 1: “Soft” to “Good to Firm” going

pd = (576/606) = 0.95

OR= 2.11

pd/OR = 0.45

Group 2: “Firm” going

pd = (10/606) = 0.017

OR= 4.25

pd/OR = 0.00388

PAF = 1 – (0.45+0.004) = 0.546 **= 54.6%**

Population attributable fractions for each of the above recommended risk factors, for each categorical outcome significantly associated with multiple outcomes are shown in Table 12-6.

Table 12-6: Population attributable fractions for risk factors identified as being significantly associated with multiple outcomes in the models. Risk factor categories associated with increased likelihood of outcome are described, with the number of starts each category referred to in the 2001-2009 data set.

	Fatal H	**Fatal St**	**Ten Inj H**	**Ten Inj St**	**Epi H**	**Epi St**	**HL # H**	**HL # St**	**Plv # NH**	**PFL # H**	**PFL # St**
PAF % Season (% St)	**5** Sum (14)	**4.6** Sum (12)	**6.7** Sum (14)	**6** Sum (12)	**7.8** Sp (30)	**27.2** Wi/Sp (66)	N/A	**13.5** Sum (12)	**39.5** Wi/Sp (63)	N/A	N/A
PAF % Going (% St)	**28.4** >GTS (55)	**54.6** >H (m) (93)	**73.3** >H (m) (92.5)	**67.5** >S (m) (75)	**25.4** >S (75)	**27.5** >GTS (55)	N/A	N/A	N/A	**25** >G (20)	N/A
PAF % Dist (km) (% St)		**6** >4.8 (22)				N/A	N/A	N/A	**17.9** >4.4 (23)	N/A	N/A
PAF % Prev Inj (% St)	N/A	N/A	**3** Yes (0.001)	**5.7** Yes (0.007)	**7** Yes (1.3)	**15.6** Yes (3)	N/A	N/A	N/A	N/A	N/A
PAF % Age (yrs) (% St)			N/A		N/A	N/A	**21.7** >6 (35.5)	N/A	N/A	N/A	N/A
PAF % % Pre Fl (% St)					**4.9** >75 (7.2)	**1** >75 (0.4)	**13.1** >50 (21)	**3.1** >60 (0.4)	**10.7** >75 (4)		**7.4** >38 (7)

Key: Fatal=Fatality; H=Hurdle; St=Steeplechase; Ten Inj=superficial digital flexor tendinopathy; Epi=Epistaxis; HL = Hind limb; # = Fracture; Plv=Pelvis; NH = National Hunt; PFL = Proximal forelimb; PAF%=Population attributable fraction; Sum=summer; Sp=Spring; Wi=Winter; N/A=significant association not identified or identifiable; Going=surface firmness; >GTS=firmer than “good to soft”; >H=firmer than “heavy”; (m) = multiple categories of the risk factor evaluated simultaneously; >S=firmer than “soft”; >G=firmer than “good”; Dist=race distance; Grey squares refer to where a significant association was observed, but the format of the risk factor was continuous, so no PAF could be produced; Prev Inj=previous injury; % Prev Fl=percentage of previous career in flat racing.

It was not possible to produce PAFs for the risk factors in continuous forms. To facilitate analysis of these, categorisation and/or production of upper cut-offs should be considered, i.e. production of an upper age limit or race distance. The modelling techniques employed in this thesis, avoided risk factor categorisation based on pre-conceived ideas about likely relationships, but in this instance, discussion with the racing authorities, followed by further analysis may be warranted.

The PAFs shown in Table 12-6, demonstrate the percentage of cases of each outcome that could theoretically be avoided if the category reported was stopped from racing. For example, if steeplechase races in winter and spring were stopped, based on these data 27.2% of cases of epistaxis would have been avoided. Likewise, if running on any going firmer than “heavy” was prevented, based on these data 73.3% of cases of SDF tendinopathy in hurdle racing would have been avoided. Because of the number of starts that would need to be cancelled, neither of these suggestions is likely to be considered feasible by the BHA. The percentage starts that occurred under each category are reported (bracketed in the bottom row of each square). Generally the larger PAFs are associated with large percentages of starts, as would be expected. For example stopping all steeplechase racing in winter and spring would result in elimination of 66% of starts, whilst stopping hurdle races on anything other than heavy going would result in elimination of 92.5% of starts.

Alternatively the focus should be on risk factors with a high PAF but a low percentage starts, as making changes to these will have the potential to make a large reduction in outcome frequency without having a major impact on the number of starts. Based on Table 12-6; previous injuries for SDF tendinopathy and Epistaxis would be worth considering in the first instance. Once again injury severity needs to be taken into account. It appears that it would be possible to reduce their prevalence without having a major impact on the number of jump starts. However, it might also be considered as appropriate to restrict more races in order to reduce the likelihood of a more severe outcome such as fatality. In addition, the outcome for horses that are prevented from racing needs to be considered. There is undoubtedly a population of horses that will not progress from racing to alternative careers and their futures need to be considered when imposing regulations restricting horses from racing.

12.10 Overall Conclusion

Following extensive examination of the common injuries that occur in NH racing in GB, it is clear that injury rates are actually low. The work of all of the veterinary surgeons, racecourse staff, members of the BHA and the Jockey Club should be highly commended. However, as an investigator, it does lead to the rather disappointing conclusion that whilst improvements can still potentially be made, it is probable that making further significant reductions to that rate will be difficult and for some outcomes maybe even impossible. It has been recognised that underlying outcome frequencies occur in populations (Johns, 2012), this is likely true for injuries that occur in racing, such that if races are run, injuries are bound to happen, in other words, there is an "irreducible minimum" to which we may be close already. That is not to suggest that this research is not important, quite the opposite, as it provides a means of auditing the current situation, focusses attention on potential problems, guides further legislation and very importantly provides continued justification for jump racing in GB.

Potential future avenues to the research include: further examination of variables not included in these analyses (including race course management factors, training information and more detailed treatment and medication records which should be submitted prior to racing); further evaluation of predictive models as a means of determining each horse's risk of injury prior to racing; and investigation of the introduction of additional diagnostic aids (radiography and ultrasonography) at the racecourses and post-mortem schemes to help clarify the diagnoses for horses injured during racing.

13 Appendices

13.1 Appendix 1: Veterinary Reporting Form – used to record details of injuries sustained during racing prior to the Year 2000

THE JOCKEY CLUB

VETERINARY REPORT FORM (VRF1)

SECTION 1 - To be completed by the Veterinary Officer and sent to Weatherbys (Fax no 01933 440807)

Racecourse: Date: VO: ☐ NIL

Race no. Horse Trainer

Tendon/Ligament	☐ Strain			☐ Rupture		☐ Severed			☐ Lameness				
☐ SDFT	☐ LF	☐ RF	☐ LH	☐ RH	☐ prox	☐ mid	☐ dist	☐ LF	☐ Gr1	☐ Gr2	☐ Gr3	☐ Gr4	☐ Gr5
☐ DDFT	☐ LF	☐ RF	☐ LH	☐ RH	☐ prox	☐ mid	☐ dist	☐ RF	☐ Gr1	☐ Gr2	☐ Gr3	☐ Gr4	☐ Gr5
☐ SL	☐ LF	☐ RF	☐ LH	☐ RH	☐ prox	☐ mid	☐ dist	☐ LH	☐ Gr1	☐ Gr2	☐ Gr3	☐ Gr4	☐ Gr5
☐ DSL	☐ LF	☐ RF	☐ LH	☐ RH	☐ CL	☐ LF	☐ RF	☐ RH	☐ Gr1	☐ Gr2	☐ Gr3	☐ Gr4	☐ Gr5

Other Musculoskeletal Problems

1 ☐ Bruise/Haematoma 2 ☐ Laceration 3 ☐ Muscle Strain
4 ☐ Joint Sprain 5 ☐ Dislocation 6 ☐ Fracture

☐ Cannon	☐ LF	☐ RF	☐ LH	☐ RH	☐ Scapula	☐ LF	☐ RF
☐ Splint	☐ LF	☐ RF	☐ LH	☐ RH	☐ Shoulder	☐ LF	☐ RF
☐ Sesamoid	☐ LF	☐ RF	☐ LH	☐ RH	☐ Humerus	☐ LF	☐ RF
☐ Fetlock	☐ LF	☐ RF	☐ LH	☐ RH	☐ Elbow	☐ LF	☐ RF
☐ Pastern	☐ LF	☐ RF	☐ LH	☐ RH	☐ Radius	☐ LF	☐ RF
☐ Coronet	☐ LF	☐ RF	☐ LH	☐ RH	☐ Forearm	☐ LF	☐ RF
☐ Heel	☐ LF	☐ RF	☐ LH	☐ RH	☐ Carpus	☐ LF	☐ RF
☐ Hoof	☐ LF	☐ RF	☐ LH	☐ RH	☐ Hip	☐ LH	☐ RH
☐ Foot/P3	☐ LF	☐ RF	☐ LH	☐ RH	☐ Femur	☐ LH	☐ RH
					☐ Stifle	☐ LH	☐ RH
☐ Head	☐ Chest		☐ Pelvis		☐ Tibia	☐ LH	☐ RH
☐ Neck	☐ Trunk		☐ Quarters		☐ Thigh	☐ LH	☐ RH
☐ Back	☐ Sacroiliac				☐ Tarsus	☐ LH	☐ RH

Medical Problems

Respiratory

☐ Whistling ☐ Epistaxis
☐ Soft Palate ☐ SDF
☐ RR ↑

Cardiovascular

☐ Heart Murmur ☐ AF
☐ Vascular catastrophe ☐ Arrhythmia
☐ HR ↑

Exhausted horse syndrome

☐ Heat Exhaustion ☐ Tied up
☐ Exhaustion ☐ Ataxia
☐ Recumbency ☐ Collapse

Did accident/injury occur? ☐ Travelling ☐ Before race ☐ During race ☐ After race
Was the accident/injury? ☐ Observed only ☐ Examined ☐ Treated ☐ Untreated
If non-fatal, is expected incapacity? ☐ Short term (less than 3 months) ☐ Long term (more than 3 months)
If fatal, how/when did it occur? ☐ Died ☐ Destroyed ☐ Gun ☐ Chemical ☐ On track ☐ Off track

Comments:

☐ Display for next race only ☐ Display permanently

Examination before next race: ☐ Required ☐ Not required

SECTION 2 - To be completed by the Veterinary Surgeon/Officer attending the accident/injury and to accompanythe horse home

Name of horse: Trainer:

Treatment:

I have examined the horse described above and in my opinion it is ☐ Unfit to travel ☐ Fit to travel

Specified destination: Special requirements:

Signed: Name: Date: Time:

Telephone:

13.2 Appendix 2: Details of subheadings available in computerised recording system for injuries

Event Group	**Event Type**	**Event Structure**	**Event Region**	**Lameness/Gait**	**Event Location**	**Event Outcome**	**Fall Related**	**Action(s)**
Bone Injury	(Unspecified)	(Unspecified)	Unspecified	Not Lame	Race	Short Term	At a fence/hurdle	Next
Cardiovascular	Comminuted Fracture	Carpal	Right Hind	At Walk	Post-Race	Long Term	On the flat	Permanent
Digestive	Compound Fracture	Other (Remark)	Left Fore	Unspecified	Fall Fence/Hurdle	Chronic Condition		VO report made / Next
Exhaustion / Ataxia	Fracture	Pelvis	Both Hind	At Trot	After Finish - OLD	Destroyed		VO report made / Permanent
Gait Observations	Other (Remark)	Scapula	Right Fore	Non-Weight Bearing	Start/Stalls	Died		VO report made
Joint Injury	Possible Fracture	Skull	Left Side	At Canter/Gallop	Fall Flat	Died Off Course		Clearance / VO report made
Other M/S Injury	Arrhythmia	Thoracic spinous	Left Hind		Pre-Race	Died (Other)		Clearance / VO report made / Permanent
Other Medical	Fibrillation	Tibia/Fibula	Both Fore		Before Start - OLD	Destroyed (Other)		Clearance / VO report made / Next
Respiratory	HR Raised	Tooth	Right Side		Historical	Destroyed Off Course		
Skin	Murmur	Acc. Carpal	Behind		In Transit - OLD	Destroyed (Other)		
Tendon/Ligament Injury(No Previous)	Vascular Catastrophe	Humerus	In Front			Destroyed(Other)		
Tendon/Ligament Injury(Prev Unknown)	Choke	MC3	All Round			Died(Other)		
Tendon/Ligament Injury(With Previous)	Colic	MC3 Condylar	N/A					
	Dehydrated	MT3	Right					
	Distressed	MT3 Condylar	Both left and right					
	Fatigue	P1	Left					
	Fatigue Recumbent	Radius/Ulna	Left F+I7567					
	Heat	Sesamoid (Both)	Left					
	Heat Recumbent	Sesamoid (Lateral)						
	Myopathic ('tied up')	Cervical						
	Prolonged Recovery	Tuber Coxae						
	Lame	Costal						
	Patellar Fixation	Femur						
	Poor Mover	Head						

Event Group	Event Type	Event Structure	Event Region	Lameness/Gait	Event Location	Event Outcome	Fall Related	Action(s)
	Stiff	Knee area						
	Stringhalt	Mandible						
	Unlevel	MC2/4						
	Dislocation	Neck						
	Effusion	P2						
	Enlargement	P3						
	Penetration	Patella						
	Sprain	Sacro-coccygeal						
	Avulsion	Sesamoid (Medial)						
	Bruise / Haematoma	Tarsal						
	Inflammation /Sore	Thoraco-lumbar						
	Lacerated	Tuber Calcis						
	Laceration / Wound	MT2/4						
	Muscle Strain	Fetlock Joint						
	Puncture	Intercarpal						
	Concussion	Radio-carpal						
	In Season	Sacroiliac						
	Neurologic (Remark)	Stifle joint						
	Cough	Coffin joint						
	Epistaxis	Hock joint						
	Gurgling	Intercervical						
	Nasal Discharge	Pastern Joint						
	RR raised	Shoulder joint						
	Scope blood	Elbow joint						
	Scope laryngeal hemiplegia	Elbow area						
	Scope mucopus	Fetlock area						
	Scope NAD	Foot						
	Scope pharyngitis	Hock area						
	Scope SP displacement	Mouth						
	SDF	Pastern						
	Tubed	Sheath						
	Whistling/Roaring	Shin						
	Dermatitis	Shoulder area						
	Rainscold	Sole						
	Ringworm	Tendon area						
	Sarcoids	Hoof						
	Urticaria/Allergy	Back						
	Bruised	Chest						
	Dislocated	Coronet						
	Moderate (Strain)	Eye						

Event Group	Event Type	Event Structure	Event Region	Lameness/Gait	Event Location	Event Outcome	Fall Related	Action(s)
	Severe (Breakdown / Rupture)	Face						
	Severed	Forearm						
	Slight (Strain)	Frog						
		Heel						
		Nostril						
		Quarters						
		Ribs						
		Stifle area						
		Thigh						
		Trunk						
		Lip						
		Withers						
		Ear						
		Eyelid						
		Jaw						
		Muzzle						
		Perineum						
		Tongue						
		Abdomen						
		Suspensory						
		SDFT						
		T.Achilis/SDFT						
		DDFT						
		Check						
		Sesamoidean ligs						

13.3 Appendix 3 – R code used to calculate number of starts during specified time periods

The required variables as follows: race id, date, animal identification number, birth date (in specified format YYYYMMDD) and horse age were saved in a csv file.

The following R script written by Dr Matt Denwood MRCVS, was run:

```
if(!file.exists('tim.input.csv')) stop('The file "tim.input.csv" does not exist in the working directory')
alldata <- read.csv("tim.input.csv")

if(!all(names(alldata)==c("Race.ID", "Date", "Animal.ID", "Birth.Date", "Age", "starts.last.15days", "starts.last.30days", "starts.last.60days", "starts.last.90days", "starts.last.180days", "starts.last.365days", "starts.ever"))) stop('The colunm names must be as follows:  Race.ID, Date, Animal.ID, Birth.Date, Age, starts.last.15days, starts.last.30days, starts.last.60days, starts.last.90days, starts.last.180days, starts.last.365days, starts.ever')

#alldata <- alldata[1:100,]
ddata <- alldata
data <- as.matrix(alldata)

#dimnames(data)[[2]]

cat('Analysing data...\n')

years <- as.numeric(unlist(lapply(strsplit(as.character(data[,"Date"]), split=""), function(x) return(paste(x[1:4], collapse="")))))

minyear <- min(years)
maxyear <- max(years)

days <- 1:(366*(maxyear-minyear+1))
dates <- as.Date(paste(minyear, "-01-01", sep=""))+(days-1)

dates <- as.numeric(unlist(lapply(strsplit(as.character(dates), split="-", fixed=TRUE), function(x) return(paste(x, collapse="")))))

animalnumbers <- unique(data[,"Animal.ID"])
n.animals <- length(animalnumbers)
racedates <- vector('list', length=n.animals)

pb <- txtProgressBar()
for(i in 1:nrow(data)){

	animal <- which(animalnumbers==data[i,"Animal.ID"])
	racedates[[animal]] <- c(racedates[[animal]], which(dates==data[i,"Date"]))

	setTxtProgressBar(pb, i/nrow(data))
```

```
}
close(pb)


#summary(unlist(lapply(racedates, function(x) return(length(x)))))

pb <- txtProgressBar()

for(i in 1:nrow(data)){

	animal <- which(animalnumbers==data[i,"Animal.ID"])
	thedate <- which(dates==data[i,"Date"])
	starts <- racedates[[animal]]
	for(d in c(15, 30, 60, 90, 180, 365)){
		data[i,paste("starts.last.", d, "days", sep="")] <- sum(starts < thedate & starts
> (thedate-d))
	}
	data[i,"starts.ever"] <- sum(starts < thedate)
	setTxtProgressBar(pb, i/nrow(data))
}
close(pb)

# Check a random animal to make sure code is OK:
#a <- sample(animalnumbers, 1)
#data[which(data[,"Animal.ID"]==a),][order(data[which(data[,"Animal.ID"]==a),"starts.ev
er"]),]

ddata[,6:ncol(ddata)] <- as.numeric(data[,6:ncol(ddata)])
write.csv(data.frame(ddata), file="tim.output.csv", row.names=FALSE)

cat('Analysis complete - file "tim.output.csv" is in the working directory\n')
```

The initial script (above) did not include a calculation of the number of starts in a 270 day period, so this was re-run using the following code:

```
datestodo <- c(270)

if(!file.exists('tim.input.csv')) stop('The file "tim.input.csv" does not exist in the working directory')
alldata <- read.csv("tim.input.csv")

if(!all(names(alldata)==c("Race.ID", "Date", "Animal.ID", "Birth.Date", "Age", paste("starts.last.", datestodo, "days", sep="")))) stop('The colunm names must be as follows:  Race.ID, Date, Animal.ID, Birth.Date, Age, starts.last.x.days')

#alldata <- alldata[1:100,]
ddata <- alldata
data <- as.matrix(alldata)

#dimnames(data)[[2]]

cat('Analysing data...\n')

years <- as.numeric(unlist(lapply(strsplit(as.character(data[,"Date"]), split=""), function(x) return(paste(x[1:4], collapse="")))))

minyear <- min(years)
maxyear <- max(years)

days <- 1:(366*(maxyear-minyear+1))
dates <- as.Date(paste(minyear, "-01-01", sep=""))+(days-1)

dates <- as.numeric(unlist(lapply(strsplit(as.character(dates), split="-", fixed=TRUE), function(x) return(paste(x, collapse="")))))

animalnumbers <- unique(data[,"Animal.ID"])
n.animals <- length(animalnumbers)
racedates <- vector('list', length=n.animals)

pb <- txtProgressBar()
for(i in 1:nrow(data)){

	animal <- which(animalnumbers==data[i,"Animal.ID"])
	racedates[[animal]] <- c(racedates[[animal]], which(dates==data[i,"Date"]))

	setTxtProgressBar(pb, i/nrow(data))
}
close(pb)


#summary(unlist(lapply(racedates, function(x) return(length(x)))))

pb <- txtProgressBar()

for(i in 1:nrow(data)){
```

```
        animal <- which(animalnumbers==data[i,"Animal.ID"])
        thedate <- which(dates==data[i,"Date"])

        starts <- racedates[[animal]]

        for(d in datestodo){
                data[i,paste("starts.last.", d, "days", sep="")] <- sum(starts < thedate & starts
> (thedate-d))
        }
        setTxtProgressBar(pb, i/nrow(data))
}
close(pb)

# Check a random animal to make sure code is OK:
#a <- sample(animalnumbers, 1)
#data[which(data[,"Animal.ID"]==a),][order(data[which(data[,"Animal.ID"]==a),"starts.la
st.270days"]),]

ddata[,6:ncol(ddata)] <- as.numeric(data[,6:ncol(ddata)])
write.csv(data.frame(ddata), file="tim.output.csv", row.names=FALSE)

cat('Analysis complete - file "tim.output.csv" is in the working directory\n')
```

