Risk Factors for Horse Falls and Injuries in National Hunt Horse Racing in the UK

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by

Gina Louise Pinchbeck

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Abstract

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Gina L. Pinchbeck

The aim of this study was to identify factors associated with an increase or decrease in the risk of falling in National Hunt racing in the UK and to quantify the contribution of falling to injury and fatality in horses participating in hurdle and steeplechase racing.

Analysis of retrospective data from the 1999 racing year on all UK racecourses identified falling risks of 6.0 per 100 starts in steeplechase racing and 2.1 per 100 starts in hurdling. The death risk among fallers was 3.7% in steeplechasing and 7.1% in hurdling. Of all deaths recorded that year, during steeplechase and hurdle racing, 38% were associated with a fall. Examination of the sources of variation in the risk of falling, with the start as level-1, showed that a proportion of level-2 variation resided at the horse, the race and the sire level in steeplechasing, with very little clustering at any level in hurdling other than level-1. Trainer and jockey contributed very little to the variation in the risk of falling. Results of multivariable analyses of these data also showed that some of the risk factors for falling are different for hurdling and steeplechasing. In steeplechasing younger horses, increasing race distance and lack of previous racing experience were all associated with an increase in the risk of falling. In hurdling, starting hurdling at an older age and less experienced jockeys were associated with an increase in the risk of falling.

A prospective cohort study of hurdle and steeplechase racing was performed on 6 UK racecourses over a 2- year period providing information on the frequency of exposures of particular racing practices. The fatality risk of fallers was 6.5% and the injury risk of fallers was 8.9%. This study identified that longer journey times to the racecourse were associated with an increased risk of falling and that sunny weather also increased the risk of falling. There was also some evidence that pre-race behaviour was associated with falling.

The injury risk in the cohort study was 2.8 per 100 starts. The commonest types of injury were superficial digital flexor tendon injuries and lacerations. Risk of injury was associated with race distance and weight carried. Withholding water was associated with an increase risk of all types of injury including medical events, and both fast races and poor foot conformation were associated with an increased risk of musculoskeletal injuries.

A nested case-control study, utilising video analysis of races, identified that the majority of falls were due to mistakes at fences and not due to horse injury prior to jumping the fence. The study also identified that horses which were being whipped and which were progressing through the race were at greater risk of falling.

Case-control studies in hurdle and steeplechase racing were conducted using a novel approach in which the jumping effort was the outcome of interest. Cases were jumping efforts that resulted in a fall and controls were selected from all successful jumping efforts.

In hurdling the frequency of falls was 1 per 447 jumping efforts and in steeplechasing 1 per 254 jumping efforts. In hurdling the risk of falling increased at later flights in the race, with the exception of the first flight. Speed and distance were also associated with the risk of falling with the shortest (2 mile), fastest races having the greatest risk. Horses participating in their first ever hurdle race were at almost 5 times the risk of falling compared to those that had hurdled before. In the steeplechase case-control study, downhill approaches to fences and higher take off boards were associated with an increased risk. The distance from the previous fence and the previous fence type were also associated with falling; if the previous fence was a water jump, the risk of falling was increased. The greater number of times a horse had run on the steeplechase course the lower the risk of falling.

This study has confirmed that falling contributes to fatality and injury in hurdle and steeplechase racing in the UK. It has identified a number of risk factors, some of which are modifiable. Controlled intervention studies evaluating these modifications are now required.

Introduction

Injuries and fatalities in racehorses continue to be a major concern to both the general public and the racing industry and have a significant impact on equine welfare both in the UK and abroad. Whilst some may argue that injuries are an inevitable part of the sport of racing, most involved in the racing industry are seeking to make racing as safe a sport as possible for equines. Racing often receives negative publicity in response to fatalities, particularly when such fatalities occur at high profile race meetings. For example, newspaper headlines such as "Butchered at the races" (Daily Record 2000), "The sport of killings" (Mannan 1999) and "Gold Cup: Tragedy casts a long shadow" (Down 2000) highlight high profile races where equine fatalities have occurred. Articles have also been written in recent years in popular large-scale magazines such as "They shoot horses, don't they" (Reid, Marie Claire 2000). The public concern of such fatalities is large and increasing in recent years and the racing industry has come under increasing pressure from groups concerned with animal welfare. However, equine fatalities also have a major effect on the Thoroughbred industry which is a major contributor to the UK economy generating in excess of £600 million per year and economic loss occurs whenever horses are injured and killed. This study was funded by members of the racing industry with the long-term objective of improving equine welfare on their racecourses. The primary aims of the study were to identify and quantify risk factors for horse falls and injury in National Hunt racing in the UK.

Organisation of the UK National Hunt racing industry

National Hunt racing takes place on 42 of the 59 racecourses in the UK and consists of National Hunt flat racing, hurdle racing and steeplechase racing. The British

Horseracing Board (BHB) is the governing and administrative body for racing and is responsible for the marketing, promotion and financial position of racing. The BHB is also responsible for the fixture list and race planning and the employment of handicappers. The Jockey Club is the regulatory authority for horseracing and is responsible for:

- Racecourse medical and veterinary arrangements for riders and horses.
- Employment and direction of its Racecourse Officials.
- Licensing of racecourses, clerks of the course, and jockeys.
- Licensing of trainers, riders, valets and the registration of owners and stable employees.
- Disciplinary matters
- Security and anti-doping measures
- The conduct of a day's racing

The Jockey Club, through Racecourse Holdings Trust (RHT), owns and operates twelve racecourses. Each racecourse is run as an individual commercial enterprise, with RHT acting to ensure the standards of operation throughout the group.

Weatherbys under contract to BHB supply the administration required for racing in the UK. They maintain all of racing's records, grant names for horses and issue passports, approve colours and take all entries and declarations. They also provide essential statistics for racing and breeding. This information is available either in paper format or through subscription on-line.

Raceform is the official form book that records comprehensive race details of every domestic race. A computer version is available and is provided through weekly updated disks by post. The *Racing Post* is the sole daily newspaper specialising in racing that is also available on line (www.racingpost.co.uk). The online version has a comprehensive database similar to that of Raceform, access to which is available free of charge. During this thesis data from Weatherbys, Computer Raceform, The Racing Post and the Jockey Club were used.

The licensing of racecourses is under the jurisdiction of the Jockey Club and the placement and construction of hurdle and steeplechase fences is governed by the Jockey Club general instructions. Non-metric units of measurements are still used in the Jockey Club regulations. Racecourse distances are measured in yards and furlongs (1 furlong =198 metres) and regulations for fence measurements are given in feet and inches (1 foot=30 centimetres). In hurdle racing there are to be at least 8 flights in the first 2 miles of the course with an additional flight for every additional quarter of a mile. Members of the racecourse staff are positioned at every flight during racing and there are spare timber hurdles at each flight so that broken hurdles can be replaced. Timber hurdles should be made of ash or oak and must be not less than 3ft 6 inches from the top bar to the bottom bar. The hurdles are laced with birch or other suitable material. When placed the top bar should be between 36-38 inches above the ground with an overlay of the top bar in the direction of racing of 1ft 6 inches beyond the bottom bar. A take off board of 5 to 11 inches in height is fixed securely to the bottom of the hurdle. From June 2001 the top rails and standards (vertical struts) are to be completely padded with either high-density polyethylene or closed cell foam rubber, a minimum of 0.5 inches thick and painted orange.

In steeplechase racing there are to be at least 12 fences in the first 2 miles and at least six fences in each succeeding mile. One of the fences may be a water jump and there is to be at least 1 open ditch for each mile. The majority of fences are constructed on course and consequently there is some variation in fence design between courses. However there are also Jockey Club regulations regarding fence construction. Plain fences must be a minimum of 4 ft 6 inches high and constructed with all birch or birch with spruce, broom or other material at the bottom of the fence. The fences should be built on a base of 6ft deep, measured from the take off board to the back of the fence. From 1st July 2003 any guardrails on fences should be protected with rubber padding and coloured orange. Water jumps should be a minimum of 3 ft high with water 9 ft wide and an overall width of 11.5 to 12 ft. Open ditches must be a minimum of 4 ft 6 inches high and the take off board should be between 1ft 6 inches and 2ft in height and painted light matt orange. Most courses rebuild individual fences once every 2 to 3 years.

The racing industry is very different in the UK compared to overseas. For example the majority of racing takes place on turf in the UK whereas in the USA the majority takes place on dirt tracks. National Hunt racing in the UK has many differences when compared to similar racing abroad. For example there are two distinct populations of horses that participate in National Hunt racing in the UK: i) those that began their career in flat racing and therefore began training at an early age (this scenario is similar to that in Australia); ii) those that are bred for National Hunt racing which are stored and do not begin training until the age of 4/5 years old. Horses will often remain in racing until a greater age than flat racing horses (often up until 10/11 years of age). Racecourses in the UK do not have training facilities such as exist on many racecourses in the USA and Australia, and consequently all horses have to travel, usually on the day of racing, to the racecourse. All National Hunt racing in the UK takes place on turf surfaces and a large proportion takes place in winter months and subsequently ground conditions can be very variable.

Early Studies

The Horserace Betting Levy Board have funded research into racing accidents and injuries since the 1970's (Vaughan and Mason 1975). This Racecourse Equine Fatal Accidents Scheme, which was performed between 1970 and 1973, was one of the first studies to collect information about and describe fatal accidents on UK racecourses. The study was limited by a low reporting rate (only 50-60%) of fatalities and was purely descriptive rather than analytical, as information about cases only was recorded. However, the study highlighted some areas for further research. Table 1 documents, in abbreviated form, the causes of the 124 deaths recorded, the race types in which they occurred and the numbers that were due to a fall. This shows that 55% of the reported racecourse fatalities were associated with a fall. Almost a quarter (22%) of injuries reported were vertebral fractures and 90% of these were associated with a fall at a fence. Almost all (13/14) cases of cervical vertebral fracture occurred due to a fall at a fence and all of these were subjected to trauma about the head or neck. The majority of these horses died instantly or were quadriplegic immediately after falling. Eight accidents involved an open ditch and seven accidents involved water jumps. Following this the Jockey Club introduced a new design for water jumps.

Table 1: Race type and cause of fatality and for 124 fatalities from 1970-1973 (Vaughan and Mason 1975)

	Flat	Hurdle	Steeplechase	No's Due to a Fall	Total
Cervical vertebral fracture	0	7	7	13	14
Thoraco-lumbar vertebral fracture	0	5	10	13	15
Fore limb	11	29	16	22	56
Hind limb	9	6	16	18	31
Miscellaneous and Sudden Death	0	2	6	2	8
Totals	20	49	55	69	124

Due to the concerns about racing safety many modifications have been made to racecourses and to jumps over the past 15 years and some of these modifications have had positive outcomes. At Aintree, for example, the frequency of falls at Bechers Brook, a notorious fence on the Grand National course have decreased since modifications were made prior to 1992 (unpublished data). However most modifications have been made without scientific evidence that they will alter the risk of falling, injury or fatality. Particular jumps or races have been highlighted as "high risk" without consideration for the multifactorial nature of accidents.

The Jockey Club is constantly monitoring injury and fatality rates on all racecourses. Some racecourses consistently have yearly fatality and falling risks above the national average. For example during 1999 the national average falling risk was 7.9% but the range of falling risks on individual racecourses varied from 3.1% to 15.1% and in 1998 the national average fatality risk in steeplechasing was 0.62% with a range on individual racecourses from 0% to 3.06% (Jockey Club Racecourse Department data). This indicates that some racecourses may be more risky than others or, attract a different population of runners that have increased risk of falling or fatality.