13.4 Appendix 4 - Stata “Lintrend” code

The following code was used to plot the observed proportion of outcome for groupings of the explanatory variables during univariable analysis, as an aid to identifying the most appropriate form of the variable, to help in production of a parsimonious model.

```
/* Program to plot observed proportion of D for groupings of a
*/
/*     continuous X variable                            (STB-30: sg50)
*/
/* 02/27/95  JMG  (continuous y added, 01/04/96)
*/
/* Form:emptrend y x,[groups(#), round(#), or integer]
plot([mean,prop,log]) */
/* Options Required:  groups, round, or integer  (only 1)
*/
/* Options Allowed:  plot, xlabel, ylabel, titles
*/

program define lintrend
  version 3.1
  #delimit ;
    local options "Groups(int 0) Round(real 0) Integer Plot(string)
    Title(string) *" ;
  #delimit cr
  local varlist "req ex min(2) max(2)"
  local if "opt"
  parse "`*'"
  parse "`varlist'", parse(" ")
  local choice=0
  if `groups'>0 {local choice=`choice'+1}
  if `round'>0  {local choice=`choice'+1}
  if "`integer'"=="integer" {local choice=`choice'+1}
  if `choice'==0 {
    disp "  "
    #delimit ;
    disp in red "You must chose one:" in yellow "  groups(#),"
      " round(#), or integer";
    #delimit cr
    exit
    }
  if `choice'>1 {
    disp "  "
    #delimit ;
    disp in red "You must chose only one:" in yellow "  groups(#),"
      " round(#), or integer";
    #delimit cr
    exit
    }
  preserve
  capture keep `if'
  keep `varlist'
  quietly drop if `2'==.
  sort `1'
  quietly count if `1'[_n-1]~=`1' & `1'~=.
  if _result(1)==2 {local ytype=1}
  if _result(1)>2  {local ytype=2}
  if `ytype'==1 & "`plot'"=="mean"  {
     disp "  "
```

```
     #delimit  ;
       disp in red "plot() only can be" in yellow " prop, log, or both"
         in red " for a binary Y" ;
     #delimit  cr
     exit
     }
  if `ytype'==2 & ("`plot'"=="prop" | "`plot'"=="log" | "`plot'"=="both")
{
     disp "  "
     #delimit ;
        disp in red "plot() only can be" in yellow " mean"
          in red " for a continuous Y"  ;
     #delimit  cr
     exit
     }
  local varlblx : variable label `2'
  local vallblx : value label `2'
  sort `2'

* If groups chosen, divide x into categories of equal size
  if `groups'>0  {
    quietly gen numgrps=group(`groups')
    quietly egen max=max(`2'), by(numgrps)
    quietly replace max=max[_n-1] if `2'==`2'[_n-1]
    #delimit ;
      quietly collapse `2' `1', by(max) min(min .) mean(mean .) sum(. y)
        count(total .) ;
    #delimit cr
    quietly gen _group=mean
    label var _group "Mean of `2' categories"
    }

* If round chosen, round x to nearest specified value
  if `round'>0  {
    quietly gen _group=round(`2',`round')
    #delimit ;
      quietly collapse `1' `2', by(_group) sum(y .) count(total .)
        max(. max) min(. min);
    #delimit  cr
    label var _group "`2' rounded to nearest `round'"
    }

* If integer chosen, treat categories of x as original integers
  if "`integer'"=="integer" {
    quietly gen _group=`2'
    collapse `1', by(_group) sum(y) count(total)
    label var _group "Categorized by values of `2'"
    }

* Calculate means, proportions, and log odds by groups of x
  quietly gen meany=y/total
  if `ytype'==1  {quietly gen logodds=ln(meany/(1-meany)) if y>0}
  if "`plot'"=="log" | "`plot'"=="both" {
     quietly reg logodds _group
     quietly predict hat
     }
  if "`plot'"=="mean"  {
     quietly reg meany _group
     quietly predict hat
     }
  if `ytype'==1  {
     label var meany "Proportion of `1'"
     label var logodds "Log odds of `1'"
     }
  if `ytype'==2  {label var meany "Category Mean of `1'"}
```

```
* Set up formats for output
  quietly compress
  format y %5.0f
  format total %7.0f
  if `groups'>0  {
     if _n==1  {local range=abs(max-min)}
     if `range'>=1000000  {format _group % 8.2e}
     else if `range'>=1  {format _group %10.1f}
     else if `range'>=.1  {format _group %10.2f}
     else if `range'>=.01  {format _group %10.3f}
     else if `range'>=.001  {format _group %10.4f}
     }
  if `ytype'==1  {
      format logodds %7.2f
      format meany %6.2f
      }
  if `ytype'==2  {
     egen miny=min(meany)
     if _n==1  {local ymin=miny}
     if `ymin'>=10000000  {format meany %8.2e}
     else if `ymin'>=1  {format meany %10.2f}
     else if `ymin'>=.1  {format meany %10.3f}
     else if `ymin'>=.01  {format meany %10.4f}
     else if `ymin'>=.001  {format meany %10.5f}
     else if `ymin'>=.0001 {format meany %10.6f}
     }

* Graph results
  if ("`plot'"=="prop" | "`plot'"=="both") & `ytype'==1 {
    if "`title'"=="" {
      local title "      Assessing Linearity Assumption -- Proportions"
      }
    graph meany _group, ti("`title'") `options'
      if "`plot'"=="both"  { more }
    }
  if ("`plot'"=="log" | "`plot'"=="both") & `ytype'==1 {
    if "`title'"=="" | "`plot'"=="both" {
      local title "     Assessing Linearity Assumption -- Log Odds"
      }
    graph logodds hat _group, c(.l) s(Oi) ti("`title'") `options'
    }
  if "`plot'"=="mean" & `ytype'==2 {
    if "`title'"=="" {
      local title "     Assessing Linearity Assumption -- Group Means"
      }
    graph meany hat _group, c(.l) s(Oi) ti("`title'") `options'
    }

* List results
  sort _group
  display "  "
  display "  "
  rename _group `2'
  rename meany `1'
  rename y d
  if `ytype'==1  /* outcome is binary */ {
    #delimit ;
       display "The proportion and log odds of" in green " `1' "
         in yellow "by categories of" in green " `2'" ;
       display "  ";
    #delimit cr
    if `groups'>0  {
       display in blue "  (Note: `groups' `2' categories of equal sample
size;"
```

```
        display in blue "     Uses mean `2' value for each category)"
        list `2' min max d total `1' logodds, nod noob
        }
     if `round'>0  {
        display in blue "  (Note: `2' in categories rounded to nearest
`round')"
        list `2' min max d total `1' logodds, nod noob
        }
     if "`integer'"=="integer"  {
        display in blue "  (Note: `2' in categories using original
values)"
        label val `2' `vallblx'
        list `2' d total `1' logodds, nod noob
        }
     }
   if `ytype'==2  /* outcome is continuous */ {
     #delimit ;
        display "The mean of" in green " `1' "
          in yellow "by categories of" in green " `2' " ;
        display "  ";
     #delimit cr
     if `groups'>0  {
        display in blue "  (Note: `groups' `2' categories of equal sample
size;"
        display in blue "     Uses mean `2' value for each category)"
        list `2' min max total `1', nod noob
        }
     if `round'>0  {
        display in blue "  (Note: `2' in categories rounded to nearest
`round')"
        list `2' min max total `1', nod noob
        }
     if "`integer'"=="integer"  {
        display in blue "  (Note: `2' in categories using original
values)"
        label val `2' `vallblx'
        list `2' total `1', nod noob
        }
      }
end
```

13.5 Appendix 5 – Details of the obstacles and distances run in National Hunt racing in GB (www.britishhorseracing.com)

National Hunt racing in GB is divided into two major distinct branches: Hurdles and Steeple Chase. Alongside these there are "Bumpers" which are National Hunt flat races. The Jump Racing programme runs on turf from Autumn through to Spring and takes advantage of a variety and geographical spread of racecourses.

Hurdles

Timber obstacles of a minimum 3'6" in height are cleared. Hurdles races are divided into the following categories, determined by age, experience and distance:

•2 mile Juvenile

•2 mile Novice

•2 mile Open

•2½ mile Novice

•2½ mile Open

•3+ mile Novice

•3+ mile Open

Please note:'Juvenile' races are those open only to 3 year old horses if the race is in October-December, or 4 year olds only if the race is in January-April.

'Novice' races are only open to horses who, at the start of the Jumps season, are yet to win a race. However, the horse can continue to run in Novice races all season even after it wins a race, so long as at the start of the season it had never won a race.

'Open' races are open to all horses.

Steeple Chase

Where there are a variety of obstacles to be cleared which can include:

•Plain fence: which are a minimum of 4'6" in height on the take off side

•Water Jump: where horses clear a fence of at least 3' in height and land in water 3" deep

•Open Ditch: Are a minimum of 4'6" in height on the take off side with a ditch on the take off side

Again, Steeplechasing is divided into the following categories based on age, experience and distance:

•2 mile Novice

•2 mile Open

•2½ mile Novice

•2½ mile Open

•3+ mile Novice

•3+ mile Open

Each category has a Championship race at either the Cheltenham Festival or the Aintree Grand National Meeting. Each of the above categories are then divided into Grades based on the quality of the horses involved.

Bumpers (National Hunt Flat Races)

Generally the last race on a Jumps card, Bumpers allow novice horses to race on flat ground in order to become accustomed to racing before facing the challenge of Jump racing.

Other race definitions in National Hunt racing:

There are also some other kinds of race, all of which sit among the above categories:

Handicap Race

Races where the horse will carry a certain amount of weight, depending on the horse's handicap rating. The better the horse, the higher the rating so the more weight it will carry, thus giving horses of a poorer quality an even chance of winning the race.

Claiming Race

Also known as a 'claimer'. This is a race in which any runner may be claimed after the race for an advertised sum or more. If the owner of any runner wishes it to carry less than the maximum weight, the price at which it may be claimed is reduced accordingly.

Selling Race

Also known as a 'seller', a selling race is a race in which the winner must be put up for auction.

Maiden Race

Horses who have not yet won a race are referred to as maidens, hence a Maiden race is a race for non winners.

Apprentice Race

A race for apprentice jockeys only.

13.6 Appendix 6. Results of univariable logistic regression comparisons between predictor variables and each of the outcomes

The first analysis that was performed was for the outcome superficial digital flexor tendinopathy in hurdle racing, so this table (13-1) is presented first. Included with Table 13-1 are additional categorisations of variables (grey boxes with white text), to help explain the process used in determining the most appropriate variable form to include in the multivariable models.

List of Tables in Appendix 6:

Table 13-1: Results of univariable logistic regression analysis of risk factors for superficial digital flexor tendinopathy in horses undertaking hurdle racing in Great Britain (2001-2009).

Risk factor for SDF tendinopathy in hurdle Racing	TOTAL n=169668	Cases (%) n=1031	Controls (%) n=168637	Wald P-value	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES						
Track Going						
Heavy	12816	21 (2)	12795 (7)		1 (REF)	
Soft	30319	86 (8)	30233 (18)	**0.025**	1.73	1.07-2.78
Good to Soft	33661	140 (14)	33521 (20)	**<0.001**	2.54	1.62-4.07
Good	57579	404(39)	57175 (34)	**<0.001**	4.31	2.77-6.68
Good to Firm	33765	356 (35)	33409 (20)	**<0.001**	6.49	4.18-10.09
Firm	1528	24 (2)	1504 (1)	**<0.001**	9.72	5.4-17.51
Days since last hurdle race at that track						
0 to 90	156086	917 (89)	155169 (92)		1 (REF)	
≥ 91	13582	114 (11)	13468 (8)	**<0.001**	1.43	1.17-1.74
Days since last hurdle race at that track						
0 – 14	80635	492 (48)	80143 (47.5)		1 (REF)	
15 – 30	55973	299 (29)	55674 (33)	**0.069**	0.87	0.76-1.01
31 – 90	19478	126 (12)	19352 (11.5)	**0.557**	1.06	0.87-1.29
91 – 180	6794	60 (5.8)	6734 (4)	**0.007**	1.45	1.2-1.9
181 – 365	6625	52 (5)	6573 (3.9)	**0.083**	1.29	0.97-1.72
>365	163	2 (0.2)	161 (0.1)	**0.323**	2.02	0.5-8.2
Number of starts on the course over 9 years in upper 50%						
No	86998	425 (41)	86573 (51)		1 (REF)	
Yes	82670	606 (59)	82064 (49)	**<0.001**	1.5	1.33-1.7
Number of hurdle starts on the course over the last 9 years						
1 – 3310	45621	217 (21)	45404 (27)		1 (REF)	
3311 – 4699	41377	208 (20)	41169 (24.5)	**0.57**	1.05	0.87-1.28
4700 – 5824	43309	316 (31)	43309 (25.5)	**<0.001**	1.54	1.29-1.83
5825 – 7766	39361	290 (28)	39361 (23)	**<0.001**	1.55	1.3-1.85
Novice Race						
No	95599	652 (63)	94947 (56)		1 (REF)	
Yes	74069	379 (37)	73690 (44)	**<0.001**	0.75	0.66-0.85
Year 2003 or 2005						
No	132487	744 (72)	131743 (78)		1 (REF)	
Yes	37181	287 (28)	36894 (22)	**<0.001**	1.38	1.20-1.58
Year						
2001	16660	82 (8)	16578 (10)		1 (REF)	
2002	17364	106 (10)	17258 (10)	**0.142**	1.24	0.93-1.66
2003	17292	132 (13)	17160 (10)	**0.002**	1.56	1.17-2.05
2004	19598	96 (9)	19502 (12)	**0.975**	0.99	0.74-1.34
2005	19889	155 (15)	19734 (12)	**0.001**	1.59	1.21-2.08
2006	20117	129 (13)	19988 (12)	**0.060**	1.3	0.99-1.72
2007	19185	116 (11)	19069 (11)	**0.153**	1.23	0.93-1.63
2008	20391	107 (10.5)	20284 (12)	**0.662**	1.07	0.8-1.42
2009	19172	108 (10.5)	19064 (11)	**0.356**	1.14	0.86-1.52
Season						
Spring, Autumn or Winter	145809	783 (76)	145026 (86)		1 (REF)	
Summer	23859	248 (24)	23611 (14)	**<0.001**	1.95	1.69-2.25
Season						
Autumn	43066	301 (29)	42765 (26)		1 (REF)	
Spring	51462	316 (31)	51146 (30)	**0.107**	0.88	0.75-1.03
Summer	23859	248 (24)	23611 (14)	**<0.001**	1.49	1.26-1.77
Winter	51281	166 (16)	51115 (30)	**<0.001**	0.46	0.38-0.56
Time of race						
Afternoon	156737	952 (92)	155785 (92)		1 (REF)	
Morning or Evening	12931	79 (8)	12852 (8)	**0.960**	1.01	0.8-1.27
Time of race						
Afternoon	156737	952 (92)	155785 (92)		1 (REF)	
Evening	12844	79 (8)	12765 (7.95)	**0.914**	1.01	0.8-1.3
Morning	87	0 (0)	87 (0.05)	**empty**		
Race position in run sequence						
Early and middle	113741	745 (72)	112996 (67)		1 (REF)	
Late	55927	286 (28)	55641 (33)	**<0.001**	0.78	0.68-0.89
Race position in run sequence						
Early	66957	446	66511		1 (Ref)	
Late	55927	286	55641	**<0.001**	0.77	0.66-0.89
Middle	46784	299	46485	**0.579**	0.96	0.83-1.11

Risk factor for SDF tendinopathy in hurdle Racing	TOTAL n=169668	Cases (%) n=1031	Controls (%) n=168637	Wald P-value	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES CONTINUED						
Race Distance (km)	169668	1031 (100)	168637 (100)	**<0.001**	2.01	1.82-2.2
Number of runners						
1 to 12	85457	565 (55)	84892 (50)		1 (REF)	
13 to 30	84211	466 (45)	83745 (50)	**0.004**	0.84	0.74-0.95
Number of runners (quartiles)						
1-10	53571	345 (33)	53226 (31)		1 (REF)	
11-12	31886	220 (21)	31666 (19)	**0.423**	1.07	0.9-1.27
13-15	46918	264 (26)	46654 (28)	**0.098**	0.87	0.74-1.03
16-30	37293	202 (20)	31091 (22)	**0.050**	0.84	0.71-1
Sell / Claim Race						
No	149481	836 (81)	148645 (88)		1 (REF)	
Yes	20187	195 (19)	19992 (12)	**<0.001**	1.73	1.48-2.03
TRAINER RELATED VARIABLES						
Trainer Score	169668	1031 (100)	168637 (100)	**<0.001**	0.85	0.82-0.87
Trainer % First	169668	1031 (100)	168637 (100)	**<0.001**	0.95	0.94-0.96
Trainer % Placed	169668	1031 (100)	168637 (100)	**<0.001**	0.97	0.97-0.98
JOCKEY RELATED VARIABLES						
Jockey Score	169668	1031 (100)	168637 (100)	**<0.001**	0.92	0.88-0.95
Jockey % First	169668	1031 (100)	168637 (100)	**<0.001**	0.98	0.97-0.99
Jockey % Placed	169668	1031 (100)	168637 (100)	**<0.001**	0.99	0.98-0.99
Amateur Jockey						
No	159648	973 (94)	158675 (94)		1 (REF)	
Yes	10020	58 (6)	9962 (6)	**0.702**	0.95	0.73-1.24
HORSE RELATED VARIABLES						
Previous start not Hurdle						
No	133733	865 (84)	132868 (79)		1 (REF)	
Yes	35935	166 (16)	35769 (21)	**<0.001**	0.71	0.6-0.8
Horse had previous SDF tendinopathy						
No	169447	999 (97)	168448 (99.9)		1 (REF)	
Yes	221	32 (3)	189 (0.1)	**<0.001**	28.55	19.53-41.74
Age (years)	169668	1031 (100)	168637 (100)	**<0.001**	1.16	1.12-1.19
Age at first race	169668	1031 (100)	168637 (100)	**<0.001**	1.14	1.09-1.18
First Race Type						
Flat, Steeple or Hurdle	110696	604 (59)	110092 (65)		1 (REF)	
National Hunt Flat	58972	427 (41)	58545 (35)	**<0.001**	1.33	1.17-1.51
First Race Type						
Flat	85532	441 (43)	85091 (50.5)		1 (REF)	
Hurdle	24333	156 (15)	24177 (14)	**0.019**	1.24	1.04-1.5
Steeplechase	831	7 (0.7)	824 (0.5)	**0.196**	1.64	1.77-1.47
National Hunt Flat	58972	427 (41.3)	58545 (35)	**<0.001**	1.41	1.23-1.61
First Race Flat						
No	84136	590 (57)	83546 (50)		1 (REF)	
Yes	85532	441 (43)	85091 (50)	**<0.001**	0.73	0.65-0.83
% of Career as flat	169668	1031 (100)	168637 (100)	**0.559**	1.00	0.99-1.00
Change in Running Distance since last race						
-800m to +2200m	163983	988 (96)	162950 (97)		1 (REF)	
-2400m to -1000m	5730	43 (4)	5687 (3)	**0.158**	1.25	0.92-1.69
Change in running distance since last race						
0	71586	339 (33)	71247 (42)		1 (REF)	
-2400m to -1000	5730	43 (4)	5687 (3)	**0.004**	1.59	1.16-2.18
-880 to -200	38577	222 (22)	38355 (23)	**0.024**	1.22	1.03-1.44
+200 to +800	45333	340 (33)	44993 (27)	**<0.001**	1.59	1.37-1.85
+1000 to +2200	8442	87 (8)	8355 (5)	**<0.001**	2.19	1.73-2.77