One of the first studies to take advantage of the well recorded and documented data on the Thoroughbred population and their racing performance was by McKee (1995) in collaboration with the British Horse Racing Board and the British Equine Veterinary Association. This study analysed data on 1422 fatality reports and 475,000 starts that did not result in fatality from 59 UK racecourses from January 1987-December 1993. This enabled fatality rates for the different types of racing to be calculated. The fatality rate for flat racing was 0.08%, for National Hunt flat racing 0.47%, for hurdle racing 0.49% and for steeplechasing 0.7%. Cervical spine fractures were most prevalent in hurdle and steeplechase racing and 75% of these fractures were due to a fall. The study identified that the fatality rate was significantly different between racecourses and that racing on firmer surfaces had a higher fatality rate. Furthermore the fatality rates between jockey classes were also different. Subsequent to this study, in an attempt to try and decrease the identified high fatality rate in National Hunt flat racing, the Jockey Club banned amateur jockeys from participating in these races. However, this intervention seems to have had little effect on reducing the fatality rate in National Hunt flat racing as recent studies have identified no decrease in recent years to the risk of death in National Hunt flat racing of 0.4% (Parkin et al. 2002, Wood et al. 2000). This example highlights the multifactorial nature of injuries in racing and the need for multivariable analysis to allow for confounding by other factors before rational interventions can be designed and tested.

Studies outside the UK

Numerous studies have also been conducted in flat racing in various regions of the USA (table 2) and in flat and jump racing in Australia (table 3). Jump racing is rare in the USA and consequently there have been few published studies investigating this type of racing (Stephen and White 2001). More recent studies in the flat racing industry in the USA have used multivariable analysis to identify risk factors for various injury outcomes (Kobluk et al. 1989; Mohammed et al. 1991; Kane et al. 1996; Cohen et al. 1997; Estberg et al. 1998; Cohen et al. 2000; Hernandez et al. 2001). The outcome or case definition used in these studies have varied and have included serious musculoskeletal injury (requiring at least 6 months off training) (Mohammed et al.1991), fatal musculoskeletal injury (Hernandez et al. 2001), lameness (Cohen et al. 1999) as well as particular injuries such as bucked shins (Boston and Nunamaker 2000). Consequently many different, and sometimes conflicting risk factors, have been identified. These include gender, age, distance, race class, and previous number of starts, training exercise intensity, pre-race physical inspection results, hoof conformation and shoeing (Mohammed et al.1991; Cohen et al. 1999; Kane et al.1996; Kane et al. 1998; Boston and Nunamaker 2000; Hernandez et al. 2001)

In Australia where racing also takes place over jumps Bailey et al. (1997 & 1998) investigated risk factors for serious musculoskeletal injury. The study including horses jump racing was a retrospective case-control study at 4 Australian racetracks (Bailey et al. 1998). The outcome of interest was serious musculoskeletal injury that resulted in either euthanasia of the horse at the racetrack, or failure to race within 6 months of the date of injury. From the 301 cases identified from August 1988-July 1995, 53 were from steeplechase races and 52 from hurdle races. The incidences of fatal musculoskeletal injury per start were 0.63% for hurdle racing and 1.43% for steeplechase racing which are higher than figures reported in previous UK studies (Mckee 1995; Wood et al. 2000). As well as race type (flat, hurdle or steeplechase), multivariable logistic regression identified age, condition of track surface and a particular racetrack to be associated with the risk of injury. Older horses and firmer track surfaces were associated with an increased risk. However the analysis included cases from all 3 types of racing with flat races being over represented (196) and with much smaller numbers of hurdle and steeplechase cases. Although interaction terms were tested for, this over representation of flat racing may mean these results are more applicable to flat racing rather than jump racing injuries.

Track condition has been investigated as having an association with the risk of injury or breakdown in numerous previous studies (Cheney et al.1973, Clanton et al. 1991; Ueda et al. 1994; Bailey et al. 1998). In the USA where racing takes place regularly on both turf and dirt tracks, turf tracks have been shown to have significantly lower risk of breakdown (Mohammed et al. 1991). There have also been studies to examine the dynamic properties of tracks with relation to the forces exerted by horses to try and determine optimal properties of track surfaces for the least injury risk (Ratzlaff et al.1997) and different methods of assessing track hardness and composition have been investigated (Oikawa 2000). However there is still no routinely used and scientifically tested method used to assess the condition of the track surface (going) on UK National Hunt racecourses so the "going" is still determined by the clerk of the course using subjective assessment.

Due to the inherent differences already highlighted between overseas and UK racing, results from studies in other countries cannot be directly applied to the UK racing industry.

Recent Studies in the UK

At a Horserace Betting Levy Board (HBLB) workshop on equine epidemiology in 1996 the Veterinary Advisory Committee stated that prospective research should focus on identifying and quantifying track and training factors associated with traumatic injuries in racing in the UK (Mellor and Newton 1997). Subsequent to this the HBLB have funded studies on risk factors for fractures in horses in training (Verheyen et al. 2001) and on risk factors for distal limb fracture on UK racecourses (Parkin et al. 2001).

These more recent studies in the UK have applied multivariable techniques to a number of different study designs. Wood et al. (2000 & 2001a) used 10 years of retrospective data from the Jockey Club and Weatherbys to examine risk factors for all types of equine fatality in both flat and National Hunt racing. This study showed that around 74% of all fatalities on racecourses in the UK occurred in hurdle and steeplechase racing despite these races accounting for only 39% of all starts in the UK (Wood et al. 2000). Overall fatality rates of 0.1 per 100 starts for flat racing, 0.52 per 100 starts for hurdling and 0.71 per 100 starts for steeplechasing were reported. Age at the time of the race and the condition of the track surface were important risk factors for all race types. Furthermore, both in flat and hurdle racing, risk of fatality increased with increasing age at which racing had begun (Wood et al. 2001a). Increasing distance of the race was associated with fatality in hurdling and steeplechasing as was the horses previous racing experience. For example, an increase in racing frequency in the last 12 months was associated with a decrease in risk (Wood et al. 2002).

Parkin et al. (2002) used a case-control study design to examine risk factors for fatal distal limb injury sustained on the racecourse. To date this study has identified the amount of gallop work and the training surface used as risk factors for this particular type of injury. However these types of fatalities are likely to have a different aetiology to injuries sustained during falls and in fact 80% of all reported fractures were spontaneous in nature and were not associated with a jumping event.

Verheyen et al. (2002) used a prospective cohort design to evaluate risk factors for all types of fractures in a cohort of flat race horses in training in the UK. They also identified an association with the risk of fracture and the amount of gallop work done.