Risk factor for SDF tendinopathy in hurdle Racing	TOTAL n=169668	Cases (%) n=1031	Controls (%) n=168637	Wald P-value	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES CONTINUED						
Sex						
Male	133760	779 (76)	132981 (79)		1 (REF)	
Female	35908	252 (24)	35656 (21)	**0.010**	1.21	1.05-1.39
Horse's Official Rating						
None and 103 to 174	97710	475 (46)	97235 (58)		1 (REF)	
1 to 90	45674	386 (37)	45288 (27)	**<0.001**	1.74	1.52-2
91 to 102	26284	170 (16)	26114 (15)	**0.001**	1.33	1.12-1.59
Horse's Official Rating (Quartiles)						
None	56582	267 (26)	56315 (33)		1 (REF)	
1-83	28592	240 (23)	28352 (17)	**0.001**	1.79	1.5-2.13
84-102	43376	316 (31)	43060 (26)	**<0.001**	1.55	1.31-1.82
103-174	41118	208 (20)	40910 (24)	**0.451**	1.07	0.89-1.29
Weight Carried						
130 to 160lbs	150150	900 (87)	149250 (89)		1 (REF)	
161 to 186lbs	19518	131 (13)	19387 (11)	**0.225**	1.12	0.93-1.35
Weight Carried (lbs) (Quartiles)						
1-147	46776	310 (30)	46466 (28)		1 (REF)	
148-152	47662	278 (27)	47384 (28)	**0.121**	0.88	0.74-1.03
153-156	34090	200 (19)	33890 (20)	**0.178**	0.88	0.74-1.06
157-181	41140	243 (24)	40897 (24)	**0.178**	0.89	0.75-1.05
Days since horse's last hurdle race	169668	1031 (100)	168637 (100)	**<0.001**	1.00	1.0002-1.0009
Days since horse's last race of any type	169668	1031 (100)	168637 (100)	**<0.001**	1.00	1.0004-1.001
Years completed in Racing	169668	1031 (100)	168637 (100)	**<0.001**	1.07	1.04-1.11
Horse number of starts in career	169668	1031 (100)	168637 (100)	**<0.001**	0.99	0.98-0.99
Horse number of starts in the previous 90 days						
0 and 8 to 16	37500	278 (27)	37222 (22)		1 (REF)	
1 to 7	132168	753 (73)	131415 (78)	**<0.001**	0.77	0.67-0.88
Horse number of starts in the previous 90 days (Quartiles)0-1						
0 – 1	77000	521 (50.5)	76479 (45)		1 (REF	
2	38534	253 (24.5)	38281 (23)	**0.694**	0.97	0.83-1.12
3	27981	136 (13)	27845 (17)	**0.001**	0.72	0.59-0.87
4 – 16	26153	121 (12)	26032 (15)	**<0.001**	0.68	0.56-0.83
Horse number of starts in the previous 90-180 days	169668	1031 (100)	168637 (100)	**0.45**	1.01	0.98-1.05
Horse number of starts in the previous 180-270 days						
None	86832	636 (62)	86196 (51)		1 (REF)	
≥ 1 start	82836	395 (38)	82441 (49)	**0.001**	0.81	0.72-0.92
Horse number of starts in the previous 180-270 days (Quartiles vs None)						
None	95645	633 (61)	95012 (56)		1 (REF)	
1	24004	146 (14)	23858 (14)	**0.356**	0.92	0.77-1.1
2	20009	110 (11)	19899 (12)	**0.072**	0.83	0.68-1.02
3	14226	64 (6)	14162 (8)	**0.003**	0.68	0.52-0.88
4-15	15784	78 ()	15706 (9)	**0.015**	0.75	0.59-0.94
Horse number of starts in the previous 270 to 365 days	169668	1031 (100)	168637 (100)	**<0.001**	0.87	0.84-.091
Horse number of starts greater than 365 days previously						
None	497	2 (0.1)	495 (0.2)		1 (REF)	
1 to 10	83945	606 (58.9)	83339 (49.8)	**0.408**	1.80	0.45-7.23
11 to 20	38840	212 (21)	38928 (23)	**0.667**	1.36	0.34-5.48
21 to 30	21857	97 (9)	21760 (13)	**0.891**	1.10	0.27-4.49
31 to 172	24529	114 (11)	24415 (14)	**0.840**	1.16	0.28-4.69
Horse number of starts greater than 365 days previously (Quartiles)						
0 to 4	44501	356 (35)	44145 (26)		1 (REF)	
5 to 11	44797	280 (27)	44517 (27)	**0.002**	0.78	0.67-0.91
12 to 22	39452	206 (20)	39246 (23)	**<0.001**	0.65	0.54-0.77
23 to 172	40918	189 (18)	40729 (24)	**<0.001**	0.58	0.48-0.69

Values in grey with white text, give an indication of the distribution of the data prior to further categorisation.

Table 13-2: Results of univariable logistic regression analysis of risk factors for superficial digital flexor tendinopathy in horses undertaking steeplechase racing in Great Britain (2001-2009).

Risk Factor for SDF tendinopathy in steeplechase racing	TOTAL *n*=102894	Cases (%) *n*=648	Controls (%) *n*=102246	*P*-value	Odds Ratio (OR)	95% Confidence Interval
TRACK RELATED VARIABLES						
Track Going						
Heavy and Soft	25775	66 (10)	25709 (25)		1 (REF)	
Good to Soft	20417	102 (16)	20315 (20)	<0.001	1.96	1.42-2.67
Good	36852	36575(43)	277 (36)	<0.001	2.95	2.25-3.86
Good to Firm	19006	194 (30)	18812 (18)	<0.001	4.01	3.03-5.31
Firm	844	9 (1)	835 (1)	<0.001	4.2	2.08-8.45
Starts at that race course over 10 years (2000-2009)						
1 to 2785 and 3404 to 5244	75437	442 (68)	74995 (73)		1 (REF)	
2786 to 3403	27457	206 (32)	27251 (27)	**0.003**	1.28	1.09-1.51
Days since last steeplechase race at that track						
0 to 15 and > 30	73182	471 (73)	72711 (71)		1 (REF)	
16 to 30	29712	177 (27)	29535 (29)	**0.379**	0.93	0.78-1.1
RACE RELATED VARIABLES						
Race Distance (km)	102894	648 (100)	102246 (100)	**<0.001**	1.31	1.18-1.44
Sell / Claim Race						
No	102016	643 (99)	101373 (99)		1 (REF)	
Yes	878	5 (1)	873 (1)	**0.821**	0.9	0.37-2.18
Season						
Spring, Autumn or Winter	90739	517 (80)	90222 (88)		1 (REF)	
Summer	12155	131 (20)	12024 (12)	**<0.001**	1.9	1.57-2.3
Year						
2001-2005	55,039	382 (59)	54,657 (53)		1 (REF)	
2006-2009	47,855	266 (41)	47,589 (47)	**0.005**	0.79	0.68-0.94
Maiden Race						
No	100781	622 (96)	100159 (98)		1 (REF)	
Yes	2113	26 (4)	2087 (2)	**0.001**	2.01	1.35-2.98
Number of Runners	102894	648 (100)	102246 (100)	**0.199**	1.01	0.99-1.03
Position in run sequence						
Early	24790	179 (28)	24611 (24)		1 (REF)	
Middle or Late	78104	469 (72)	77635 (76)	**0.035**	0.83	0.7-0.99
Time of race						
Afternoon	93061	571 (88)	92490 (90)		1 (REF)	
Morning or Evening	9833	77 (12)	9756 (10)	**0.044**	1.28	1.0-1.62
TRAINER RELATED VARIABLES						
Trainer Mean Score (compared to other trainers in study)						
Bottom 75%	78552	542 (84)	78010 (76)		1 (REF)	
Top 25%	24342	106 (16)	24236 (24)	**<0.001**	0.63	0.51-0.78
Trainer % Placed	102894	648 (100)	102246 (100)	**<0.001**	0.98	0.97-0.99
Trainer % First	102894	648 (100)	102246 (100)	**<0.001**	0.97	0.95-0.98
JOCKEY RELATED VARIABLES						
Jockey Mean Score	102894	648 (100)	102246 (100)	**<0.001**	0.92	0.89-0.96
Jockey % Placed	102894	648 (100)	102246 (100)	**0.002**	0.99	0.98-1.0
Jockey % First	102894	648 (100)	102246 (100)	**0.007**	0.98	0.96-0.99
Amateur Jockey						
No	89528	532 (82)	88996 (87)		1 (REF)	
Yes	13366	116 (18)	13250 (13)	**<0.001**	1.46	1.2-1.79
HORSE RELATED VARIABLES						
Age (years)	102894	648 (100)	102246 (100)	**<0.001**	1.14	1.1-1.19
Age First Race (years)	102894	648 (100)	102246 (100)	**<0.001**	1.12	1.07-1.17
Years completed in racing						
0 to 4	68013	389 (60)	67624 (66)		1 (REF)	
5 to 13	34881	259 (40)	34622 (34)	**0.001**	1.3	1.11-1.52
Sex						
Male	94538	602 (93)	93936 (92)		1 (REF	
Female	8356	46 (7)	8310 (8)	**0.34**	0.86	0.64-1.17
Horse Had Previous SDF Tendinopathy						
No	102628	644 (99)	101984 (99)		1 (REF)	
Yes	266	4 (1)	262 (1)	**0.081**	2.41	0.9-6.51
Weight Carried (0.45 kg (lbs))	102894	648 (100)	102246 (100)	**0.122**	1.01	1-1.01
First race Flat						
No	75905	495 (76)	75410 (74)		1 (REF)	
Yes	26989	153 (24)	26836 (26)	**0.129**	0.87	0.72-1.04

Risk Factor for SDF tendinopathy in steeplechase racing	**TOTAL *n*=102894**	**Cases (%) *n*=648**	**Controls (%) *n*=102246**	***P*-value**	**Odds Ratio (OR)**	**95% Confidence Interval**
HORSE RELATED VARIABLES CONTINUED						
First Race Type						
Flat, Hurdle or NHF	80506	494 (76)	80012 (78)		1 (REF)	
Steeplechase	22388	154 (24)	22234 (22)	**0.214**	1.12	0.93-1.34
Horse % of career as flat	102894	648 (100)	102246 (100)	**0.021**	1.01	1.0-1.01
Horse Change in running distance since previous race						
Same / Decreased	67585	408 (63)	67177 (66)		1 (REF)	
Increased	35309	240 (37)	35069 (34)	**0.144**	1.13	0.96-1.32
Change in running distance since previous race (m)	102894	648 (100)	102246 (100)	**0.044**	1.0	1.0-1.0
Race type different to previous one						
No	85589	539 (83)	85050 (83)		1 (REF)	
Yes	17305	109 (17)	17196 (17)	**0.99**	1	0.81-1.23
Days since horse's last steeplechase race	102894	648 (100)	102246 (100)	**0.006**	1.0	1.0-1.0
Days since horse's last race of any type	102894	648 (100)	102246 (100)	**0.009**	1.0	1.0-1.0
Horse's total previous number of starts in any races						
0 to 12	26130	230 (35)	25900 (25)		1 (REF)	
13 to 21	27339	175 (27)	27164 (27)	0.001	0.73	0.6-0.88
22 to 147	49425	243 (38)	49182 (48)	<0.001	0.56	0.46-0.67
Horse number of starts in the previous 3 months						
0,1 and 5 to 16	52401	363 (56)	52038 (51)		1 (REF)	
2 to 4	50493	285 (44)	50208 (49)	**0.009**	0.81	0.7-0.95
Horse number of starts in the previous 3 to 6 months	102894	648 (100)	102246 (100)	**0.653**	1.01	0.96-1.06
Horse number of starts in the previous 6 to 9 months						
None	60692	435 (67)	60257 (59)			
1 to 11	42202	213 (33)	41989 (41)	**<0.001**	0.7	0.6-0.83
Horse number of starts in the previous 9 to 12 months						
0 and 8 to 15	43917	397 (61)	43520 (43)		1 (REF)	
1 to 7	58977	251 (39)	58726 (57)	**<0.001**	0.47	0.4-0.55
Horse number of starts greater than 1 year ago						
0 to 15	52319	394 (61)	51925 (51)		1 (REF)	
16 to 135	50575	254 (39)	50321 (49)	**<0.001**	0.67	0.57-0.78
Official Rating (compared to other horses in study)						
Lower three quartiles	78947	567 (88)	78380 (77)			
Upper quartile	23947	81 (12)	23866 (23)	**<0.001**	0.47	0.37-0.59

Table 13-3: Results of univariable logistic regression analysis of risk factors for fatality in horses undertaking hurdle racing in Great Britain (2001-2009).

Risk Factor for Fatality in Hurdle Racing	Total n=169668	Cases (%) n=752	Controls (%) n=168916	P-Value	Odds Ratio (OR)	95% Confidence Interval
TRACK RELATED VARIABLES						
Track Going						
"Heavy" to "GTS"	76796	228 (30.3)	76568 (45.3)		1 (Ref)	
"Good" to "Firm"	92872	524 (69.7)	92348 (54.7)	<0.001	1.91	1.63-2.23
Starts at that course over 10 years (2000-2009)						
1 to 5824	130307	526 (69.9)	129781 (76.8)		1 (Ref)	
>5824 (5825-7766)	39361	226 (30.1)	39135 (23.2)	<0.001	1.42	1.22-1.67
Days since last hurdle race at the track						
0 to 7	26158	141 (18.8)	26017 (15.4)		1 (Ref)	
>7 (8-952)	143510	611 (81.3)	142899 (84.6)	0.011	0.79	0.66-0.95
RACE RELATED VARIABLES						
Race Distance (km)				0.006	1.18	1.05-1.33
Sell or Claim Race						
No	149481	632 (84)	148849 (88.1)		1 (Ref)	
Yes	20187	120 (16)	20067 (11.9)	0.001	1.41	1.16-1.71
Summer Season						
No	145809	590 (78.5)	145219 (86)		1 (Ref)	
Yes	23859	162 (21.5)	23697 (14)	<0.001	1.68	1.41-2
Maiden or Novice Race						
No	78431	375 (49.9)	78056 (46.2)		1 (Ref)	
Yes	91237	377 (50.1)	90860 (53.8)	0.045	0.86	0.75-1
Number of Runners						
1 to 15	132375	580 (77.1)	131795 (78)		1 (Ref)	
>15 (16-30)	37293	172 (22.9)	37121 (22)	0.554	1.05	0.89-1.25
Position of race in run sequence						
Early or late	122884	532 (70.7)	122352 (72.4)		1 (Ref)	
Middle	46784	220 (29.3)	46564 (27.6)	0.301	1.09	0.93-1.27
Time of Race						
Afternoon or Evening	169581	750 (99.7)	168831 (99.9)		1 (Ref)	
Morning	87	2 (0.3)	85 (0.1)	0.02	5.3	1.3-21.56
Year 2003						
No	152376	647 (86)	151729 (89.8)		1 (Ref)	
Yes	17292	105 (14)	17187 (10.2)	0.001	1.43	1.17-1.76
TRAINER RELATED VARIABLES						
Trainer Mean Score				0.643	1.01	0.97-1.05
Trainer % Placed						
None	582	6 (0.8)	576 (0.3)		1 (Ref)	
>0 (1-100)	169086	746 (99.2)	168340 (99.7)	0.038	0.43	0.19-0.95
Trainer % First (per 10%)				0.181	1.1	0.96-1.27
JOCKEY RELATED VARIABLES						
Jockey Mean Score						
0	20	0 (0)	20 (0)		1 (Ref)	
>0	169648	752 (100)	168896 (100)		N/A	
Jockey % Placed						
None	528	1 (0.1)	527 (0.3)		1 (Ref)	
>0 (1-100)	169140	751 (99.9)	168389 (99.7)	0.394	2.35	0.33-16.74
Jockey % First				0.212	1.01	0.99-1.02
Amateur Jockey						
No	159648	705 (93.8)	158943 (94.1)		1 (Ref)	
Yes	10020	47 (6.3)	9973 (5.9)	0.688	1.06	0.79-1.43
HORSE RELATED VARIABLES						
Age (years)				<0.001	1.1	1.06-1.14
Age First Race (years)				0.293	1.03	0.98-1.08
Years completed in racing				<0.001	1.08	1.05-1.12
Horse Sex						
Male	133760	616 (81.9)	133144 (78.8)		1 (Ref)	
Female	35908	136 (18.1)	35772 (21.2)	0.039	0.82	0.68-0.99
Weight Carried (lbs)						
1-156	128528	561 (74.6)	127967 (75.8)		1 (Ref)	
>156 (157-181)	41140	191 (25.4)	40949 (24.2)	0.46	1.06	0.9-1.25
First Race Type						
Flat	85532	392 (52.1)	85140 (50.4)		1 (Ref)	
Hurdle	24333	119 (15.8)	24214 (14.3)	0.534	1.07	0.87-1.31
Steeplechase	831	7 (0.9)	824 (0.5)	0.11	1.85	0.87-3.91
NHF	58972	234 (31.1)	58738 (34.8)	0.08	0.87	0.74-1.02

Risk Factor for Fatality in Hurdle Racing	Total n=169668	Cases (%) n=752	Controls (%) n=168916	P-Value	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES CONTINUED						
First Race Flat						
No	84136	360 (47.9)	83776 (49.6)		1 (Ref)	
Yes	85532	392 (52.1)	85140 (50.4)	0.346	1.07	0.93-1.24
Horse % of career as flat				<0.001	1.1	1.07-1.12
Increased run distance since previous race						
No	113570	476 (63.3)	113094 (67)		1 (Ref)	
Yes	56098	276 (36.7)	55822 (33)	0.034	1.17	1.01-1.36
Change of race type since previous race						
No	133733	604 (80.3)	133129 (78.8)		1 (Ref)	
Yes	35935	148 (19.7)	35787 (21.2)	0.314	0.91	0.76-1.09
Days since horse's last race				0.025	1	1-1
Previous NH starts in lifetime						
0 to 5	50926	303 (40.3)	50623 (30)		1 (Ref)	
6 to 9	35929	163 (21.7)	35766 (21.2)	0.005	0.76	0.63-0.92
10 to 17	41235	152 (20.2)	41083 (24.3)	<0.001	0.62	0.51-0.75
>17 (18-130)	41578	134 (17.8)	41444 (24.5)	<0.001	0.54	0.44-0.66
Previous starts in any race						
0 to 8	42890	248 (33)	42642 (25.2)		1 (Ref)	
>8 (9-183)	126778	504 (67)	126274 (74.8)	<0.001	0.69	0.59-0.8
Starts in previous 3 months						
None	36977	171 (22.7)	36806 (21.8)		1 (Ref)	
>0 (1-16)	132691	581 (77.3)	132110 (78.2)	0.529	0.95	0.8-1.12
Starts in previous 3 to 6 months						
0 to 6	168183	748 (99.5)	167435 (99.1)		1 (Ref)	
>6 (7-18)	1485	4 (0.5)	1481 (0.9)	0.316	0.6	0.23-1.62
Starts previous 6 to 9 months				0.086	0.96	0.91-1.01
Number of starts in previous 9-12 months						
0 and 8 to 16	86832	428 (56.9)	86404 (51.2)		1 (Ref)	
1 to 7	82836	324 (43.1)	82512 (48.8)	0.002	0.79	0.69-0.92
Number of starts in any race >365d ago				0.041	0.99	0.99-1
Horse’s official rating						
None	56582	249 (33.1)	56333 (33.3)		1 (Ref)	
Any	113086	503 (66.9)	112583 (66.7)	0.89	1.01	0.87-1.18

Table 13-4: Results of univariable logistic regression analysis of risk factors for fatality in horses undertaking steeplechase racing in Great Britain (2001-2009).

Risk Factor for Fatality in Steeplechase Racing	Total n=102894	Cases (%) n=606	Controls (%) n=102288	P-Value	Odds Ratio (OR)	95% Confidence Interval
TRACK RELATED VARIABLES						
Track Going						
Heavy	7067	20 (3.3)	7047 (6.9)		1 (Ref)	
Soft to GTF	94983	576 (95)	94407 (92.3)	0.001	2.15	1.38-3.36
Firm	844	10 (1.7)	834 (0.8)	<0.001	4.22	1.97-9.06
Starts at that course over 10 years (2000-2009)						
1 to 2222	26931	148 (24.4)	26783 (26.2)		1 (Ref)	
>2222 (2223 - 5244)	75963	458 (75.6)	75505 (73.8)	0.326	1.1	0.91-1.32
Days since last steeplechase race at the track						
0 to 7	17806	108 (17.8)	17698 (17.3)		1 (Ref)	
>7 (8-952)	85088	498 (82.2)	84590 (82.7)	0.736	0.96	0.78-1.19
RACE RELATED VARIABLES						
Race Distance (m)						
1 to 4800	80060	448 (73.9)	79612 (77.8)		1 (Ref)	
>4800	22834	158 (26.1)	22676 (22.2)	0.021	1.24	1.03-1.49
Sell or Claim Race						
Normal	102016	601 (99.2)	101415 (99.1)		1 (Ref)	
Sell	800	5 (0.8)	795 (0.8)	0.895	1.06	0.44-2.57
Claim	78	0 (0)	78 (0.1)		1	0-0
Summer Season						
No	90739	508 (83.8)	90231 (88.2)		1 (Ref)	
Yes	12155	98 (16.2)	12057 (11.8)	0.001	1.44	1.16-1.79
Maiden or Novice Status						
Normal	65101	357 (58.9)	64744 (63.3)		1 (Ref)	
Maiden	2113	22 (3.6)	2091 (2)	0.003	1.91	1.24-2.94
Novice	35680	227 (37.5)	35453 (34.7)	0.079	1.16	0.98-1.37
Number of Runners						
1 to 7 and >9 (10-40)	80381	459 (75.7)	79922 (78.1)		1 (Ref)	
8 to 9	22513	147 (24.3)	22366 (21.9)	0.156	1.14	0.95-1.38
Position of race in run sequence						
Early or Late	65423	379 (62.5)	65044 (63.6)		1 (Ref)	
Middle	37471	227 (37.5)	37244 (36.4)	0.593	1.05	0.89-1.23
Time of Race						
Morning or afternoon	93074	546 (90.1)	92528 (90.5)		1 (Ref)	
Evening	9820	60 (9.9)	9760 (9.5)	0.764	1.04	0.8-1.36
Year 2009						
No	91185	517 (85.3)	90668 (88.6)		1 (Ref)	
Yes	11709	89 (14.7)	11620 (11.4)	0.01	1.34	1.07-1.68
TRAINER RELATED VARIABLES						
Trainer Mean Score						
0	452	6 (1)	446 (0.4)		1 (Ref)	
>0	102442	600 (99)	101842 (99.6)	0.046	0.44	0.19-0.98
Trainer % Placed						
None	1682	14 (2.3)	1668 (1.6)		1 (Ref)	
>0	101212	592 (97.7)	100620 (98.4)	0.191	0.7	0.41-1.19
Trainer % First						
None	4286	32 (5.3)	4254 (4.2)		1 (Ref)	
>0	98608	574 (94.7)	98034 (95.8)	0.169	0.78	0.54-1.11
JOCKEY RELATED VARIABLES						
Jockey Mean Score						
0 to 5	531	6 (1)	525 (0.5)		1 (Ref)	
6 to 30	102363	600 (99)	101763 (99.5)	0.109	0.52	0.23-1.16
Jockey % Placed						
None	737	5 (0.8)	732 (0.7)		1 (Ref)	
Any	102157	601 (99.2)	101556 (99.3)	0.75	0.87	0.36-2.1
Jockey % First						
None	2174	20 (3.3)	2154 (2.1)		1 (Ref)	
Any	100720	586 (96.7)	100134 (97.9)	0.043	0.63	0.4-0.99
Amateur Jockey						
No	89528	518 (85.5)	89010 (87)		1 (Ref)	
Yes	13366	88 (14.5)	13278 (13)	0.261	1.14	0.91-1.43
HORSE RELATED VARIABLES						
Age (years)				<0.001	1.08	1.04-1.13
Age first race (years)				0.06	1.05	1-1.1

Risk Factor for Fatality in Steeplechase Racing	Total n=102894	Cases (%) n=606	Controls (%) n=102288	P-Value	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES CONTINUED						
Career length (years)				0.026	1.04	1.01-1.08
Sex						
Male	94538	565 (93.2)	93973 (91.9)		1 (Ref)	
Female	8356	41 (6.8)	8315 (8.1)	0.221	0.82	0.6-1.13
Weight carried (lbs)						
1 to 161	82143	477 (78.7)	81666 (79.8)		1 (Ref)	
>161 (162-179)	20751	129 (21.3)	20622 (20.2)	0.491	1.07	0.88-1.3
First Race NHF						
No	102520	602 (99.3)	101918 (99.6)		1 (Ref)	
Yes	374	4 (0.7)	370 (0.4)	0.231	1.83	0.68-4.92
First Race Flat						
No	75905	457 (75.4)	75448 (73.8)		1 (Ref)	
Yes	26989	149 (24.6)	26840 (26.2)	0.357	0.92	0.76-1.1
Percentage of career on Flat (10%)				<0.001	1.09	1.04-1.14
Change in race distance from previous race						
Decreased	31080	173 (28.5)	30907 (30.2)		1 (Ref)	
Same or increased	71814	433 (71.5)	71381 (69.8)	0.373	1.08	0.91-1.29
Change in race distance from previous race (m)						
"-400 to -200" & 1 to 4000	66716	364 (60.1)	66352 (64.9)		1 (Ref)	
Change Race Type from previous race						
No	85589	476 (78.5)	85113 (83.2)		1 (Ref)	
Yes	17305	130 (21.5)	17175 (16.8)	0.002	1.35	1.11-1.64
Days since last race of any type					1	1-1
Number of starts in previous 3 months						
0 to 1	46316	307 (50.7)	46009 (45)		1 (Ref)	
>1 (2-12)	56578	299 (49.3)	56279 (55)	0.005	0.8	0.68-0.93
"-199-0"	36178	242 (39.9)	35936 (35.1)	0.014	1.23	1.04-1.44
Number of start in previous 3 to 6 months						
None	57298	345 (56.9)	56953 (55.7)		1 (Ref)	
Any	45596	261 (43.1)	45335 (44.3)	0.536	0.95	0.81-1.12
Number of Starts in previous 6-9 months						
None	60692	394 (65)	60298 (58.9)		1 (Ref)	
Any (1-15)	42202	212 (35)	41990 (41.1)	0.003	0.77	0.65-0.91
Number of Starts in previous 9-12 months						
None	43666	307 (50.7)	43359 (42.4)		1 (Ref)	
Any (1-16)	59228	299 (49.3)	58929 (57.6)	<0.001	0.72	0.61-0.84
Number of Starts >365 days previously				0.037	0.99	0.99-1
Entry Level Rating						
None	11753	81 (13.4)	11672 (11.4)		1 (Ref)	
Any	91141	525 (86.6)	90616 (88.6)	0.132	0.83	0.66-1.06

Table 13-5: Results of univariable logistic regression analysis of risk factors for epistaxis in horses undertaking hurdle racing in Great Britain (2001-2009).

Risk Factor for Epistaxis in Hurdle Racing	TOTAL n=169668	Cases (%) n=603	Controls (%) n=169065	Wald P-value	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES						
Days since last hurdle race at that track						
0 to 10	43793	170 (28.2)	43623 (25.8)		1 (Ref)	
11 to 952	125875	433 (71.8)	125442 (74.2)	0.181	0.89	0.74-1.06
Distance (km)	169668	603 (100)	169065 (100)	0.006	0.82	0.71-0.95
Maiden or novice race						
No	78431	233 (38.6)	78198 (46.3)		1 (Ref)	
Yes	91237	370 (61.4)	90867 (53.7)	<0.001	1.37	1.16-1.61
Number of hurdle starts on that course between 2001 and 2009						
1 to 5824	130307	453 (75.1)	129854 (76.8)		1 (Ref)	
5825 to 7766	39361	150 (24.9)	39211 (23.2)	0.329	1.1	0.91-1.32
Number of runners in race						
1 to 5	3534	11 (1.8)	3523 (2.1)		1 (Ref)	
6 to 15	162055	585 (97)	161470 (95.5)	0.626	1.16	0.64-2.11
16 to 30	4079	7 (1.2)	4072 (2.4)	0.218	0.55	0.21-1.42
Position in run sequence						
Early	66957	339 (56.2)	66618 (39.4)		1 (Ref)	
Late	55927	116 (19.2)	55811 (33)	<0.001	0.41	0.33-0.5
Middle	46784	148 (24.5)	46636 (27.6)	<0.001	0.62	0.51-0.76
Race Time						
Afternoon	156737	555 (92)	156182 (92.4)		1 (Ref)	
Evening	12844	48 (8)	12796 (7.6)	0.72	1.06	0.79-1.42
Morning	87	0 (0)	87 (0.1)		No Events	
Season						
Sum, Wint, Aut	118206	375 (62.2)	117831 (69.7)		1 (Ref)	
Spring	51462	228 (37.8)	51234 (30.3)	<0.001	1.4	1.19-1.65
Sell/Claim race						
No	149481	516 (85.6)	148965 (88.1)		1 (Ref)	
Yes	20187	87 (14.4)	20100 (11.9)	0.055	1.25	1-1.57
Track Going						
heavy to GTS	43135	116 (19.2)	43019 (25.4)		1 (Ref)	
good to firm	126533	487 (80.8)	126046 (74.6)	0.001	1.43	1.17-1.75
Year						
2000 to 2004	70914	188 (31.2)	70726 (41.8)		1 (Ref)	
2005 to 2009	98754	415 (68.8)	98339 (58.2)	<0.001	1.59	1.34-1.89
TRAINER RELATED VARIABLES						
Percentage of trainer's starts resulting in first						
0 to 6	54702	211 (35)	54491 (32.2)		1 (Ref)	
7 to 100	114966	392 (65)	114574 (67.8)	0.148	0.88	0.75-1.04
Percentage of trainer's starts resulting in a place						
0	582	4 (0.7)	578 (0.3)		1 (Ref)	
1-100	169086	599 (99.3)	168487 (99.7)	0.186	0.51	0.19-1.38
Trainer mean finish position score						
0 to 6 and 17 to 30	1165	10 (1.7)	1155 (0.7)		1 (Ref)	
7 to 16	168503	593 (98.3)	167910 (99.3)	0.005	0.41	0.22-0.76
JOCKEY RELATED VARIABLES						
Amateur jockey					1 (Ref)	
No	159648	570 (94.5)	159078 (94.1)			
Yes	10020	33 (5.5)	9987 (5.9)	0.651	0.922	0.65-1.31
Percentage of jockey's starts resulting in first						
0	2078	10 (1.7)	2068 (1.2)		1 (Ref)	
1 to 100	167590	593 (98.3)	166997 (98.8)	0.334	0.73	0.39-1.37
Percentage of jockey's starts resulting in a place						
0	528	3 (0.5)	525 (0.3)		1 (Ref)	
1-100	169140	600 (99.5)	168540 (99.7)	0.415	0.62	0.2-1.94
	169668	603 (100)	169065 (100)	<0.001	0.99	0.94-1.04
Jockey mean finish position score						
HORSE RELATED VARIABLES						
Age (years)						
3 to 5 and 8 to 16	106321 (62.7)	348 (57.7)	105973 (62.7)		1 (Ref)	
6 to 7	63347 (37.3)	255 (42.3)	63092 (37.3)	0.012	1.23	1.05-1.45
Age at first race (years)	169668 (100)	603 (100)	169065 (100)	<0.001	1.11	1.05-1.16

Risk Factor for Epistaxis in Hurdle Racing	TOTAL n=169668	Cases (%) n=603	Controls (%) n=169065	Wald P-value	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES CONTINUED						
Career length in years						
0 to 2	98936 (58.3)	389 (64.5)	98547 (58.3)		1 (Ref)	
3 to 4	44808 (26.4)	142 (23.5)	44666 (26.4)	0.028	0.81	0.66-0.98
5 to 13	25924 (15.3)	72 (11.9)	25852 (15.3)	0.007	0.71	0.55-0.91
Change in running distance from horse's previous race						
Increase or Decrease	103418 (61)	383 (63.5)	103035 (60.9)		1 (Ref)	
Same	66250 (39)	220 (36.5)	66030 (39.1)	0.197	0.9	0.76-1.06
Sex						
Male	133760 (78.8)	476 (78.9)	133284 (78.8)		1 (Ref)	
Female	35908 (21.2)	127 (21.1)	35781 (21.2)	0.951	0.99	0.82-1.21
Horse's Official rating at start of race						
Unrated	56582 (33.3)	269 (44.6)	56313 (33.3)		1 (Ref)	
Rated	113086 (66.7)	334 (55.4)	112752 (66.7)	<0.001	0.62	0.53-0.73
Weight carried (lbs)						
1 to 147 and 157 to 181	87916 (51.8)	279 (46.3)	87637 (51.8)		1 (Ref)	
148 to 156	81752 (48.2)	324 (53.7)	81428 (48.2)	0.006	1.25	1.06-1.47
Proportion of field beaten	169668 (100)	603 (100)	169065 (100)	<0.001	0.96	0.96-0.97
Horse had previous episode of epistaxis whilst racing						
No	167432 (98.7)	554 (91.9)	166878 (98.7)		1 (Ref)	
Yes	2236 (1.3)	49 (8.1)	2187 (1.3)	<0.001	6.75	5.02-9.07
Percentage of horse's career on the flat						
0 to 75	157443 (92.8)	524 (86.9)	156919 (92.8)		1 (Ref)	
76 to 100	12225 (7.2)	79 (13.1)	12146 (7.2)	<0.001	1.95	1.54-2.47
Horse's previous race of a different race type						
No	133733 (78.8)	449 (74.5)	133284 (78.8)		1 (Ref)	
Yes	35935 (21.2)	154 (25.5)	35781 (21.2)	0.009	1.28	1.06-1.53
Horse's first race type						
F,H,St	110696 (65.2)	366 (60.7)	110330 (65.3)		1 (Ref)	
NHF	58972 (34.8)	237 (39.3)	58735 (34.7)	0.019	1.22	1.03-1.43
Horse's first race a flat race						
No	84136 (49.6)	325 (53.9)	83811 (49.6)		1 (Ref)	
Yes	85532 (50.4)	278 (46.1)	85254 (50.4)	0.034	0.84	0.72-0.99
Days since horse's last race	169668 (100)	603 (100)	169065 (100)	0.027	1	1-1
Horse's number of starts in previous 3 months						
0 to 1	77000 (45.4)	315 (52.2)	76685 (45.4)		1 (Ref)	
2 to 16	92668 (54.6)	288 (47.8)	92380 (54.6)	0.001	0.76	0.65-0.89
Horse's number of starts in previous 3 to 6 months						
None	84984 (50.1)	296 (49.1)	84688 (50.1)		1 (Ref)	
1 to 2	48962 (28.9)	206 (34.2)	48756 (28.8)	0.037	1.21	1.01-1.44
3 to 18	35722 (21.1)	101 (16.7)	35621 (21.1)	0.07	0.81	0.65-1.02
Horse's number of starts in previous 6 to 9 months	169668 (100)	603 (100)	169065 (100)	0.003	0.92	0.87-0.97
Horse's number of starts in previous 9 to 12 months						
0 to 2	132998 (78.4)	515 (85.4)	132483 (78.4)		1 (Ref)	
3	16636 (9.8)	44 (7.3)	16592 (9.8)	0.015	0.68	0.5-0.93
4 to 16	20034 (11.8)	44 (7.3)	19990 (11.8)	<0.001	0.57	0.42-0.77
Horse's number of starts >365 days previously						
0 to 11	89298 (52.6)	376 (62.4)	88922 (52.6)		1 (Ref)	
12 to 172	80370 (47.4)	227 (37.6)	80143 (47.4)	<0.001	0.67	0.57-0.79
Horse's number of previous starts in career						
0 to 8	42890 (25.3)	215 (35.7)	42675 (25.2)		1 (Ref)	
9 to 29	86248 (50.8)	288 (47.8)	85960 (50.8)	<0.001	0.67	0.56-0.79
30 to 183	40530 (23.9)	100 (16.6)	40430 (23.9)	<0.001	0.49	0.39-0.62

Table 13-6: Results of univariable logistic regression analysis of risk factors for epistaxis in horses undertaking steeplechase racing in Great Britain (2001-2009).

Risk Factor for Epistaxis in Steeplechase Racing	Total (%) n=102894	Cases (%) n=550	Controls (%) n=102344	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES						
Days since last race at that track	102894 (100)	550 (100)	102344 (100)	0.165	1	1-1
Distance (km)						
3.2 to 4.8	80060 (77.8)	449 (81.6)	79611 (77.8)		1 (Ref)	
4.9 to 7.2	22834 (22.2)	101 (18.4)	22733 (22.2)	0.031	0.79	0.63-0.98
Maiden or novice race						
Normal Race	65101 (63.3)	304 (55.3)	64797 (63.3)		1 (Ref)	
Maiden Race	2113 (2.1)	15 (2.7)	2098 (2)	0.112	1.52	0.91-2.56
Novice Race	35680 (34.7)	231 (42)	35449 (34.6)	<0.001	1.39	1.17-1.65
Number of steeplechase starts on that course between 2000 and 2009						
1-2801 and 3525-5244	74714 (72.6)	391 (71.1)	74323 (72.6)		1 (Ref)	
2802 to 3524	28180 (27.4)	159 (28.9)	28021 (27.4)	0.422	1.08	0.9-1.3
Number of runners in race						
1 to 7	29903 (29.1)	170 (30.9)	29733 (29.1)		1 (Ref)	
8 to 9	22513 (21.9)	128 (23.3)	22385 (21.9)	0.999	1.0	0.79-1.26
10 to 12	26385 (25.6)	135 (24.5)	26250 (25.6)	0.359	0.9	0.72-1.12
13 to 40	24093 (23.4)	117 (21.3)	23976 (23.4)	0.188	0.85	0.67-1.08
Position in run sequence						
Early	24790 (24.1)	191 (34.7)	24599 (24)		1 (Ref)	
Late	40633 (39.5)	134 (24.4)	40499 (39.6)	<0.001	0.43	0.34-0.53
Middle	37471 (36.4)	225 (40.9)	37246 (36.4)	0.011	0.78	0.64-0.94
Race time						
Afternoon	93061 (90.4)	510 (92.7)	92551 (90.4)		1 (Ref)	
Morning /Evening	9833 (9.6)	40 (7.3)	9793 (9.6)	0.069	0.74	0.54-1.02
Season						
Sum or Aut	35360 (34.4)	167 (30.4)	35193 (34.4)		1 (Ref)	
Spring or Winter	67534 (65.6)	383 (69.6)	67151 (65.6)	0.048	1.2	1-1.44
Claiming race						
No	102816 (99.9)	548 (99.6)	102268 (99.9)		1 (Ref)	
Yes	78 (0.1)	2 (0.4)	76 (0.1)	0.027	4.91	1.2-20.05
Track Going						
“Heavy” to “GTS”	46192 (44.9)	195 (35.5)	45997 (44.9)		1 (Ref)	
"Good" to "Firm"	56702 (55.1)	355 (64.5)	56347 (55.1)	<0.001	1.49	1.25-1.77
Year						
2001 to 2004	43273 (42.1)	188 (34.2)	43085 (42.1)		1 (Ref)	
2005 to 2009	59621 (57.9)	362 (65.8)	59259 (57.9)	<0.001	1.4	1.17-1.67
TRAINER RELATED VARIABLES						
Percentage of trainer's starts resulting in first						
0 to 4	15663 (15.2)	79 (14.4)	15584 (15.2)		1 (Ref)	
5 to 16	76067 (73.9)	423 (76.9)	75644 (73.9)	0.425	1.1	0.87-1.4
17 to 100	11164 (10.9)	48 (8.7)	11116 (10.9)	0.382	0.85	0.59-1.22
Percentage of trainer's starts resulting in a place						
0-23 and 30-100	78179 (76)	391 (71.1)	77788 (76)		1 (Ref)	
30 to 36	24715 (24)	159 (28.9)	24556 (24)	0.007	1.29	1.07-1.55
Trainer mean finish position score						
0 to 6	2070 (2)	12 (2.2)	2058 (2)		1 (Ref)	
7 to 16	100327 (97.5)	538 (97.8)	99789 (97.5)	0.789	0.92	0.52-1.64
17 to 30	497 (0.5)	0 (0)	497 (0.5)		NA	
JOCKEY RELATED VARIABLES						
Amateur Jockey						
No	89528 (87)	510 (92.7)	89018 (87)		1 (Ref)	
Yes	13366 (13)	40 (7.3)	13326 (13)	<0.001	0.52	0.38-0.72
Percentage of jockey's starts resulting in first						
0-9 and 14-100	72243 (70.2)	368 (66.9)	71875 (70.2)		1 (Ref)	
10 to 13	30651 (29.8)	182 (33.1)	30469 (29.8)	0.09	1.17	0.98-1.39
Percentage of jockey's starts resulting in a place						
0-24 and 37-100	52542 (51.1)	256 (46.5)	52286 (51.1)		1 (Ref)	
25 to 36	50352 (48.9)	294 (53.5)	50058 (48.9)	0.034	1.2	1.01-1.42
Jockey mean finish position score						
0 to 5	531 (0.5)	7 (1.3)	524 (0.5)		1 (Ref)	
6 to 30	102363 (99.5)	543 (98.7)	101820 (99.5)	0.016	0.4	0.19-0.85