Epidemiological techniques and computing power have advanced in recent years such that large data sets can now be more easily manipulated and analysed. Diseases or injuries that are inevitably multifactorial, such as injuries in racing, can be investigated and allowance made for potential confounders (Hosmer and Lemeshow 2000). Recently there has also interest in the veterinary field in multilevel modelling (Green et al. 1998; Goldstein et al. 2000; Wood et al. 2000; Dohoo et al. 2001; Christley et al. 2002; Hirst et al. 2002). The use of these techniques allows control for the clustering which occurs within the racing hierarchy (for example horses within a particular training yard) thus making our estimates of any odds ratios or relative risks more accurate. The study by Wood et al. (2001a) used hierarchical models to estimate the proportion of variation in the risk of fatality residing at different hierarchical levels within racing in both flat and hurdle racing. There was a small but significant amount of variation at the level of trainer in both flat and hurdle racing and at the level of the race in hurdling. There was only a very small amount of variation at the level of the jockey. Risk did vary between racecourses although when fixed effects were added much of this variation was accounted for by the racing surface (going).

Injuries in Jockeys

In a study of deaths from sport and leisure activities in England and Wales horse riding was the most hazardous activity (Avery et al.1990) and the injury rate among jockeys, particularly in jump racing and point-to-pointing are high (Staight 1999). The falling risk for National Hunt Jockeys (including where only the Jockey falls) have been quoted as between one in every 10 rides with an injury rate of 4.25% (Allen 1992), to one in every 14 rides with an injury to fall rate of 18.5% (Staight 1999). Rates of falling and injury in amateur and point to point jockeys were even higher (Staight 1999). Common injuries include clavicle fractures (Middleton et al. 1995; Staight 1999) as well as other fractures. Head and neck injuries including concussion are also common (Waller et al. 2002; Staight 1999). Some injuries can be life threatening (Fletcher et al. 1995) and since 1981 there have been 5 human fatalities in National Hunt racing. Many injuries are serious enough to result in time away from riding and in 1995/1996 13% of falls resulted in concussion that involved between 2 and 21 days away from riding.

Thesis aims and outline

The aim of this thesis was to identify and quantify risk factors associated with horse falls and injuries in National Hunt racehorses in the UK. We also wanted to estimate the frequency of falling, injuries, and fatalities that result from falls. As falling in National Hunt racing has not been investigated previously, we had a number of hypotheses we wished to test. These included:

i) Previous training and schooling regimes and the race day routine are associated with the risk of horses falling and sustaining injuries.

ii) The behaviour of the horse during transport and at the racecourse is associated with falling.

iii) Previous racing experience of horses and jockeys is associated with the risk of falling.

iv) Racetrack, fence design and particular types of races are associated with falling and injuries.

v) Within-race incidents are associated with falling.

To investigate falling and injuries in National Hunt racing in the UK we used a number of approaches and study designs. These are presented in this thesis as 7 manuscripts.

In manuscripts 1 and 2 retrospective data was utilised, from steeplechasing and hurdling respectively, that was readily available from disk-based (Raceform Ltd) and on-line databases (www.racingpost.co.uk). This data was used to estimate the incidence of falling and fatality risk of fallers, and also to examine areas of clustering within the hierarchy of racing that contribute to the risk of falling. This information was then used to inform the design of subsequent studies. We also investigated a number of risk factors in these studies.

Manuscript 3 describes results from a prospective cohort study conducted on selected UK racecourses. As with all cohort studies, information on a large number of animals had to be collected to achieve a sample size with enough power to detect associations and, in this study, both hurdle and steeplechase data were collected together. The races were attended by the author and information obtained by questionnaire and observations at the racecourse. This allowed the incidence of falling and also the frequency of particular practices within National Hunt racing to be evaluated. Horses within the cohort were also followed for injuries reported by the veterinary surgeons and Jockey Club Veterinary Officers. This enabled us to estimate the injury risk of fallers and also to quantify the association between the variables collected within the cohort and an outcome of injury. These results are presented in manuscript 4.

In manuscript 5 the results of a video study are described which includes descriptive data on all falls within the cohort. A nested case-control study was also conducted to identify within-race risk factors. This involved viewing of all cases and controls on synchronised freeze frame videos and recording information relating to the horses' position, mistakes made in the race and the actions of the jockeys.

The fence design and populations of horses taking part is different between steeplechasing and hurdling. We hypothesised that some risk factors may be different between the two types of racing. To evaluate detailed information on course and fence design and on horses and jockey past racing performance two case-control studies were conducted, one in hurdling and one in steeplechasing. This study involved intermittent visits to the racecourses but did not require attendance on race days. The number of racecourses was extended to 12 to ensure a range of course designs and topography and to ensure adequate sample sizes were achieved within the study period. The results of these studies are presented in manuscripts 6 and 7.

Several of the manuscripts have short appendices attached in order to provide further data

Table 2. Previous published epidemiological studies investigating racehorse injuries in the USA. The table shows the population studied, the particular outcome studied, the study design and analytical methods used and factors identified as being associated with the outcome.