Risk Factor for Epistaxis in Steeplechase Racing	Total (%) n=102894	Cases (%) n=550	Controls (%) n=102344	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES						
Age (years)						
3 to 10	89190 (86.7)	496 (90.2)	88694 (86.7)		1 (Ref)	
11 to 16	13704 (13.3)	54 (9.8)	13650 (13.3)	0.016	0.71	0.53-0.94
Age at first race (years)						
2 to 5	81408 (79.1)	424 (77.1)	80984 (79.1)		1 (Ref)	
6 to 13	21486 (20.9)	126 (22.9)	21360 (20.9)	0.241	1.13	0.92-1.38
Career length (years)						
0 to 5	81538 (79.2)	467 (84.9)	81071 (79.2)		1 (Ref)	
6 to 13	21356 (20.8)	83 (15.1)	21273 (20.8)	0.001	0.68	0.54-0.86
Change in running distance from horse's previous race						
Decrease or Same	67585 (65.7)	361 (65.6)	67224 (65.7)		1 (Ref)	
Increase	35309 (34.3)	189 (34.4)	35120 (34.3)	0.981	1	0.84-1.2
Sex						
Male	94538 (91.9)	500 (90.9)	94038 (91.9)		1 (Ref)	
Female	8356 (8.1)	50 (9.1)	8306 (8.1)	0.404	1.13	0.85-1.52
Horse's Official rating at start of race						
Unrated to 97	52806 (51.3)	265 (48.2)	52541 (51.3)		1 (Ref)	
98 to 186	50088 (48.7)	285 (51.8)	49803 (48.7)	0.14	1.13	0.96-1.34
Weight carried (lbs)						
1-148 and 162-181	47568 (46.2)	219 (39.8)	47349 (46.3)		1 (Ref)	
149 to 161	55326 (53.8)	331 (60.2)	54995 (53.7)	0.003	1.3	1.1-1.54
Proportion of field beaten	102894 (100)	550 (100)	102344 (100)	<0.001	0.97	0.97-0.98
Horse had previous episode of epistaxis whilst racing						
No	99459 (96.7)	447 (81.3)	99012 (96.7)		1 (Ref)	
Yes	3435 (3.3)	103 (18.7)	3332 (3.3)	<0.001	6.85	5.51-8.51
Percentage of horse's career on the flat						
0 to 75	102529 (99.6)	543 (98.7)	101986 (99.7)		1 (Ref)	
76 to 100	365 (0.4)	7 (1.3)	358 (0.3)	0.001	3.67	1.73-7.8
Horse's previous race of a different race type						
No	85589 (83.2)	452 (82.2)	85137 (83.2)		1 (Ref)	
Yes	17305 (16.8)	98 (17.8)	17207 (16.8)	0.53	1.07	0.86-1.34
Horse's first race type						
Flat, St, NHF	49751 (48.4)	240 (43.6)	49511 (48.4)		1 (Ref)	
Hurdle	53143 (51.6)	310 (56.4)	52833 (51.6)	0.027	1.21	1.02-1.43
Horse's first race a flat race						
No	75905 (73.8)	423 (76.9)	75482 (73.8)		1 (Ref)	
Yes	26989 (26.2)	127 (23.1)	26862 (26.2)	0.094	0.84	0.69-1.03
Days since horse's last race						
0 to 14	26290 (25.6)	120 (21.8)	26170 (25.6)		1 (Ref)	
15 to 2990	76604 (74.4)	430 (78.2)	76174 (74.4)	0.045	1.23	1.01-1.51
Horse's number of starts in previous 3 months						
0 to 2	69423 (67.5)	407 (74)	69016 (67.4)		1 (Ref)	
3 to 16	33471 (32.5)	143 (26)	33328 (32.6)	0.001	0.73	0.6-0.88
Horse's number of starts in previous 3-6 months						
0 to 8	102851 (99.96)	548 (99.6)	102303 (99.96)		1 (Ref)	
9 to 18	43 (0.04)	2 (0.4)	41 (0.04)	0.002	9.11	2.2-37.74
Horse's number of starts in previous 3-6 months						
None	60692 (59)	357 (64.9)	60335 (59)		1 (Ref)	
1 to 15	42202 (41)	193 (35.1)	42009 (41)	0.005	0.78	0.65-0.93
Horse's number of starts in previous 9 to 12 months	102894 (100)	550 (100)	102344 (100)	0.02	0.94	0.89-0.99
Horse's number of starts > 365 days previously	102894 (100)	550 (100)	102344 (100)	<0.001	0.99	0.98-0.99
Horse's number of previous starts in career						
0 to 21	53469 (52)	336 (61.1)	53133 (51.9)		1 (Ref)	
22 to 33	24609 (23.9)	119 (21.6)	24490 (23.9)	0.014	0.77	0.62-0.95
34 to 183	24816 (24.1)	95 (17.3)	24721 (24.2)	<0.001	0.61	0.48-0.76

Table 13-7: Results of univariable logistic regression analysis of risk factors for hind limb fracture in horses undertaking hurdle racing in Great Britain (2001-2009).

Risk Factor for Hind limb fracture in Hurdle racing	Total (%) n=169668	Cases (%) n=99	Controls (%) n=169569	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES						
Days since last Hurdle race at that track						
0 to 10 and >15 (16-952)	126440	81 (81.8)	126359 (74.5)		1 (Ref)	
11 to 15	43228	18 (18.2)	43210 (25.5)	0.098	0.65	0.39-1.08
Race Distance (m)						
1 to 4400	146713	81 (81.8)	146632 (86.5)		1 (Ref)	
>4400 (4401-7200)	22955	18 (18.2)	22937 (13.5)	0.178	1.42	0.85-2.37
Maiden or Novice Race						
No	78431	42 (42.4)	78389 (46.2)		1 (Ref)	
Yes	91237	57 (57.6)	91180 (53.8)	0.448	1.17	0.78-1.74
Number of hurdle starts at that course 2000-2009						
1 to 4948	86800	48 (48.5)	86752 (51.2)		1 (Ref)	
>4948 (4949-7766)	82868	51 (51.5)	82817 (48.8)	0.595	1.11	0.75-1.65
Number of runners						
1 to 15	132375	75 (75.8)	132300 (78)	1 (Ref)		
>15 (16-40)	37293	24 (24.2)	37269 (22)	0.587	1.14	0.72-1.8
Position in run sequence						
Early or Middle	113741	68 (68.7)	113673 (67)	1 (Ref)		
Late	55927	31 (31.3)	55896 (33)	0.727	0.93	0.61-1.42
Time of Race						
Morning or Afternoon	156824	91 (91.9)	156733 (92.4)	1 (Ref)		
Evening	12844	8 (8.1)	12836 (7.6)	0.848	1.07	0.52-2.21
Season						
Autumn or Spring	94528	51 (51.5)	94477 (55.7)		1 (Ref)	
Summer or Winter	75140	48 (48.5)	75092 (44.3)	0.401	1.18	0.8-1.76
Claiming Race						
No (normal + sell)	166648	98 (99)	166550 (98.2)	1 (Ref)		
Yes	3020	1 (1)	3019 (1.8)	0.568	0.56	0.08-4.04
Going						
Heavy	12816	6 (6.1)	12810 (7.6)		1 (Ref)	
Soft to Firm	156852	93 (93.9)	156759 (92.4)	0.575	1.27	0.55-2.89
Year						
2001 and 2004-2005	56147	13 (13.1)	56134 (33.1)		1 (Ref)	
2002-2003 and 2006-2009	113521	86 (86.9)	113435 (66.9)	<0.001	3.27	1.83-5.87
TRAINER RELATED VARIABLES						
Trainer % Placed						
0 to 21	46266	16 (16.2)	46250 (27.3)	1 (Ref)		
>21 (22-100)	123402	83 (83.8)	123319 (72.7)	0.015	1.95	1.14-3.32
Trainer Mean Score						
0 to 13	129186	72 (72.7)	129114 (76.1)	1 (Ref)		
>13 (14-30)	40482	27 (27.3)	40455 (23.9)	0.426	1.2	0.77-1.86
Trainer % First						
0 to 6	54702	23 (23.2)	54679 (32.2)	1 (Ref)		
>6 (7-100)	114966	76 (76.8)	114890 (67.8)	0.057	1.57	0.99-2.51
JOCKEY RELATED VARIABLES						
Jockey Mean Score						
0 to 11 and >13 (14-30)	91761	49 (49.5)	91712 (54.1)	1 (Ref)		
12 to 13	77907	50 (50.5)	77857 (45.9)	0.36	1.2	0.81-1.78
Jockey % Placed						
0 to 22 and 36 to 100	80679	44 (44.4)	80635 (47.6)	1 (Ref)		
23 to 35	88989	55 (55.6)	88934 (52.4)	0.536	1.13	0.76-1.68
Jockey % First						
0 to 6 and >12 (13-100)	82354	40 (40.4)	82314 (48.5)	1 (Ref)		
7 to 12	87314	59 (59.6)	87255 (51.5)	0.107	1.39	0.93-2.08
Amateur Jockey						
No	159648	94 (94.9)	159554 (94.1)	1 (Ref)		
Yes	10020	5 (5.1)	10015 (5.9)	0.718	0.85	0.34-2.08
HORSE RELATED VARIABLES						
Age first race (years)				0.002	1.22	1.08-1.38
Weight carried (lbs)			0.008	1.04	1.01-1.07	
% Previous career Flat						
0 and >50 (51-100)	115752	86 (86.9)	115666 (68.2)		1 (Ref)	
1 to 50	53916	13 (13.1)	53903 (31.8)	<0.001	0.32	0.18-0.58

Risk Factor for Hind limb fracture in Hurdle racing	Total (%) n=169668	Cases (%) n=99	Controls (%) n=169569	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES CONTINUED						
Career length (years)						
0 to 1 and 5 to 13	86252	66 (66.7)	86186 (50.8)		1 (Ref)	
2 to 4	83416	33 (33.3)	83383 (49.2)	0.002	0.52	0.34-0.78
First race type						
Flat or Steeplechase	86363	36 (36.4)	86327 (50.9)		1 (Ref)	
Hurdle	24333	22 (22.2)	24311 (14.3)	0.004	2.17	1.28-3.69
NHF	58972	41 (41.4)	58931 (34.8)	0.025	1.67	1.07-2.61
First Race Flat						
No	84136	63 (63.6)	84073 (49.6)		1 (Ref)	
Yes	85532	36 (36.4)	85496 (50.4)	0.006	0.56	0.37-0.85
Horse Age 7 years						
No	143687	74 (74.7)	143613 (84.7)		1 (Ref)	
Yes	25981	25 (25.3)	25956 (15.3)	0.007	1.87	1.19-2.94
Entry level rating						
None and 103 to 186	97700	69 (69.7)	97631 (57.6)		1 (Ref)	
0 to 102	71968	30 (30.3)	71938 (42.4)	0.016	0.59	0.38-0.91
Change in running distance						
Increased or Decreased	103418	66 (66.7)	103352 (60.9)		1 (Ref)	
No change	66250	33 (33.3)	66217 (39.1)	0.245	0.78	0.51-1.19
Sex						
Male	133760	80 (80.8)	133680 (78.8)		1 (Ref)	
Female	35908	19 (19.2)	35889 (21.2)	0.631	0.88	0.54-1.46
Change race type from previous race						
No	133733	77 (77.8)	133656 (78.8)		1 (Ref)	
Yes	35935	22 (22.2)	35913 (21.2)	0.8	1.06	0.66-1.71
Change in race distance from previous race (m)						
"-4000 to 0"	115893	67 (67.7)	115826 (68.3)		1 (Ref)	
1 to 4000	53775	32 (32.3)	53743 (31.7)	0.893	1.03	0.68-1.57
Starts in previous 3 months						
0 to 2	115534	74 (74.7)	115460 (68.1)		1 (Ref)	
>2 (3-16)	54134	25 (25.3)	54109 (31.9)	0.157	0.72	0.46-1.13
6 Starts in previous 3 to 6 months						
No	167530	95 (96)	167435 (98.7)		1 (Ref)	
Yes	2138	4 (4)	2134 (1.3)	0.019	3.3	1.21-8.99
4 Starts in previous 6-9 months						
No	161175	98 (99)	161077 (95)		1 (Ref)	
Yes	8493	1 (1)	8492 (5)	0.102	0.19	0.03-1.39
Any Starts in previous 9-12 months						
No	96435	62 (62.6)	96373 (56.8)		1 (Ref)	
Yes	73233	37 (37.4)	73196 (43.2)	0.246	0.79	0.52-1.18
Number of starts >365d previously				0.002	0.97	0.95-0.99

Table 13-8: Results of univariable logistic regression analysis of risk factors for hind limb fracture in horses undertaking steeplechase racing in Great Britain (2001-2009).

Risk Factor for Hind limb fracture in Steeplechase racing	Total (%) n=102894	Cases (%) n=90	Controls (%) n=102804	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES						
Days since last Steeplechase race at that track				0.265	1	1-1
Race Distance						
1 to 3800	27062	21 (23.3)	27041 (26.3)		1 (Ref)	
>3800 (3801-7200)	75832	69 (76.7)	75763 (73.7)	0.084	1.28	0.97-1.68
Maiden or Novice Race						
No	65101	58 (64.4)	65043 (63.3)	1 (Ref)		
Yes	37793	32 (35.6)	37761 (36.7)	0.817	0.95	0.62-1.46
Number of steeplechase starts at that course 2000-2009						
1 to 2222	26931	32 (35.6)	26899 (26.2)	1 (Ref)		
>2222 (2223-7766)	75963	58 (64.4)	75905 (73.8)	0.045	0.64	0.42-0.99
Number of Runners						
1 to 9	52416	56 (62.2)	52360 (50.9)	1 (Ref)		
10 to 40	50478	34 (37.8)	50444 (49.1)	0.034	0.63	0.41-0.97
Race Position in Run Sequence						
Early	24790	27 (30)	24763 (24.1)	1 (Ref)		
Middle or Late	78104	63 (70)	78041 (75.9)	0.192	0.74	0.47-1.16
Time of Race						
Afternoon	93061	80 (88.9)	92981 (90.4)	1 (Ref)		
Morning or Evening	9833	10 (11.1)	9823 (9.6)	0.616	1.18	0.61-2.28
Summer Season						
No	90739	70 (77.8)	90669 (88.2)	1 (Ref)		
Yes	12155	20 (22.2)	12135 (11.8)	0.003	2.13	1.3-3.51
Sell / Claim Race	102894	0	102894			
Going						
heavy, GTF or Firm	26917	32 (35.6)	26885 (26.2)		1 (Ref)	
Soft to Good	75977	58 (64.4)	75919 (73.8)	0.044	0.64	0.42-0.99
Year						
2001, 2003 or 2009	32560	38 (42.2)	32522 (31.6)		1 (Ref)	
2002 or 2004-2008	70334	52 (57.8)	70282 (68.4)	0.032	0.63	0.42-0.96
TRAINER RELATED VARIABLES						
Trainer % First						
0 to 6 and 10 to 100	77501	66 (73.3)	77435 (75.3)	1 (Ref)		
7 to 9	25393	24 (26.7)	25369 (24.7)	0.662	1.11	0.7-1.77
Trainer Mean Score						
0 to 13	78552	65 (72.2)	78487 (76.3)	1 (Ref)		
>13 (14-30)	24342	25 (27.8)	24317 (23.7)	0.358	1.24	0.78-1.97
Trainer % Placed						
None	1682	1 (1.1)	1681 (1.6)	1 (Ref)		
Any (1-100)	101212	89 (98.9)	101123 (98.4)	1.48	0.69	0.2-10.6
JOCKEY RELATED VARIABLES						
Jockey % First						
0 to 9	52420	38 (42.2)	52382 (51)	1 (Ref)		
>9 (10-100)	50474	52 (57.8)	50422 (49)	0.099	1.42	0.94-2.16
Jockey Mean Score						
0 to 12	68400	51 (56.7)	68349 (66.5)	1 (Ref)		
>12 (13 to 30)	34494	39 (43.3)	34455 (33.5)	0.05	1.52	1-2.3
Jockey % Placed						
None	737	1 (1.1)	736 (0.7)		1 (Ref)	
Any (1 to 100)	102157	89 (98.9)	102068 (99.3)	0.659	0.64	0.09-4.61
Amateur Jockey						
No	89528	81 (90)	89447 (87)	1 (Ref)		
Yes	13366	9 (10)	13357 (13)	0.4	0.74	0.37-1.48
HORSE RELATED VARIABLES						
Previous career % flat						
0 to 59	102529	87 (96.7)	102442 (99.6)	1 (Ref)		
>59 (60-100)	365	3 (3.3)	362 (0.4)	<0.001	9.76	3.07-30.99
First Race Type						
F, St, NHF	49751	36 (40)	49715 (48.4)	1 (Ref)		
Hurdle	53143	54 (60)	53089 (51.6)	0.114	1.4	0.92-2.14
Age (years)			0.125	1.08	0.98-1.2	

Risk Factor for Hind limb fracture in Steeplechase racing	Total (%) n=102894	Cases (%) n=90	Controls (%) n=102804	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES CONTINUED						
Official Rating						
None up to 78 and 116 to 184	50383	51 (56.7)	50332 (49)		1 (Ref)	
79 to 115	52511	39 (43.3)	52472 (51)	0.145	0.73	0.48-1.11
First Race Flat						
No	75905	72 (80)	75833 (73.8)		1 (Ref)	
Yes	26989	18 (20)	26971 (26.2)	0.181	0.7	0.42-1.18
Race Different from previous						
No	85589	70 (77.8)	85519 (83.2)		1 (Ref)	
Yes	17305	20 (22.2)	17285 (16.8)	0.172	1.41	0.86-2.32
Age First Race (years)						
0 to 4 and >5	73374	59 (65.6)	73315 (71.3)		1 (Ref)	
4	29520	31 (34.4)	29489 (28.7)	0.229	1.31	0.85-2.02
Sex						
Male	94538	85 (94.4)	94453 (91.9)		1 (Ref)	
Female	8356	5 (5.6)	8351 (8.1)	0.376	0.67	0.27-1.64
Change in running distance from previous race (m)						
"-4000 to 0"	67506	63 (70)	67443 (65.6)		1 (Ref)	
1 to 4000	35388	27 (30)	35361 (34.4)	0.381	0.82	0.52-1.28
Weight Carried (lbs)						
1 to 148	26817	20 (22.2)	26797 (26.1)		1 (Ref)	
149 to 179	76077	70 (77.8)	76007 (73.9)	0.407	1.23	0.75-2.03
Career Length (years)				0.474	1.04	0.94-1.14
Change in running distance from previous						
Decreased or same	67585	57 (63.3)	67528 (65.7)		1 (Ref)	
Increased	35309	33 (36.7)	35276 (34.3)	0.639	1.11	0.72-1.7
Starts in previous 3 months						
None	23058	13 (14.4)	23045 (22.4)		1 (Ref)	
>0 (1-16)	79836	77 (85.6)	79759 (77.6)	0.073	1.71	0.95-3.08
Starts in previous 3-6 months						
0-2 and >3	93418	76 (84.4)	93342 (90.8)		1 (Ref)	
3	9476	14 (15.6)	9462 (9.2)	0.04	1.82	1.03-3.21
Starts in previous 6 to 9 months				0.344	0.93	0.79-1.08
Starts in previous 9 to 12 months				0.108	0.9	0.78-1.02
Starts > 1 year previously				0.718	1	0.98-1.01
Days since horses last race						
0 to 14 and 55 to 2990	51921	38 (42.2)	51883 (50.5)		1 (Ref)	
15 to 54	50973	52 (57.8)	50921 (49.5)	0.12	1.39	0.92-2.12

Table 13-9: Results of univariable logistic regression analysis of risk factors for pelvic fracture in horses undertaking National Hracing in Great Britain (2001-2009).