Author & Year	Population studied	Outcome	Study design	Analysis	Factors identified
Boston & Nunamaker 2000	226 TB's in training in Eastern USA	Bucked shins	Retrospective and prospective cohort	Survival analysis	Exercise levels
Cheney et al. 1973	All horse belonging to trainers at Californian race tracks	Lameness	Questionnaire survey	Descriptive	Racetrack surface.
Clanton 1991	TB's racing at 3 Minnesota race tracks 1987	Breakdown, acute injury (6 months off)		Descriptive	Racetrack conditions –moisture, composition strength.
Cohen et al. 1997	TB's racing at 4 Kentucky race tracks 1994-1996	Musculoskeletal injury	Case-control study	Multivariable conditional logistic regression	Stumbling; Lead leg change; whip use; race position; Earnings; Pre-race physical inspection.
Cohen et al. 1999	TB's racing at 4 Kentucky race tracks 1996-1997	Injury (lameness/change in gait)	Cohort studied	Generalised estimating equations	Pre-race inspection; Age; Class; Race number; Distance
Cohen et al. 2000	TB's racing at 4 Kentucky race tracks 1994-1996	Musculoskeletal injury	Case-control study	Multivariable conditional logistic regression	Age; Distance exercised; Beyers number;
Estberg et al. 1998	All starts on California race tracks 1992	Catastrophic musculoskeletal injury	Retrospective longitudinal	Multivariable regression analysis	Gender; Age; Race type; Race meet.
Hernandez et al. 2001	TB's at 2 Florida racetracks 1995-1998	Catastrophic musculoskeletal injury	Case-control	Multivariable conditional logistic regression	Age; Gender; Racing surface; Days since last race
Johnson et al. 1994	All equine fatalities at California racetracks 1990-1994	Death or euthanasia	Post mortem case series	Descriptive	Stress fractures
Johnson et al.1994	All equine fatalities at California tracks 1990-1992	Death or euthanasia	Post mortem case series	Descriptive	Age

Author & Year	Population studied	Outcome	Study design	Analysis	Factors identified
Kane et al. 1996	201 TB's that died at California racetracks 1992-1994	Fatal musculoskeletal injury	Case-control study	Multivariable logistic regression	Toe grabs and rim shoes
Kane et al. 1998	95 TB's that died at California racetracks	Fatal musculoskeletal injury; Suspensory apparatus failure; Condylar fracture	Case-control study	Multivariable logistic regression	Toe angle, toe-heel angle difference.
Kobluk et al. 1989	95 racing TB's at one race track, Minnesota	Musculoskeletal problem	Prospective cohort (pilot study)	Descriptive and multivariable regression analysis	Conformation and shoeing
Kobluk et al. 1990	95 racing TB's at one race track, Minnesota	Musculoskeletal problem	Prospective cohort (pilot study)	Descriptive	Exercise levels
Mohammed et al. 1991	TB's racing at New York race tracks 1986-1988	Musculoskeletal Injury (6 months off)	Case-control study	Multivariable logistic regression	Track condition; Seasons raced; Number starts per year; Age
Peloso et al. 1994	TB's racing at 4 Kentucky race tracks 1992-1993	Catastrophic and non-catastrophic musculoskeletal injury	Concurrent case-control	Descriptive and comparative	Track position;
Robinson et al. 1988	Racing TB's at one race track, Minnesota	Severe musculoskeletal breakdowns	Case-control	Univariable or multivariable (unclear)	Age; Claiming race; site on track.
Rooney 1982	Two racing venue	Lameness		Descriptive	Race length; Fatigue.

Table 3 Previous published epidemiological studies investigating racehorse injuries in Australia and Japan. The table shows the population studied, the particular outcome studied, the study design and analytical methods used and factors identified as being associated with the outcome.

Author & year	Population studied	Outcome	Study design	Analysis	Factors identified
Bailey et al. 1997	Sydney race trainers	Wastage perceptions	Survey	Descriptive	Shin soreness; Respiratory problems; Lameness
Bailey et al. 1997	TB's racing at 4 Melbourne racecourses 1988- 1995 (flat only)	Serious musculoskeletal injury (6 months off)	Retrospective case-control study	Multivariable logistic regression	Distance; Track condition; Age
Bailey et al. 1997	TB's racing at 2 Sydney race tracks 1985-1995	Serious musculoskeletal injury (6 months off)	Retrospective case-control study	Multivariable logistic regression	Age; Barrier position; Class of race;
Bailey et al. 1998	TB's racing at 4 Melbourne racecourses 1988- 1995 (flat and jump)	Serious musculoskeletal injury (6 months off)	Retrospective case-control study	Multivariable logistic regression	Race course; Track condition; Age; Race type;
Bailey et al. 1999	553 TB's on sale 1991 Sydney yearling sale	First race and career duration	Retrospective cohort	Survival analysis	Gender; Age at first start;
Bailey et al. 1999	169 TB yearlings with 24 trainers	Training reduced or prevented	Prospective cohort	Survival analysis	Age; Injuries
Bourke 1995	TB's racing on 67 Victoria race tracks 1986-93	Fatalities	Retrospective	Descriptive	Race type, falls
Oikawa et al. 1994	TB' racing at Hanshin racecourse 1989-1990	Locomotor injury (3 months off)	Intervention study	Descriptive	Remodelling of racetrack –upgrade slope added, decreased curvature.
Ueda et al. 1993	58 horses racing at 8 Japanese racetracks	Racing injuries (race had to be halted)	Observational	Descriptive	Lead leg; whip use;

Table 4 UK. Previous published epidemiological studies investigating racehorse injuries in the UK. The table shows the population studied, the particular outcome studied, the study design and analytical methods used and factors identified as being associated with the outcome.

Author & year	Population studied	Outcome	Study design	Analysis	Factors identified
Mckee 1995	All starts on 59 UK racecourses 1987-1993	Race course death or euthanasia	Retrospective cohort	Descriptive	Racecourse; Falls; Jockeys
Parkin 2002	All starts on UK racecourses 1999-2002	Fatal distal limb fracture	Case-control study	Multivariable logistic regression	Surface trained on, work in training.
Pickersgill 2000	All horse at 2 flat training yards	Fracture injury	Cohort	Descriptive and univariable logistic regression	Racing frequency
Vaughan and Mason 1975	Reported UK racecourse fatalities 1970-1973	Race course death or euthanasia	Case series	Descriptive	Falls; Clinical features
Verheyen 2001	13 flat UK training yards	Fracture	Prospective cohort	Multivariable logistic regression	Distance galloped in training.
Williams et al. 2001	All starts on UK racecourses 1996-1998	Reported clinical events, fatalities and injuries	Survey	Descriptive	Age; Track surface condition
Wood et al 2000&2001	All starts on UK racecourses 1990-1999	Fatality on the racecourse	Retrospective	Multivariable logistic regression & multilevel modelling	Age, ground surface, distance of race, previous racing career.

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Risk factors and sources of variation in horse falls in steeplechase racing in the UK

Pinchbeck, G.L.[1,] Clegg, P.D.[1], Proudman, C.J.[1], Morgan, K.L.[1], Wood, J.L.N[2], French. N.P.[1]

[1]*Epidemiology Group, Department of Veterinary Clinical Science and Animal Husbandry, University of Liverpool, Leahurst, Neston, CH64 7TE, UK.*

[2]*Epidemiology Unit, Animal Health Trust, Kentford, Newmarket, Suffolk, CB8 7UU, UK.*

Corresponding Author. G.L. Pinchbeck

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Abstract

This study identified risk factors associated with falling during steeplechase racing.

We used retrospective data from all steeplechase runs on UK racecourses during 1999: 10,866 starts with 647 horse falls. The relationship between continuous variables and falling was assessed using generalised additive models. Polynomial fits were then included in a multi-level, multivariable logistic regression model. The number of runners had a linear, positive association with the risk of falling. The distance of the race had a non-linear relationship with the risk of falling; the risk steadily increased in races up to 23 furlongs (1furlong~198 metres), and then decreased in longer races. Age also had a significant, non-linear, relationship with the risk of falling with a decreasing risk up to 12 years of age followed by an increasing risk in older horses. Horses that wore visors and had raced previously were associated with a decrease in the risk of falling. Intra-class correlation coefficients showed that although most of the variation resided at the start (level 1), a proportion of variation in the risk of falling could be attributed to horse and race. Trainer and jockey contributed very little to the variation in the risk of falling.

Introduction

There are two types of jump racing in the UK: Steeplechasing and hurdling. Steeplechase racing takes place on 43 tracks in the UK and horses that fall over steeplechase fences whilst racing often do so in full public view. Steeplechase racing takes place over fences constructed from a wooden base and birch or spruce interior. Plain fences vary in height from a minimum of 4 feet 6 inches for plain and some fences have open ditch fences. Some courses also have water jumps. Falls over fences may result in injury to both the horse and jockey. The fatality and injury rates for racing over fences are higher than for flat or hurdle racing (McKee, 1995; Bailey et al. 1998; Williams et al. 2001; Wood et al. 2000) with around 31% of all equine fatalities on racecourses in the UK occurring in steeplechase racing despite steeplechase racing accounting for only 14% of all races in the UK (Wood et al. 2000). In the UK, equine fatality rates of 0.1 per 100 starts for flat racing, 0.52 per 100 starts for hurdling and 0.71 per 100 starts for steeplechasing have been reported (Wood et al. 2000). A study by Bailey et al. (1998), conducted at 4 Australian racetracks, found incidence risks for fatal musculoskeletal injury of 0.06% for flat racing, 0.63% for hurdling and 1.43% for steeplechasing. That study identified harder tracks, older horses and one racecourse as significant risk factors. Although this study accounted for type of race it did not differentiate between or compare risk factors for flat and jump racing. In two descriptive studies of fatalities on UK racecourses, between 50% (McKee 1995) and 55% (Vaughan and Mason 1975) of all fatalities in jump racing were associated with falls.

To our knowledge, there have not been any previous studies that specifically address risk factors for falling over steeplechase fences during racing. The first aim of the present study was to identify significant risk factors associated with falling. A second aim was to use variance component models to estimate the contribution of various levels of clustering to the variation in falling (so that levels that account for an important amount of the variability can be targeted for further research). Potential areas of clustering in steeplechase racing include starts within the same race and on one particular track, and starts by the same horse trained by the same trainer or ridden by the same jockey. Allowing for this clustering is also important when estimating the regression coefficients and allowed evaluation of whether or not the effects of variables changed with different levels of clustering (Dohoo et al 2001).

Materials and Methods

Data

We used a retrospective data set from Computer Raceform (a commercially available electronic database; Table 1), and data from the Jockey Club on fatalities recorded on UK racecourses. Data from 1st January 1999 to 31st December 1999 were analysed providing information on every start in steeplechase races, including hunter-chase races on all racecourses in the UK during this period. Hunter-chase races are run over the same courses and distances as steeplechase races but are confined to horses that have regularly been fox-hunted during the season in which they are competing.

The data were checked for validity by comparison with two independent data sources. The number of races and starts were compared with a data set for the same year from Weatherbys Ltd. The most common discrepancy was the inclusion in the data set of runners that had been withdrawn "not under starters orders" and these were removed from the data set. Data on horses that fell were checked against an independent data source (Racing Post online – www.racingpost.co.uk).

Statistical Analysis

Fixed Effects: Logistic Regression and Generalised Additive Models (GAM)

Univariable screening of all variables was performed using contingency tables for categorical variables and univariable logistic regression models for continuous variables. Variables with a $p<0.25$ were considered for inclusion in a multivariable model which was built using backward elimination procedures where variables with a term-wise Wald test $P<0.05$ or variables that improved the fit (likelihood ratio chi-square $P<0.05$) were retained in the model. Two-way interaction terms were tested between all plausible biological terms. Variables considered *a priori* to be biologically important (such as gender of the horse and track surface) were forced into the model.

For continuous variables with P-value <0.25 (number of runners, age of horse, number of races in the last 12 months and distance of the race), the functional form (shape) of the relationship between the variable and the risk of a horse falling was explored using generalised additive models (GAM) (Hastie and Tibshirani 1990). The variables were fitted using a multivariable logistic GAM (Hastie and Tibshirani

1990) to account for confounding (all variables left in the multivariable logistic regression model were included). A GAM is an extension of generalised linear models where variables are included additively but the usual linear function of a covariate is replaced with a smoothing function so individual variables are not assumed to have a linear relationship with the outcome. Cubic spline smoothers were used for these models but comparison using loess smoothers showed that the resulting plots were very similar. The GAM models were fitted in S-Plus (S-plus 2000, Mathsoft Inc.). The functional form of the continuous variables was then used to inform the polynomial fits in the multivariable logistic regression model. To reduce the effect of any unwanted multicollinearity resulting from the use of polynomial terms, the continuous variables age, distance and number of runs in the last 12 months were centered by subtraction of the sample mean (age mean=8 years, distance mean=19.9 furlongs, number of runs in the last 12 months mean=5.5) from all observations (Kleinbaum et al. 1982). Centering of explanatory variables is also recommended when using random effects models so that the explained variance at higher levels is for the average level-one unit (Snijders and Bosker 2000).