Risk Factor for Pelvic fracture in National Hunt racing	Total (%) n=298295	Cases (%) n=86	Controls (%) n=298209	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
RACE RELATED VARIABLES						
Days since last race at that track				0.649	1	1-1
Race Distance (m)						
1 to 4400	231090	56 (65.1)	231034 (77.5)		1 (Ref)	
>4400 (4401-7200)	67205	30 (34.9)	67175 (22.5)	0.007	1.84	1.18-2.87
Maiden Race						
No (normal + novice)	164993	47 (54.7)	164946 (55.3)		1 (Ref)	
Yes	133302	39 (45.3)	133263 (44.7)	0.902	1.03	0.67-1.57
Number of starts at that course 2000-2009						
1 - 1593 or 8171 - 10241	150608	39 (45.3)	150569 (50.5)		1 (Ref)	
5694 - 8170 or 10242-12665	147687	47 (54.7)	147640 (49.5)	0.341	1.23	0.8-1.88
Number of runners				0.006	1.06	1.02-1.11
Position in run sequence						
Early or Late	213909	51 (59.3)	213858 (71.7)		1 (Ref)	
Middle	84386	35 (40.7)	84351 (28.3)	0.012	1.74	1.13-2.68
Race Time						
Afternoon	274220	83 (96.5)	274137 (91.9)		1 (Ref)	
Morning or Evening	24075	3 (3.5)	24072 (8.1)	0.131	0.41	0.13-1.3
Season						
Summer or Autumn	111087	19 (22.1)	111068 (37.2)		1 (Ref)	
Winter or Spring	187208	67 (77.9)	187141 (62.8)	0.004	2.09	1.26-3.48
Sell or Claim Race						
No	277230	81 (94.2)	277149 (92.9)		1 (Ref)	
Yes	21065	5 (5.8)	21060 (7.1)	0.652	0.81	0.33-2
Going						
Heavy and GTF-Firm	81889	11 (12.8)	81878 (27.5)		1 (Ref)	
Soft to Good	216406	75 (87.2)	216331 (72.5)	0.003	2.58	1.37-4.86
Year						
2001	29471	10 (11.6)	29461 (9.9)		1 (Ref)	
2002	30700	8 (9.3)	30692 (10.3)	0.578	0.77	0.3-1.95
2003	30204	6 (7)	30198 (10.1)	0.3	0.59	0.21-1.61
2004	34052	14 (16.3)	34038 (11.4)	0.643	1.21	0.54-2.73
2005	34620	6 (7)	34614 (11.6)	0.193	0.51	0.19-1.41
2006	35409	9 (10.5)	35400 (11.9)	0.529	0.75	0.3-1.84
2007	33690	16 (18.6)	33674 (11.3)	0.404	1.4	0.64-3.09
2008	36077	8 (9.3)	36069 (12.1)	0.37	0.65	0.26-1.66
2009	34072	9 (10.5)	34063 (11.4)	0.586	0.78	0.32-1.92
TRAINER RELATED VARIABLES						
Trainer % First						
0-13	240024	62 (72.1)	239962 (80.5)		1 (Ref)	
>13 (14-100)	58271	24 (27.9)	58247 (19.5)	0.052	1.59	1-2.55
Trainer Mean Score						
0 to 13	227805	58 (67.4)	227747 (76.4)		1 (Ref)	
>13 (14-30)	70490	28 (32.6)	70462 (23.6)	0.053	1.56	0.99-2.45
Trainer % Placed						
0 to 36	234422	152	234270		1 (Ref)	
>36 (37-100)	63873	53	63820	0.122	1.27	0.93-1.75
JOCKEY RELATED VARIABLES						
Jockey % First						
None	4683	5 (5.8)	4678 (1.6)		1 (Ref)	
Any (1-100)	293612	81 (94.2)	293531 (98.4)	0.003	0.26	0.1-0.64
Jockey % Placed						
0 to 23	80857	20 (23.3)	80837 (27.1)	1 (Ref)		
>23 (24-100)	217438	66 (76.7)	217372 (72.9)	0.423	1.23	0.74-2.02
Jockey Mean Score						
0 to 11 or 14 to 30	159979	42 (48.8)	159937 (53.6)	1 (Ref)		
12 to 13	138316	44 (51.2)	138272 (46.4)	0.373	1.21	0.79-1.85
Amateur Jockey						
No	272679	79 (91.9)	272600 (91.4)		1 (Ref)	
Yes	25616	7 (8.1)	25609 (8.6)	0.882	0.94	0.44-2.04
HORSE RELATED VARIABLES						
Previous career flat %						
0 to 75	285522	75 (87.2)	285447 (95.7)		1 (Ref)	
>75 (76-100)	12773	11 (12.8)	12762 (4.3)	<0.001	3.28	1.74-6.18

Risk Factor for Pelvic fracture in National Hunt racing	Total (%) n=298295	Cases (%) n=86	Controls (%) n=298209	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
HORSE RELATED VARIABLES CONTINUED						
Official Rating						
None	93905	33 (38.4)	93872 (31.5)		1 (Ref)	
0 - 85	57096	7 (8.1)	57089 (19.1)	0.011	0.35	0.15-0.79
86-105	75533	16 (18.6)	75517 (25.3)	0.097	0.6	0.33-1.1
106-186	71761	30 (34.9)	71731 (24.1)	0.491	1.19	0.73-1.95
Change in running distance from previous						
Decreased or Same	205406	50 (58.1)	205356 (68.9)		1 (Ref)	
Increased	92889	36 (41.9)	92853 (31.1)	0.033	1.59	1.04-2.44
Actual Distance Change from previous						
"-400 to 0"	205646	52 (60.5)	205594 (68.9)		1 (Ref)	
1 to 4000	92649	34 (39.5)	92615 (31.1)	0.091	1.45	0.94-2.24
First Race Type						
F, H or NHF	275076	75 (87.2)	275001 (92.2)		1 (Ref)	
Steeple	23219	11 (12.8)	23208 (7.8)	0.087	1.74	0.92-3.27
Horse Age (Years)						
3 to 6 or 9 to 16	216904	56 (65.1)	216848 (72.7)		1 (Ref)	
7 to 8	81391	30 (34.9)	81361 (27.3)	0.116	1.43	0.92-2.22
Change race type from previous race						
No	245024	65 (75.6)	244959 (82.1)		1 (Ref)	
Yes	53271	21 (24.4)	53250 (17.9)	0.115	1.49	0.91-2.43
Weight Carried (lbs)						
1 to 147 or 159-181	142589	36 (41.9)	142553 (47.8)		1 (Ref)	
148 to 158	155706	50 (58.1)	155656 (52.2)	0.271	1.27	0.83-1.95
Career Length (years)						
0 to 1	99220	24 (27.9)	99196 (33.3)		1 (Ref)	
>1 (2-13)	199075	62 (72.1)	199013 (66.7)	0.293	1.29	0.8-2.06
Sex						
Male	245294	74 (86)	245220 (82.2)		1 (Ref)	
Female	53001	12 (14)	52989 (17.8)	0.356	0.75	0.41-1.38
First Race Flat						
No	185128	56 (65.1)	185072 (62.1)		1 (Ref)	
Yes	113167	30 (34.9)	113137 (37.9)	0.56	0.88	0.56-1.37
Age First Race (years)				0.637	1.03	0.9-1.19
Starts in previous 3 months						
None	75952	32 (37.2)	75920 (25.5)		1 (Ref)	
Any (1-16)	222343	54 (62.8)	222289 (74.5)	0.014	0.58	0.37-0.89
Starts in previous 3-6 months						
None	165703	51 (59.3)	165652 (55.5)		1 (Ref)	
Any (1-18)	132592	35 (40.7)	132557 (44.5)	0.484	0.86	0.56-1.32
Starts in previous 6 to 9 months				0.638	0.96	0.83-1.12
Starts in previous 9 to 12 months						
None	154996	48 (55.8)	154948 (52)		1 (Ref)	
Any (1-16)	143299	38 (44.2)	143261 (48)	0.475	0.86	0.56-1.31
Starts greater than 365 days previously						
0 to 5	82948	35 (40.7)	82913 (27.8)		1 (Ref)	
6 to 12	73729	15 (17.4)	73714 (24.7)	0.018	0.48	0.26-0.88
13 to 23	69671	21 (24.4)	69650 (23.4)	0.223	0.71	0.42-1.23
24 to 172	71947	15 (17.4)	71932 (24.1)	0.022	0.49	0.27-0.9
Previous lifetime starts						
0 to 9	82349	35 (40.7)	82314 (27.6)		1 (Ref)	
>9 (10-183)	215946	51 (59.3)	215895 (72.4)	0.007	0.56	0.36-0.85

Table 13-10: Results of univariable logistic regression analysis of risk factors for proximal forelimb fractures in hurdle racing in Great Britain (2001-2009).

Risk Factor for proximal forelimb fracture in Hurdle racing	Total (%) n=169668	Cases (%) n=97	Controls (%) n=169571	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
			RACE RELATED VARIABLES			
Days since last race at that track						
0 - 10 and>15 (16-952)	126440	81 (83.5)	126359 (74.5)		1 (Ref)	
11 to 15	43228	16 (16.5)	43212 (25.5)	0.045	0.58	0.34-0.99
Race Distance (m)				0.002	1	1-1
Maiden Race						
No (Normal or novice)	78431	42 (43.3)	78389 (46.2)		1 (Ref)	
Yes	91237	55 (56.7)	91182 (53.8)	0.563	1.13	0.75-1.68
Number of hurdle starts at track 2000-2009						
1 to 5824	130307	62 (63.9)	130245 (76.8)		1 (Ref)	
>5824 (5825-7766)	39361	35 (36.1)	39326 (23.2)	0.003	1.87	1.24-2.83
Number of runners						
1 to 10 and 13 to 40	137782	84 (86.6)	137698 (81.2)		1 (Ref)	
11 to 12	31886	13 (13.4)	31873 (18.8)	0.177	0.67	0.37-1.2
Position in run sequence						
Early	66957	35 (36.1)	66922 (39.5)		1 (Ref)	
Middle or Late	102711	62 (63.9)	102649 (60.5)	0.496	1.15	0.76-1.75
Race Time						
Afternoon	156737	87 (89.7)	156650 (92.4)	1 (Ref)		
Evening	12844	10 (10.3)	12834 (7.6)	0.311	1.4	0.73-2.7
Morning	87	0 (0)	87 (0.1)		1	0-0
Season						
Spring or Autumn	94528	57 (58.8)	94471 (55.7)		1 (Ref)	
Summer	23859	25 (25.8)	23834 (14.1)	0.021	1.74	1.09-2.78
Winter	51281	15 (15.5)	51266 (30.2)	0.013	0.48	0.27-0.86
Claiming Race						
No (Normal or sell)	166648	93 (95.9)	166555 (98.2)		1 (Ref)	
Yes	3020	4 (4.1)	3016 (1.8)	0.09	2.38	0.87-6.47
Track Going						
Heavy to Good	134375	56 (57.7)	134319 (79.2)		1 (Ref)	
GTF to Firm	35293	41 (42.3)	35252 (20.8)	<0.001	2.79	1.86-4.17
Year 2003						
No	152376	81 (83.5)	152295 (89.8)		1 (Ref)	
Yes	17292	16 (16.5)	17276 (10.2)	0.043	1.74	1.02-2.98
			TRAINER RELATED VARIABLES			
Trainer % First						
0 to 6	54702	27 (27.8)	54675 (32.2)		1 (Ref)	
>6 (7-100)	114966	70 (72.2)	114896 (67.8)	0.354	1.23	0.79-1.92
Trainer Mean Score						
0 to 11	56464	28 (28.9)	56436 (33.3)		1 (Ref)	
>11 (12-30)	113204	69 (71.1)	113135 (66.7)	0.357	1.23	0.79-1.91
Trainer % Placed						
None	582	1 (1)	581 (0.3)		1 (Ref)	
Any	169086	96 (99)	168990 (99.7)	0.271	0.33	0.05-2.37
			JOCKEY RELATED VARIABLES			
Jockey % First						
0 to 6 and 10 to 12	80794	43 (44.3)	80751 (47.6)		1 (Ref)	
7 to 9 and 13 to 100	88874	54 (55.7)	88820 (52.4)	0.517	1.14	0.76-1.7
Jockey % Placed						
0 to 22	42676	23 (23.7)	42653 (25.2)		1 (Ref)	
>22 (23-100)	126992	74 (76.3)	126918 (74.8)	0.744	1.08	0.68-1.73
Jockey Mean Score						
0 to 11	69279	43 (44.3)	69236 (40.8)		1 (Ref)	
12	48608	24 (24.7)	48584 (28.7)	0.369	0.8	0.48-1.31
13	29299	13 (13.4)	29286 (17.3)	0.289	0.71	0.38-1.33
14 to 30	22482	17 (17.5)	22465 (13.2)	0.491	1.22	0.69-2.14
Amateur Jockey						
No	159648	89 (91.8)	159559 (94.1)		1 (Ref)	
Yes	10020	8 (8.2)	10012 (5.9)	0.33	1.43	0.69-2.95

Risk Factor for upper forelimb fracture in Hurdle racing	Total (%) n=169668	Cases (%) n=97	Controls (%) n=169571	Wald P-values	Odds Ratio (OR)	95% Confidence Interval
			HORSE RELATED VARIABLES			
% Prev Career Flat				<0.001	1.03	1.02-1.03
Sex						
Male	133760	87 (89.7)	133673 (78.8)		1 (Ref)	
Female	35908	10 (10.3)	35898 (21.2)	0.011	0.43	0.22-0.82
Days since last race				0.001	1	1-1
Career length (years)						
0 to 4	143744	68 (70.1)	143676 (84.7)		1 (Ref)	
>4 (5-13)	25924	29 (29.9)	25895 (15.3)	<0.001	2.37	1.53-3.66
Age first race (years)				0.003	0.79	0.67-0.92
First Race Type						
Flat or St	86363	69 (71.1)	86294 (50.9)		1 (Ref)	
Hurdle or NHF	83305	28 (28.9)	83277 (49.1)	<0.001	0.42	0.27-0.65
First Race Flat						
No	84136	29 (29.9)	84107 (49.6)		1 (Ref)	
Yes	85532	68 (70.1)	85464 (50.4)	<0.001	2.31	1.49-3.56
Change in race distance from previous						
"-4000 to -200 and 1 to 4000"	98082	48 (49.5)	98034 (57.8)		1 (Ref)	
"-199 to 0"	71586	49 (50.5)	71537 (42.2)	0.098	1.4	0.94-2.08
Weight Carried (lbs)						
1 to 152 and 157 to 181	135578	71 (73.2)	135507 (79.9)		1 (Ref)	
153 to 156	34090	26 (26.8)	34064 (20.1)	0.101	1.46	0.93-2.28
Change run distance from previous						
Decreased or increased	103418	52 (53.6)	103366 (61)		1 (Ref)	
Same	66250	45 (46.4)	66205 (39)	0.14	1.35	0.91-2.01
Change race type from previous race						
No	133733	72 (74.2)	133661 (78.8)		1 (Ref)	
Yes	35935	25 (25.8)	35910 (21.2)	0.269	1.29	0.82-2.04
Official rating						
None	56582	37 (38.1)	56545 (33.3)		1 (Ref)	
Any	113086	60 (61.9)	113026 (66.7)	0.317	0.81	0.54-1.22
Starts in previous 3 months				0.596	1.03	0.91-1.17
Starts in previous 3 to 6 months						
1 to 6 and >7 (8-18)	168714	95 (97.9)	168619 (99.4)		1 (Ref)	
7	954	2 (2.1)	952 (0.6)	0.066	3.73	0.92-15.15
Starts in previous 6 to 9 months						
1 to 2 and >7 (8-15)	140153	77 (79.4)	140076 (82.6)		1 (Ref)	
3 to 7	29515	20 (20.6)	29495 (17.4)	0.403	1.23	0.75-2.02
Starts in previous 9 to 12 months						
0 to 1	86832	56 (57.7)	86776 (51.2)		1 (Ref)	
1 to 4	73233	32 (33)	73201 (43.2)	0.079	0.68	0.44-1.05
>4 (5-16)	9603	9 (9.3)	9594 (5.7)	0.298	1.45	0.72-2.94
Lifetime Starts						
0 to 29	129138	65 (67)	129073 (76.1)		1 (Ref)	
>29 (30-183)	40530	32 (33)	40498 (23.9)	0.037	1.57	1.03-2.4

Table 13-11: Results of univariable logistic regression analysis of risk factors for proximal forelimb fractures in Steeplechase racing in Great Britain (2001-2009)

Risk Factor for proximal forelimb fracture in Steeplechase racing	Total (%) n=102894	Cases (%) n=122	Controls (%) n=102772	Wald P-values	Odds Ratio (OR)	95% C.I.
Days since last race at that track						
0 to 10 and >15 (16-952)	76,919	82 (67.2)	76837 (74.8)		1 (Ref)	
11 to 15	25,975	40 (32.8)	25935 (25.2)	0.056	1.45	0.99-2.11
Race Distance (m)						
1 to 3800 and >4200 (4201-7200)	75,714	78 (63.9)	75636 (73.6)		1 (Ref)	
3801 to 4200	27,180	44 (36.1)	27136 (26.4)	0.016	1.57	1.09-2.28
Novice Race						
No	67,214	62 (50.8)	67152 (65.3)		1 (Ref)	
Yes	35,680	60 (49.2)	35620 (34.7)	0.001	1.82	1.28-2.6
Number of steeplechase starts at track 2000-2009						
1 to 2222	26,931	35 (28.7)	26896 (26.2)		1 (Ref)	
>2222 (2223-5244)	75,963	87 (71.3)	75876 (73.8)	0.527	0.88	0.6-1.3
Number of runners						
1 to 7	29,903	39 (32)	29864 (29.1)		1 (Ref)	
>7 (8-40)	72,991	83 (68)	72908 (70.9)	0.48	0.87	0.6-1.28
Race position in run sequence						
Early or Middle	62,261	70 (57.4)	62191 (60.5)		1 (Ref)	
Late	40,633	52 (42.6)	40581 (39.5)	0.479	1.14	0.8-1.63
Race Time						
Morning or Afternoon	93,074	108 (88.5)	92966 (90.5)		1 (Ref)	
Evening	9,820	14 (11.5)	9806 (9.5)	0.468	1.23	0.7-2.15
Season						
Autumn or Winter	53,662	59 (48.4)	53603 (52.2)		1 (Ref)	
Spring or Summer	49,232	63 (51.6)	49169 (47.8)	0.402	1.16	0.82-1.66
Going						
Heavy to GTF	102,050	120 (98.4)	101930 (99.2)		1 (Ref)	
Firm	844	2 (1.6)	842 (0.8)	0.325	2.02	0.5-8.17
Year						
2001, 2005-2006, 2008	47,047	49 (40.2)	46998 (45.7)		1 (Ref)	
2002 to 2004, 2007 or 2009	55,847	73 (59.8)	55774 (54.3)	0.218	1.26	0.87-1.8
TRAINER RELATED VARIABLES						
Trainer % First						
0	4,286	7 (5.7)	4279 (4.2)		1 (Ref)	
>0 (1-100)	98,608	115 (94.3)	98493 (95.8)	0.387	0.71	0.33-1.53
Trainer % Placed						
0	1,682	5 (4.1)	1677 (1.6)		1 (Ref)	
>0 (1-100)	101,212	117 (95.9)	101095 (98.4)	0.039	0.39	0.16-0.95
Trainer Mean Score						
0	452	2 (1.6)	450 (0.4)		1 (Ref)	
>0 (1-30)	102,442	120 (98.4)	102322 (99.6)	0.062	0.26	0.07-1.07
JOCKEY RELATED VARIABLES						
Jockey % First						
0	2,174	4 (3.3)	2170 (2.1)		1 (Ref)	
>0 (1-100)	100,720	118 (96.7)	100602 (97.9)	0.374	0.64	0.23-1.73
Jockey % Placed						
0 to 24 and 31 to 36	52,021	55 (45.1)	51966 (50.6)		1 (Ref)	
25 to 30 and >36 (37-100)	50,873	67 (54.9)	50806 (49.4)	0.227	1.25	0.87-1.78
Jockey Mean Score						
0 to 11 and >13 (14-30)	54,306	72 (59)	54234 (52.8)		1 (Ref)	
12 to 13	48,588	50 (41)	48538 (47.2)	0.168	0.78	0.54-1.11
Amateur Jockey						
No	89,528	97 (79.5)	89431 (87)		1 (Ref)	
Yes	13,366	25 (20.5)	13341 (13)	0.015	1.73	1.11-2.68
HORSE RELATED VARIABLES						
Previous Career Flat %						
0 to 38	96,107	105 (86.1)	96002 (93.4)	1 (Ref)		
>38 (39-100)	6,787	17 (13.9)	6770 (6.6)	0.001	2.3	1.37-3.83
Days since last race			0.009	1	1-1	
Weight Carried (lbs)						
1 to 154	52,053	51 (41.8)	52002 (50.6)	1 (Ref)		
>154 (155-179)	50,841	71 (58.2)	50770 (49.4)	0.053	1.43	0.99-2.04