Random effects

Initially intercept only, 2-level models were fitted to assess the contribution of each possible individual level of clustering. The levels included horse, race, track, trainer, jockey, sire and dam where level 1 was always the individual run. As suggested by Dohoo et al. (2001) different methods of model fitting were used to compare outputs: maximum likelihood estimates, 1^{st} order marginal quasi-likelihood models using iterative weighted least squares (it was not possible to fit penalised quasi-likelihood models for some random variables) and Markov Chain Monte Carlo

(MCMC) simulations using Metropolis-Hastings sampling (with diffuse priors, a burn-in period of 10^4 iterations and a run of 10^5 iterations) and MCMC using Gibbs sampling, a burn-in period of 5000 iterations and a run of 50,000 iterations.

Subsequently 3-level models were fitted using MCMC using Metropolis-Hastings sampling with diffuse priors, a burn-in of 10^5 iterations and a run of 10^6 iterations. To estimate the proportion of variance attributed to each level, approximations of the intra-class correlation coefficients were calculated using a latent-variable approach which assumes the binary outcome arises from an underlying continuous distribution and that the level 1 variance is on the logit scale is $\pi^2/3$. The random-effects, intercept-only 3-level model that accounted for most of the variance (sire-horse-run) then was extended to include all significant fixed effects (from the logistic regression model) and the variance estimates reassessed.

Statistical analyses were done with the software packages EGRET (Egret Application 2.0, Cytel Software Corporation), MlwiN (MlwiN 1.10,0006, IOE, London), WinBUGS (WinBUGS 1.3, MRC Biostatistics Unit, Cambridge) and S-plus (S-Plus 4.6, Mathsoft Inc.).

Results

Descriptive statistics

There were 10,866 horse starts in steeplechase races in the UK in 1999. Of these 8,308 starts were available for analysis with 7,661 horses finishing the race and 647 fallers. The remaining runners were pulled up during the race, were brought down by another horse, refused to jump a fence or unseated the jockey and were not included in the analysis. The falling risk was 6.0/100 starts and 3.7% of fallers died. Of all the deaths recorded on the racecourse from these 10,866 starts, 42% were associated with a fall. Table 1 shows descriptive statistics of the fixed level variables and Table 2 shows the number of data points at each hierarchical level considered in the random effects models.

Generalised Additive Models

The results from the multivariable logistic GAM are shown in Fig. 1. Four continuous variables were significantly associated with the risk of falling and three of these demonstrated a significantly non-linear relationship.

The continuous variable plots demonstrate that the number of runners in the race was described well by a positive linear relationship with no evidence of non-linearity (chi-square for non-linearity $P=0.1$). Distance, age, and the number of runs the horse has had in the last 12 months all had non-linear relationships ($P<0.05$) with the outcome. Distance and age appeared to have a cubic relationship and when fitted in this form in the multivariable logistic regression model, the fit of the model (likelihood-ratio test statistic <0.05) was improved. The number of runs a horse has had in the previous 12 months appeared to have a quadratic relationship with the outcome and this form provided the best fit in the final logistic regression model. The variables were included in a multivariable logistic regression model in these forms.

Table 1: Descriptive statistics of the fixed effect variables available for analysis from computer Raceform Ltd. for 8308 horse starts in the UK during 1999.

Categorical Variables	Cases (Falls) (n=647)		Controls (n=7661)	
	N	%	*N*	%
Gender				
Mare	75	12	727	9
Gelding/Stallion	572	88	6934	91
Headgear worn				
None	587	91	6817	89
Blinkers	55	8	645	8
Visor	5	1	197	3
Official British Horse racing Board rating				
Unrated	252	39	1935	25
1-78	66	10	1091	15
79-98	169	26	2185	28
99-172	160	25	2450	32
First race type				
Flat	91	14	1234	16
National Hunt flat	256	39	2761	36
Hurdle	108	17	1266	17
Steeplechase	62	10	748	10
Missing	130	20	1652	21
Steeple Chased before?				
No	121	19	697	9
Yes in UK	518	80	6872	90
Yes-outside UK	8	1	92	1
Jockey allowance				
Professional	463	72	5616	73
Claiming 3lbs	55	9	626	8
Claiming 5lbls	48	7	580	8
Claiming 7lbs	81	12	839	11
Type of race				
Chase	574	89	6851	89
Hunter-chase	73	11	810	11
Condition of track surface				
Firm	10	1	112	1
Good-firm	96	15	1588	21
Good	200	31	2581	34
Good-soft	161	25	1604	21
Soft	143	22	1397	18
Heavy	37	6	379	5
Season				
Winter	242	37	2200	29
Spring	224	35	2876	37
Summer	45	7	740	10
Autumn	136	21	1845	24
Continuous variables	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
Age of horse (years)	7.8	1.8	8.2	1.8
Number of races in last 12 months	4.5	3.5	5.8	3.7
Weight carried by horse (*lbs*)	153.6	8.7	153.5	9.1
Distance of race (furlongs)	20.6	3.7	19.6	3.5
Number of runners starting the race	9.7	4.2	9.0	3.8

Random Effects

The variance estimates show that when run was used as the first level, the largest proportion of level-2 variance appears to be due to horse, race and dam with very little attributable to trainer and jockey. The variance estimates using Markov Chain Monte Carlo (MCMC) simulations with Metropolis-Hastings sampling (with diffuse priors), a burn-in period of 10^4 iterations and a run of 10^5 iterations are shown in Table 2. The other methods of model fitting gave similar variance estimates except for the MQL estimates using MLWin, which gave a consistently lower estimate. Table 3 shows the variance estimates and intra-class correlation coefficients when the nested hierarchical structure of the data was taken into account. The estimates were obtained using MCMC simulation models. The variance estimate for dam decreased from approximately 0.87 to 0.075 when horse was nested within dam. The largest proportion of remaining variation was due to horse followed by race, sire, track, dam, trainer and jockey.