Risk Factor for upper forelimb fracture in Steeplechase racing	Total (%) n=102894	Cases (%) n=122	Controls (%) n=102772	Wald P-values	Odds Ratio (OR)	95% C.I.
HORSE RELATED VARIABLES CONTINUED						
Change in race distance from previous						
"-4000 to -200 and >200	56,878	57 (46.7)	56821 (55.3)		1 (Ref)	
"-199 to 200"	46,016	65 (53.3)	45951 (44.7)	0.058	1.41	0.99-2.01
Change in running distance from previous						
Decreased or increased	66,389	69 (56.6)	66320 (64.5)		1 (Ref)	
No change	36,505	53 (43.4)	36452 (35.5)	0.067	1.4	0.98-2
Change race type from previous						
No	85,589	95 (77.9)	85494 (83.2)		1 (Ref)	
Yes	17,305	27 (22.1)	17278 (16.8)	0.118	1.41	0.92-2.16
Career length (years)						
0 to 4	68,013	74 (60.7)	67939 (66.1)		1 (Ref)	
>4 (5-13)	34,881	48 (39.3)	34833 (33.9)	0.205	1.27	0.88-1.82
Official Rating						
None	11,753	18 (14.8)	11735 (11.4)		1 (Ref)	
Any	91,141	104 (85.2)	91037 (88.6)	0.249	0.74	0.45-1.23
First Race Type						
F, St or NHF	49,751	53 (43.4)	49698 (48.4)		1 (Ref)	
Hurdle	53,143	69 (56.6)	53074 (51.6)	0.278	1.22	0.85-1.74
Age (years)				0.357	1.04	0.95-1.14
Age first race (years)				0.491	1.04	0.93-1.16
First Race Flat						
No	75,905	92 (75.4)	75813 (73.8)			
Yes	26,989	30 (24.6)	26959 (26.2)	0.68	0.92	0.61-1.38
Sex						
Male	94,538	112 (91.8)	94426 (91.9)		1 (Ref)	
Female	8,356	10 (8.2)	8346 (8.1)	0.976	1.01	0.53-1.93
Starts in previous 3 months				0.131	0.91	0.81-1.03
Starts in previous 3 to 6 months						
0	57,298	67 (54.9)	57231 (55.7)		1 (Ref)	
>0 (1-12)	45,596	55 (45.1)	45541 (44.3)	0.864	1.03	0.72-1.47
Starts in previous 6 to 9 months						
0 to 1 and >4 (5-11)	78,064	99 (81.1)	77965 (75.9)		1 (Ref)	
2 to 4	24,830	23 (18.9)	24807 (24.1)	0.174	0.73	0.46-1.15
Starts in previous 9 to 12 months						
0	43,666	68 (55.7)	43598 (42.4)		1 (Ref)	
1 to 6	58,467	53 (43.4)	58414 (56.8)	0.003	0.58	0.41-0.83
>6 (7-16)	761	1 (0.8)	760 (0.7)	0.866	0.84	0.12-6.08
Starts >365 days previously						
0 to 27	78,502	102 (83.6)	78400 (76.3)		1 (Ref)	
>27 (28-135)	24,392	20 (16.4)	24372 (23.7)	0.06	0.63	0.39-1.02
Lifetime previous starts						
0 to 21	53,469	77 (63.1)	53392 (52)		1 (Ref)	

13.7 Appendix 7: Example post-mortem findings report form.

TP.

Thoroughbred Injury Prevention Study

Post Mortem Report

Case No.: 0164

Suspensory apparatus rupture.

1. *Internal Findings:*

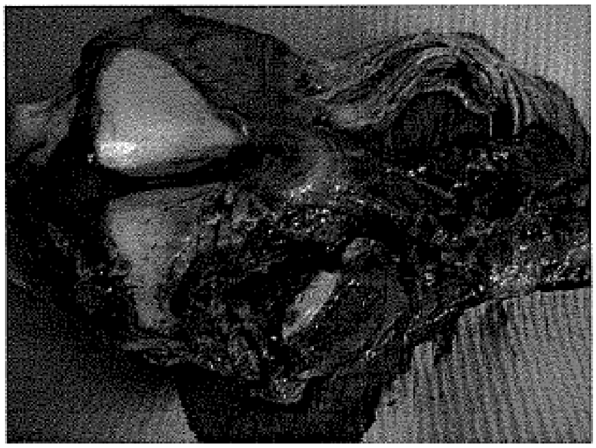
- The whole of the lateral branch of the suspensory apparatus was ruptured or stretched. The whole of the lateral half of the main body of the suspensory apparatus was also stretched. The region of the medial branch immediately proximal to the medial proximal sesamoid bone was also severely stretched and partially torn. There were also two avulsion fractures from the abaxial edge of the medial proximal sesamoid bone and one from the palmar surface of this bone.

Comment:

- This case was classified as a suspensory apparatus breakdown on the basis that the soft tissue injuries were more extensive than the fractures.

Figure 1. DP view of the proximal sesamoid bone region from the right fore limb.

Distal



Proximal

13.8 Appendix 8: Multivariable model showing variables significantly associated with the risk of pelvic fracture, with possible pelvic fracture cases not included as controls.

Risk Factors for Pelvic fracture in National Hunt racing	TOTAL (%) n=298295	Cases (%) n=86	Controls (%) n=298209	**P-value**	Odds Ratio (OR)	95% CI
% Career on Flat						
0 to 75	285522 (95.72)	75 (87.21)	285447 (95.72)		1 (Ref)	
>75	12773 (4.28)	11 (12.79)	12762 (4.28)	**<0.001**	6.03	3.06-11.87
Season						
Summer and Autumn	111087 (37.24)	19 (22.09)	111068 (37.25)		1 (Ref)	
Winter and Spring	187208 (62.76)	67 (77.91)	187141 (62.75)	**0.005**	2.03	1.2-3.41
Race Distance (km)						
2.4 to 4.4	231090 (77.47)	56 (65.12)	231034 (77.47)		1 (Ref)	
>4.4	67205 (22.53)	30 (34.88)	67175 (22.53)	**0.004**	2.05	1.29-3.28
Race Position in run sequence						
Early or Late	213909 (71.71)	51 (59.3)	213858 (71.71)		1 (Ref)	
Middle	84386 (28.29)	35 (40.7)	84351 (28.29)	**0.004**	1.93	1.24-2.99
Jockey % of finishes in 1st place						
None	4683 (1.57)	5 (5.81)	4678 (1.57)		1 (Ref)	
Any	293612 (98.43)	81 (94.19)	293531 (98.43)	**0.035**	0.31	0.12-0.79
Trainer % of finishes in 1-3						
0 to 36	234422 (78.59)	58 (67.44)	234364 (78.59)		1 (Ref)	
>36	63873 (21.41)	28 (32.56)	63845 (21.41)	**0.015**	1.81	1.14-2.86
Starts in previous 3 months						
None	75952 (25.46)	32 (37.21)	75920 (25.46)		1 (Ref)	
Greater than none	222343 (74.54)	54 (62.79)	222289 (74.54)	**0.01**	0.54	0.35-0.85
Number of starts >1 year previously				**0.005**		
0 to 5	82948 (27.81)	35 (40.7)	82913 (27.8)		1 (Ref)	
6 to 12	73729 (24.72)	15 (17.44)	73714 (24.72)	*0.007*	0.43	0.23-0.79
13 to 23	69671 (23.36)	21 (24.42)	69650 (23.36)	*0.058*	0.59	0.34-1.02
24 to 172	71947 (24.12)	15 (17.44)	71932 (24.12)	*0.002*	0.38	0.2-0.7
Number of runners in race				**0.03**	1.05	1.01-1.1

Bolded P-values are likelihood ratio test P-values, whilst italicised P-values are Wald test P-values

Percentage change in odds ratios for each of the variables compared between the multivariable models for pelvic fracture in National Hunt racing, with and without possible fracture cases included as controls.

Variables	% Change in Odds Ratio
% Career on Flat	0.004113
Season	0.003453
Race Distance (km)	0.012653
Race Position in run sequence	0.001245
Jockey % of finishes in 1st place	-0.01019
Trainer % of finishes in 1-3	-0.00864
Starts in previous 3 months	-0.00434
Number of starts >1 year previously	
0 to 5	
6 to 12	-0.00486
13 to 23	-0.00504
24 to 172	0.000319
Number of runners in race	0.000571

14 List of References

Alonso, J.M., Edouard, P., Fischetto, G., Adams, B., Depiesse, F., Mountjoy, M., 2012. Determination of future prevention strategies in elite track and field: analysis of Daegu 2011 IAAF Championships injuries and illnesses surveillance. British Journal of Sports Medicine 46, 505–14.

Altman, D.G., Machin, D., Bryant, T.N., Gardner, M.J., 2000. Statistics with Confidence. BMJ Books, London.

Altman, D.G., Vergouwe, Y., Royston, P., Moons, K.G.M., 2009. Prognosis and prognostic research: validating a prognostic model. Bmj 338, b605–b605.

Anthenill, L.A., Stover, S.M., Gardner, I.A., Hill, A.E., 2007. Risk factors for proximal sesamoid bone fractures associated with exercise history and horseshoe characteristics in Thoroughbred racehorses. American Journal of Veterinary Research 68, 760–771.

Arnoczky, S.P., Lavagnino, M., Egerbacher, M., 2008. The response of tendon cells to changing loads: implications in the etiopathogenesis of tendinopathy. In: Woo, S.L., Renstrom, P.A., Arnoczky, S.P. (Eds.), Tendinopathy in Athletes,. Blackwell Publishing, Oxford, pp. 44–59.

Avella, C.S., Ely, E.R., Verheyen, K.L.P., Price, J.S., Wood, J.L.N., Smith, R.K., 2009. Ultrasonographic assessment of the superficial digital flexor tendons of National Hunt racehorses in training over two racing seasons. Equine Veterinary Journal 41, 449–454.

Bagley, S.C., White, H., Golomb, B.A., 2001. Logistic regression in the medical literature: standards for use and reporting, with particular attention to one medical domain. Journal of clinical epidemiology 54, 979–985.

Bailey, C.J., Reid, S.W.J., Hodgson, D.R., Bourke, J.M., Rose, R.J., 1998. Flat, hurdle and steeple racing: risk factors for musculoskeletal injury. Equine Veterinary Journal 30, 498–503.

Bailey, C.J., Reid, S.W.J., Hodgson, D.R., Rose, R.J., 1999. Factors associated with time until first race and career duration for Thoroughbred racehorses. American Journal of Veterinary Research 60, 1196–1200.

Bailey, C.J., Reid, S.W.J., Hodgson, D.R., Suann, C.J., Rose, R.J., 1997. Risk factors associated with musculoskeletal injuries in Australian thoroughbred racehorses. Preventive Veterinary Medicine 32, 47–55.

Birks, E.K., Shuler, K.M., Soma, L.R., Martin, B.B., Marconato, L., Del Piero, F., Teleis, D.C., Schar, D., Hessinger, A.E., Uboh, C.E., 2002. EIPH: postrace endoscopic evaluation of Standardbreds and Thoroughbreds. Equine Veterinary Journal. Supplement 34, 375–8.

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Clarke, A.F., Slocombe, R.F., 2007a. Risk factors for Thoroughbred racehorse fatality in flat starts in Victoria, Australia (1989-2004). Equine Veterinary Journal 39, 430–437.

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Clarke, A.F., Slocombe, R.F., 2007b. Risk factors for Thoroughbred racehorse fatality in jump starts in Victoria, Australia (1989-2004). Equine Veterinary Journal 39, 422–428.

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Slocombe, R.F., Clarke, A.F., 2006. Risk of fatality and causes of death of Thoroughbred horses associated with racing in Victoria, Australia: 1989-2004. Equine Veterinary Journal 38, 312–8.

Boden, L.A., Charles, J.A., Slocombe, R.F., Sandy, J.R., Finnin, P.J., Morton, J.M., Clarke, A.F., 2005. Sudden death in racing Thoroughbreds in Victoria, Australia. Equine Veterinary Journal 37, 269–71.

Bourke, J.M., 1994. Fatalities on racecourses in Victoria. A seven year study. In: Proceedings of the 10th International Conference of Racing Analysts and Veterinarians. Stockholm, pp. 265–268.

Butcher, M.T., Hermanson, J.W., Ducharme, N.G., Mitchell, L.M., Soderholm, L. V, Bertram, J.E. a, 2007. Superficial digital flexor tendon lesions in racehorses as a sequela to muscle fatigue: a preliminary study. Equine veterinary journal 39, 540–5.

Carrier, T.K., Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Read, D.H., Ardans, A.A., 1998. Association between long periods without high-speed workouts and risk of complete humeral or pelvic fracture in thoroughbred racehorses: 54 cases (1991-1994). Journal of the American Veterinary Medical Association 212, 1582–1587.

Cherdchutham, W., Becker, C.K., Smith, R.K., Barneveld, A., Van Weeren, P.R., 1999. Age-related changes and effect of exercise on the molecular composition of immature equine superficial digital flexor tendons. Equine Veterinary Journal. Supplement 31, 86–94.

Cherdchutham, W., Becker, C.K., Spek, E.R., Voorhout, W.F., Van Weeren, P.R., 2001. Effects of exercise on the diameter of collagen fibrils in the central core and periphery of the superficial digital flexor tendon in foals. American Journal of Veterinary Research 62, 1563–1570.

Cogger, N., Perkins, N.R., Hodgson, D.R., Reid, S.W.J., Evans, D.L., 2006. Risk factors for musculoskeletal injuries in 2-year-old Thoroughbred racehorses. Preventive veterinary medicine 74, 36–43.

Cohen, N.D., Berry, S.M., Peloso, J.G., Mundy, G.D., Howard, I.C., 2000. Association of high-speed exercise with racing injury in thoroughbreds. Journal of the American Veterinary Medical Association 216, 1273–8.

Cook, W.R., 1974. Epistaxis in the racehorse. Equine veterinary journal 6, 45–58.

Corsan, B., 2012. Non-musculoskeletal lesions documented during necropsy of thoroughbred racehorses following catastrophic injury or sudden death during racing. In: ICRAV. Philadelphia.

Davis, C.S., Smith, R.K., 2006. Diagnosis and management of tendon and ligament disorders. In: Auer, J.A., Stick, J.A. (Eds.), Equine Surgery. Elsevier Saunders, St Louis, MO, USA, pp. 1086–1111.

Dohoo, I., Martin, W., Stryhn, H., 2010. Veterinary Epidemiologic Research, 2nd ed. AVC Inc., Charlottetown.

Dowling, B.A., Dart, A.J., 2005. Mechanical and functional properties of the equine superficial digital flexor tendon. The Veterinary Journal 170, 184–192.

Dyson, S.J., 2004. Medical management of superficial digital flexor tendonitis: a comparative study in 219 horses (1992-2000). Equine Veterinary Journal 36, 415–9.

Egan, D., 2011. International Race Day Medication Summit. In: International Summit on Race Day Medication, EIPH and the Racehorse. New York.

Ely, E.R., 2010. Epidemiology of Fractures and Tendon Injuries in National Hunt Racehorses in Training. University of London.

Ely, E.R., Avella, C.S., Price, J.S., Smith, R.K., Wood, J.L.N., Verheyen, K.L.P., 2009. Descriptive epidemiology of fracture, tendon and suspensory ligament injuries in National Hunt racehorses in training. Equine Veterinary Journal 41, 372–378.

Ely, E.R., Verheyen, K.L.P., Wood, J.L.N., 2004. Fractures and tendon injuries in National Hunt horses in training in the UK: a pilot study. Equine veterinary journal 36, 365–7.

Epp, T.S., McDonough, P., Padilla, D.J., Gentile, J.M., Edwards, K.L., Erickson, H.H., Poole, D.C., 2006. Exercise-induced pulmonary haemorrhage during submaximal exercise. Equine Veterinary Journal. Supplement 502–507.

Estberg, L., Gardner, I. a, Stover, S.M., Johnson, B.J., 1998a. A case-crossover study of intensive racing and training schedules and risk of catastrophic musculoskeletal injury and lay-up in California thoroughbred racehorses. Preventive Veterinary Medicine 33, 159–70.

Estberg, L., Gardner, I.A., Stover, S.M., Johnson, B.J., Case, J.T., Ardans, A.A., 1995. Cumulative racing-speed exercise distance cluster as a risk factor for fatal musculoskeletal injury in Thoroughbred racehorses in California. Preventive Veterinary Medicine 24, 253–263.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Case, J.T., Ardans, A.A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J., Woods, L.W., 1996. Fatal musculoskeletal injuries incurred during racing and training in thoroughbreds. Journal of the American Veterinary Medical Association 208, 92–96.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Jack, R.A., Case, J.T., Ardans, A.A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J., Woods, L.W., 1998b. Relationship between race start characteristics and risk of catastrophic injury in thoroughbreds: 78 cases (1992). Journal of the American Veterinary Medical Association 212, 544–549.

Garett, J.M., 1996. Graphical assessment of linear trend. In: Stata Technical Bulletin Reprints. Stata Press, College Station, TX, pp. 152–160.

Goldstein, H., Browne, W., Rasbash, J., 2002. Partitioning variation in multilevel models. Understanding Statistics 1, 223–231.

Goodship, A.E., Birch, H.L., 2001. Exercise effects on the skeletal tissues. WB Saunders, London.

Haussler, K.K., Stover, S.M., 1998. Stress fractures of the vertebral lamina and pelvis in Thoroughbred racehorses. Equine Veterinary Journal 30, 374–381.

Henley, W.E., Rogers, K., Harkins, L.S., Wood, J.L.N., 2006. A comparison of survival models for assessing risk of racehorse fatality. Preventive Veterinary Medicine 74, 3–20.

Hernandez, J.A., Hawkins, D.L., Scollay, M.C., 2001. Race-start characteristics and risk of catastrophic musculoskeletal injury in Thoroughbred racehorses. Journal of the American Veterinary Medical Association 218, 83–6.

Hernandez, J.A., Scollay, M.C., Hawkins, D.L., Corda, J.A., Krueger, T.M., 2005. Evaluation of horseshoe characteristics and high-speed exercise history as possible risk factors for catastrophic musculoskeletal injury in thoroughbred racehorses. American Journal of Veterinary Research 66, 1314–20.

Hill, A.E., Stover, S.M., Gardner, I.A., Kane, A.J., Whitcomb, M.B., Emerson, A.G., 2001. Risk factors for and outcomes of noncatastrophic suspensory apparatus injury in Thoroughbred racehorses. Journal of the American Veterinary Medical Association 218, 1136–1144.

Hill, T., Carmichael, D., Maylin, G.A., Krook, L., 1986. Track condition and racing injuries in thoroughbred horses. Cornell Vet 76, 361–379.

Hinchcliff, K.W., 2009. Exercise induced pulmonary haemorrhage. Kentucky Equine Research IV, 367–377.

Hinchcliff, K.W., Jackson, M.A., Morley, P.S., Brown, J.A., Dredge, A.F., O'Callaghan, P.A., McCaffrey, J.P., Slocombe, R.E., Clarke, A.E., 2005. Association between exercise-induced pulmonary hemorrhage and performance in Thoroughbred racehorses. Journal of the American Veterinary Medical Association 227, 768–74.

Hinchcliff, K.W., Morley, P.S., Jackson, M. a, Brown, J. a, Dredge, a F., O'Callaghan, P. a, McCaffrey, J.P., Slocombe, R.F., Clarke, a F., 2010. Risk factors for exercise-induced pulmonary haemorrhage in Thoroughbred racehorses. Equine Veterinary Journal. Supplement 42, 228–34.

Hosaka, Y., Ozoe, S., Kirisawa, R., Ueda, H., Takehana, K., Yamaguchi, M., 2006. Effect of heat on synthesis of gelatinases and pro-inflammatory cytokines in equine tendinocytes. Biomedical research (Tokyo, Japan) 27, 233–41.

Hosmer, D.W., Lemeshow, S., 2000. Applied Logistic Regression, 2nd ed. John Wiley and Sons Inc., New York.

Johns, G., 2012. Paved With Good Intentions: The Road Home and the Irreducible Minimum of Homelessness in Australia. Agenda A journal of policy analysis and reform 19.

Johnson, B.J., Stover, S.M., Daft, B.M., Kinde, H., Read, D.H., Barr, B.C., Anderson, M.L., Moore, J., Woods, L.W., Stoltz, J., 1994. Causes of death in racehorses over a 2 year period. Equine Veterinary Journal 26, 327–30.

Jorgensen, J.S., Genovese, R.L., 2003. Superficial digital flexor tendonitis. In: Ross, M.W., Dyson, S.J. (Eds.), Diagnosis and Management of Lameness in the Horse. WB Saunders, Philadelphia, pp. 628–644.

Kai, M., Takahashi, T., Aoki, O., Oki, H., 1999. Influence of rough track surfaces on components of vertical forces in cantering thoroughbred horses. Equine veterinary journal. Supplement 30, 214–7.

Kane, A.J., Stover, S.M., Gardner, I.A., Case, J.T., Johnson, B.J., Read, D.H., Ardans, A.A., 1996. Horseshoe characteristics as possible risk factors for fatal musculoskeletal injury of thoroughbred racehorses. American Journal of Veterinary Research 57, 1147–1152.

Kasashima, Y., Takahashi, T., Smith, R.K., Goodship, A.E., Kuwano, A., Ueno, T., Hirano, S., 2004. Prevalence of superficial digital flexor tendonitis and suspensory desmitis in Japanese Thoroughbred flat racehorses in 1999. Equine Veterinary Journal 36, 346–50.

Kawcak, C.E., McIlwraith, C.W., Norrdin, R.W., Park, R.D., Steyn, P.S., 2000. Clinical effects of exercise on subchondral bone of carpal and metacarpophalangeal joints in horses. American Journal of Veterinary Research 61, 1252–1258.

Keegan, K.G., Dent, E. V, Wilson, D.A., Janicek, J., Kramer, J., Lacarrubba, A., Walsh, D.M., Cassells, M.W., Esther, T.M., Schiltz, P., Frees, K.E., Wilhite, C.L., Clark, J.M., Pollitt, C.C., Shaw, R., Norris, T., 2010. Repeatability of subjective evaluation of lameness in horses. Equine veterinary journal 42, 92–7.

Ker, R.F., 1981. Dynamic tensile properties of the plantaris tendon of sheep (Ovis aries). The Journal of experimental biology 93, 283–302.

Kim, B.S., Kim, J.H., Ryu, S.H., Yang, Y.J., 1998. The effect of exercise-induced pulmonary haemorrhage (EIPH) on performance of Thoroughbred racehorses at the Seoul racecourse. Korean journal of veterinary clinical medicine 15, 427–431.

Krook, L., Maylin, G.A., 1988. Fractures in Thoroughbred race horses. Cornell Veterinary Journal Suppl. 78, 1–133.

Lam, K.H., Parkin, T.D.H., Riggs, C.M., Morgan, K.L., 2007a. Descriptive analysis of retirement of Thoroughbred racehorses due to tendon injuries at the Hong Kong Jockey Club (1992-2004). Equine Veterinary Journal 39, 143–148.

Lam, K.H., Parkin, T.D.H., Riggs, C.M., Morgan, K.L., 2007b. Evaluation of detailed training data to identify risk factors for retirement because of tendon injuries in Thoroughbred racehorses. American Journal of Veterinary Research 68, 1188–1197.

Lapointe, J.M., Vrins, A., McCarvill, E., 1994. A survey of exercise-induced pulmonary haemorrhage in Quebec standardbred racehorses. Equine Veterinary Journal 26, 482–485.

Loitz, B.J., Zernicke, R.F., 1992. Strenuous exercise-induced remodeling of mature bone: relationships between in-vivo strains and bone mechanics. Journal of Experimental Biology 170, 1–18.

Lyle, C.H., Uzal, F.A., McGorum, B.C., Aida, H., Blissitt, K.J., Case, J.T., Charles, J.T., Gardner, I., Horadagoda, N., Kusano, K., Lam, K.H., Pack, J.D., Parkin, T.D.H., Slocombe, R.F., Stewart, B.D., Boden, L.A., 2011. Sudden death in racing Thoroughbred horses: an international multicentre study of post mortem findings. Equine Veterinary Journal 43, 324–31.

Mantel, N., 1970. Why Stepdown Procedures in Variable Selection. Technometrics 12, 621–625.

Marr, C.M., Love, S., Boyd, J.S., McKellar, Q., 1993. Factors affecting the clinical outcome of injuries to the superficial digital flexor tendon in National Hunt and point-to-point racehorses. Veterinary Record 132, 476–479.

Mason, D.K., Collins, E.A., Watkins, K.L., 1983. Exercise-induced pulmonary haemorrhage in horses. In: Snow, D.H., Persson, S.G.B., Rose, R.J. (Eds.), Equine Exercise Physiology. Granta Editions, Cambridge, pp. 57–63.

Mckee, S.L., 1995. An update on racing fatalities in the UK. Equine Veterinary Education 7, 202–204.

Metoffice, 2011. UK climate summaries [WWW Document]. URL http://www.metoffice.gov.uk/climate/uk/

Mohammed, H.O., Hill, T., Lowe, J., 1991. Risk factors associated with injuries in thoroughbred horses. Equine Veterinary Journal 23, 445–8.

Mohammed, H.O., Hill, T., Lowe, J., 1992. The risk of severity of limb injuries in racing Thoroughbred horses. Cornell Vet 82, 331–341.

Montgomery, T., 1965. Leg problems in race horses. Vet Med Small Anim Clin 60, 1106–1108.

Moons, K.G.M., Royston, P., Vergouwe, Y., Grobbee, D.E., Altman, D.G., 2009. Prognosis and prognostic research: what, why, and how? British Medical Journal 338, 1317–1320.

Newton, J.R., Rogers, K., Marlin, D.J., Wood, J.L.N., Williams, R.B., 2005. Risk factors for epistaxis on British racecourses: evidence for locomotory impact-induced trauma contributing to the aetiology of exercise-induced pulmonary haemorrhage. Equine Veterinary Journal 37, 402–11.

Newton, J.R., Wood, J.L.N., 2002. Evidence of an association between inflammatory airway disease and EIPH in young Thoroughbreds during training. Equine Veterinary Journal. Supplement 417–424.

O’Meara, B., Bladon, B., Parkin, T.D.H., Fraser, B., Lischer, C.J., 2010. An investigation of the relationship between race performance and superficial digital flexor tendonitis in the Thoroughbred racehorse. Equine Veterinary Journal 42, 322–326.

Parkin, T.D.H., 2002. Identification of risk factors for fatal distal limb fractures in racing Thoroughbreds. University of Liverpool.

Parkin, T.D.H., 2007a. Workshop report epidemiology of training and racing injuries. Equine Veterinary Journal 39, 466–469.

Parkin, T.D.H., 2007b. Epidemiology of training and racing injuries. Equine Veterinary Journal 39, 466–469.

Parkin, T.D.H., 2010. Track surfaces and lameness: Epidemiological aspects of racehorse injury. In: Ross, M.W. (Ed.), Diagnosis and Management of Lameness in the Horse. Saunders Elsevier, St Louis, MO, USA, p. 974.

Parkin, T.D.H., Brown, P.E., French, N.P., Morgan, K.L., 2005. Clinical Evidence Notebook Cooking the books or simply getting the best out of the data ? Assessing the nature of the relationship between variables. Health (San Francisco) 37, 189–191.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M., Morgan, K.L., 2004a. Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. Equine Veterinary Journal 36, 521–6.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M., Morgan, K.L., 2004b. Risk factors for fatal lateral condylar fracture of the third metacarpus/metatarsus in UK racing. Equine Veterinary Journal 37, 192–9.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M., Morgan, K.L., 2004c. Risk of fatal distal limb fractures among thoroughbreds involved in the five types of racing in the United Kingdom. Veterinary Record 154, 493–497.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M., Morgan, K.L., 2004d. Horse-level risk factors for fatal distal limb fracture in racing Thoroughbreds in the UK. Equine Veterinary Journal 36, 513–9.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M., Morgan, K.L., 2004e. Epidemiology of catastrophic fractures during racing. In: Proceedings of the 15th International Conference of Racing Analysts and Veterinarians. Dubai, pp. 1–7.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M., Morgan, K.L., 2006. Catastrophic fracture of the lateral condyle of the third metacarpus/metatarsus in UK racehorses - fracture descriptions and pre-existing pathology. The Veterinary Journal 171, 157–65.

Parkin, T.D.H., Ecob, R., Hillyer, L., Morris, T., Rogers, K., Stirk, A.J., Webbon, P.M., Newton, J.R., 2009. Modelling hierarchical and cross-classified data structures during the investigation of horse racing injury. In: Society of Veterinary Epidemiology and Preventative Medicine. London, pp. 138–150.

Parkin, T.D.H., Rogers, K., Stirk, A.J., 2000. Risk factors for tendon strain injury during racing in Great Britain. In: Proceedings of the 16th International Conference of Racing Analysts and Veterinarians. R&W Publications, Newmarket, p. 104.

Parkin, T.D.H., Welsh, C.E., 2012. Heritability of musculoskeletal disorders in Thoroughbreds. In: ICRAV. Philadelphia.

Pascoe, J.R., Ferraro, G.L., Cannon, J.H., Arthur, R.M., Wheat, J.D., 1981. Exercise-induced pulmonary hemorrhage in racing thoroughbreds: a preliminary study. American Journal of Veterinary Research 42, 703–707.

Patterson-Kane, J.C., Firth, E.C., Goodship, A.E., Parry, D.A., 1997a. Age-related differences in collagen crimp patterns in the superficial digital flexor tendon core region of untrained horses. Australian Veterinary Journal 75, 39–44.

Patterson-Kane, J.C., Parry, D.A., Birch, H.L., Goodship, A.E., Firth, E.C., 1997b. An age-related study of morphology and cross-link composition of collagen fibrils in the digital flexor tendons of young thoroughbred horses. Connective Tissue Research 36, 253–260.

Peduzzi, P., Concato, J., Kemper, E., Holford, T.R., Feinstein, a R., 1996. A simulation study of the number of events per variable in logistic regression analysis. Journal of clinical epidemiology 49, 1373–9.

Peloso, J.G., Mundy, G.D., Cohen, N.D., 1994. Prevalence of, and factors associated with, musculoskeletal racing injuries of thoroughbreds. Journal of the American Veterinary Medical Association 204, 620–626.

Perkins, N.R., Reid, S.W.J., Morris, R.S., 2005a. Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. New Zealand Veterinary Journal 53, 171–183.

Perkins, N.R., Reid, S.W.J., Morris, R.S., 2005b. Risk factors for injury to the superficial digital flexor tendon and suspensory apparatus in Thoroughbred racehorses in New Zealand. New Zealand Veterinary Journal 53, 184–192.

Pfaff, G., 1976. The incidence of epistaxis in racehorses in South Africa. Journal of the South African Veterinary Association 47, 215–218.

Pinchbeck, G.L., 2004. Horse injuries and racing practices in National Hunt racehorses in the UK: the results of a prospective cohort study. The Veterinary Journal 167, 45–52.

Pinchbeck, G.L., Clegg, P.D., Proudman, C.J., Morgan, K.L., Wood, J.L.N., French, N.P., 2002. Risk factors and sources of variation in horse falls in steeplechase racing in the UK. Preventive veterinary medicine 55, 179–92.

Poole, R.R., Meagher, D.M., 1990. Pathogenic findings and pathogenesis of racetrack injuries. Veterinary Clinics of North America: Equine Practice 6, 1–29.

Raphel, C.F., Soma, L.R., 1982. Exercise-induced pulmonary hemorrhage in Thoroughbreds after racing and breezing. American Journal of Veterinary Research 43, 1123–1127.

Richardson, D., 2012. Surgical management of the critically injured horse. In: ICRAV. Philadelphia.

Riggs, C.M., Vaughan, L.C., Evans, G.P., Lanyon, L.E., Boyde, A., 1993. Mechanical implications of collagen fiber orientation in cortical bone of the equine radius. Anatomy and Embryology 187, 239–248.

Riggs, C.M., Whitehouse, G.H., Boyde, A., 1999a. Structural variation of the distal condyles of the third metacarpal and third metatarsal bones in the horse. Equine Veterinary Journal 31, 130–139.

Riggs, C.M., Whitehouse, G.H., Boyde, A., 1999b. Pathology of the distal condyles of the third metacarpal and third metatarsal bones of the horse. Equine Veterinary Journal 31, 140–148.

Rodriguez, G., Goldman, N., 1995. An assessment of estimation procedures for multilevel models with binary responses. Journal of the Royal Statistical Society: Series A (Statistics in Society) 158, 73–89.

Ross, M., 2011. Lameness in Horses: Basic Facts Before Starting. In: Ross, M., Dyson, S. (Eds.), Diagnosis and Management of Lameness in the Horse. Saunders Elsevier, p. 4.

Royston, P., Moons, K.G.M., Altman, D.G., Vergouwe, Y., 2009. Prognosis and prognostic research: Developing a prognostic model. Bmj 338, b604–b604.

Royston, P., Sauerbrei, W., 2008. Multivariable Model - Building: A Pragmatic Approach to Regression Anaylsis based on Fractional Polynomials for Modelling Continuous Variables. John Wiley and Sons Inc., Chichester.

Sauerbrei, W., Royston, P., 1999. Building multivariable prognostic and diagnostic models: transformation of the predictors by using fractional polynomials. Journal of the Royal Statistical Society: Series A (Statistics in Society) 162, 71–94.

Schroter, R.C., Marlin, D.J., Denny, E., 1998. Exercise-induced pulmonary haemorrhage (EIPH) in horses results from locomotory impact induced trauma--a novel, unifying concept. Equine Veterinary Journal 30, 186–192.

Smith, R.K., 2011. Pathophysiology of tendon injury. In: Ross, M.W., Dyson, S.J. (Eds.), Diagnosis and Management of Lameness in the Horse. Elsevier Saunders, St Louis, MO, USA, pp. 704–705.

Smith, R.K., Birch, H.L., Goodman, S., Heinegard, D., Goodship, A.E., 2002. The influence of ageing and exercise on tendon growth and degeneration—hypotheses for the initiation and prevention of strain-induced tendinopathies. Comparative Biochemistry and Physiology 133, 1039–1050.

Smith, R.K., Birch, H.L., Patterson-Kane, J.C., Firth, E.C., Williams, L., Cherdchutham, W., Van Weeren, P.R., Goodship, A.E., 1999. Should equine athletes commence training during skeletal development?: changes in tendon matrix associated with development, ageing, function and exercise. Equine Veterinary Journal. Supplement 30, 201–209.

Snijders, T., Bosker, R., 1999. Multilevel analysis: An introduction to basic and advanced multilevel modelling. Sage Publications, London.

Stephen, J.O., White, N.A., Mccormick, W.H., Cowles, R.R., Corley, K.T.T., 2003. Risk factors and prevalence of injuries in horses during various types of steeplechase races. Journal of the American Veterinary Medical Association 223, 1788–1790.

Stewart, B.D., 2011. A Summary of “Bleeder” Data from the Hong Kong Jockey Club. In: In: International Summit on Race Day Medication, EIPH and the Racehorse. New York.

Stover, S.M., 2012. Overview of the pathogenesis of skeletal injuries. In: ICRAV. Philadelphia.

Stover, S.M., Johnson, B.J., Daft, B.M., Read, D.H., Anders, M., Barr, B.C., Kinde, H., Moore, J., Stoltz, J., Ardans, A.A., Poole, R.R., 1992. An association between complete and incomplete stress fractures of the humerus in racehorses. Equine Veterinary Journal 24, 260–263.

Stover, S.M., Murray, A., 2008. The California Postmortem Program: leading the way. Veterinary Clinics of North America: Equine Practice 24, 21–36.

Takahashi, T., Hiraga, a, Ohmura, H., Kai, M., Jones, J.H., 2001. Frequency of and risk factors for epistaxis associated with exercise-induced pulmonary hemorrhage in horses: 251,609 race starts (1992-1997). Journal of the American Veterinary Medical Association 218, 1462–4.

Takahashi, T., Kasashima, Y., Ueno, Y., 2004. Association between race history and risk of superficial digital flexor tendon injury in Thoroughbred racehorses. Journal of the American Veterinary Medical Association 225, 90–93.

Thrusfield, M., 2007. Veterinary Epidemiology, 3rd ed. Blackwell Science Ltd., Oxford.

Vallance, S.A., Case, J.T., Entwistle, R.C., Kinde, H., Barr, B.C., Moore, J., Anderson, M.L., Arthur, R.M., Stover, S.M., 2012. Characteristics of Thoroughbred and Quarter Horse racehorses that sustained a complete scapular fracture. Equine veterinary journal 44, 425–31.

Vallance, S.A., Spriet, M., Stover, S.M., 2011. Catastrophic scapular fractures in Californian racehorses: pathology, morphometry and bone density. Equine veterinary journal 43, 676–85.

Van Mechelen, W., 1992. Running injuries. A review of the epidemiological literature. Sports Medicine 14, 320–325.

Vaughan, L.C., Mason, B.J.E., 1976. A clinic-pathological study of racing accidents in horses: a report of a study on equine fatal accidents on racecourses. London.

Verheyen, K.L.P., Newton, J.R., Price, J.S., Wood, J.L.N., 2006a. A case-control study of factors associated with pelvic and tibial stress fractures in Thoroughbred racehorses in training in the UK. Preventive Veterinary Medicine 74, 21–35.

Verheyen, K.L.P., Price, J.S., Lanyon, L.E., Wood, J.L.N., 2006b. Exercise distance and speed affect the risk of fracture in racehorses. Bone 39, 1322–30.

Verheyen, K.L.P., Wood, J.L.N., 2004. Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. Equine Veterinary Journal 36, 167–73.

Weideman, H., Schoeman, S.J., Jordaan, G.F., 2004. The inheritance of liability to epistaxis in the southern African Thoroughbred. Journal of the South African Veterinary Association 75.

Weideman, H., Schoeman, S.J., Jordaan, G.F., Kidd, M., 2003. Epistaxis related to exercise-induced pulmonary haemorrhage in South African Thoroughbreds. Journal of the South African Veterinary Association 74, 127–131.

Weller, R., Pfau, T., Verheyen, K.L.P., May, S.A., Wilson, A.M., 2006. The effect of conformation on orthopaedic health and performance in a cohort of National Hunt racehorses: Preliminary results. Equine veterinary journal 38, 622–627.

Williams, R.B., Harkins, L.S., Hammond, C.J., Wood, J.L.N., 2001. Racehorse injuries, clinical problems and fatalities recorded on British racecourses from flat racing and National Hunt racing during 1996, 1997 and 1998. Equine Veterinary Journal 33, 478–86.

Wilsher, S., Allen, W.R., Wood, J.L.N., 2006. General Articles Factors associated with failure of Thoroughbred horses to train and race. Equine Veterinary Journal 38, 113–118.

Wilson, E.B., 1927. Probable Inference, the Law of Succession, and Statistical Inference. Journal of the American Statistical Association 22, 209–212.

Wilson, J.H., Robinson, R.A., Jenson, R.C., 1996. Equine soft tissue injuries associated with racing: descriptive statistics from American racetracks. In: Proceedings of the 1996 Dubai International Equine Symposium. pp. 1–21.

Witte, T.H., Knill, K., Wilson, A.M., 2004. Determination of peak vertical ground reaction force from duty factor in the horse. Journal of Experimental Biology 207, 3639–3648.

Wood, J.L.N., Eastment, J., Lakhani, K.H., 2001. Modelling a retrospective study of death on racecourses. In: Proceedings of the Society for Veterinary Epidemiology and Preventive Medicine. Noordwijkerhout, pp. 115–126.

Wood, J.L.N., Harkins, L.S., Rogers, K., 2000. A retrospective study of factors associated with racehorse fatality on British racecourses from 1990-1999. In: Proceedings of the 13th International Conference of Racing Analysts and Veterinarians. Cambridge, pp. 274–277.