Table 2: Description, numbers at each level and variance estimates with 95% credibility intervals of the seven random variables available for analysis from computer Raceform Ltd for 8308 horse starts in the UK during 1999. Variance estimates were obtained using Markov Chain Monte Carlo (MCMC) simulations with Metropolis-Hastings sampling (with diffuse priors, a burn-in period of 10^4 iterations and a run of 10^5 iterations).

Random variable	N	Variance estimate	Lower 95% credibility interval	Upper 95% credibility interval
Dam	2585	0.88	0.60	1.27
Horse	2762	1.04	0.61	1.46
Jockey	503	0.04	0.01	0.09
Race	1352	0.42	0.23	0.60
Racecourse	43	0.08	0.02	0.19
Sire	779	0.24	0.06	0.41
Trainer	789	0.01	0.00	0.08

Figure 1: Graphs representing the functional forms of the continuous variables modelled in a multivariable generalised additive model (where the continuous fixed effects are fitted using smoothers) to determine the shape of the relationship between the predictor variable and the outcome (log odds of falling during a steeplechase race). The plots show the fitted curves with 95% confidence intervals (dashed lines). The rug plots along the x-axis represent the number of data points. This model included all fixed effects from the final multivariable logistic regression model.

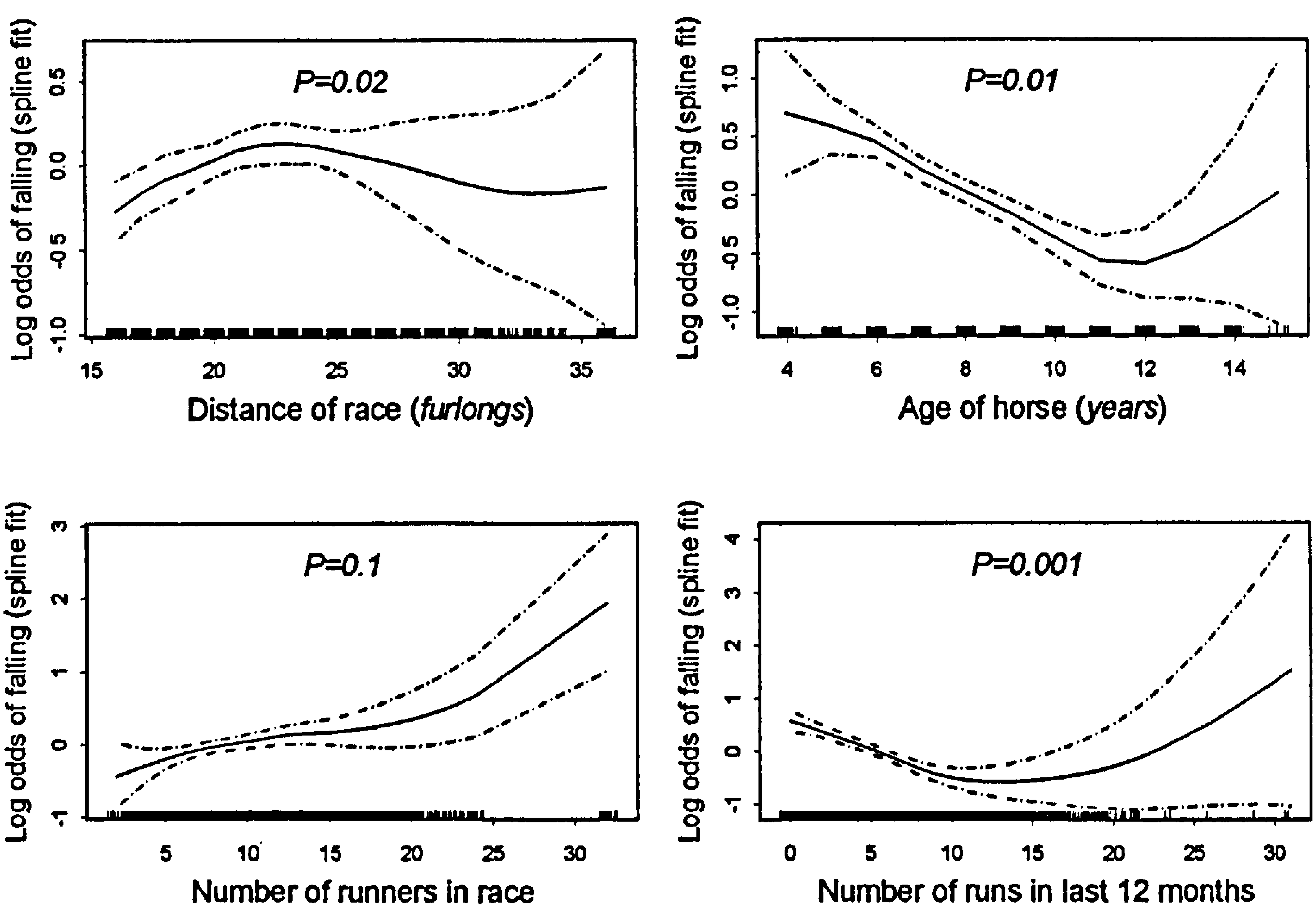


Table 3: Multilevel, intercept-only models of the variation in the risk of horse falls in steeplechasing in the UK, calculated using Markov Chain Monte Carlo simulations. Four nested hierarchical models are shown and level 1 is the run or start (*N*=8308) in all models.

Levels	Variable	Variance	95% Credibility Intervals	Intra-class correlation coefficient [a]
Model 1				
Level 3	Dam	0.08	0.007, 0.16	1.7%
Level 2	Horse	0.94	0.58, 1.40	21.9%
Model 2				
Level 3	Sire	0.18	0.04, 0.39	4.2%
Level 2	Horse	0.87	0.54, 1.30	20.0%
Model 3				
Level 3	Track	0.08	0.02, 0.18	2.1%
Level 2	Race	0.38	0.15, 0.61	10.2%
Model 4				
Level 3	Trainer	0.02	0.003, 0.05	0.4%
Level 2	Horse	0.98	0.48, 1.50	22.8%

[a] Calculated using a latent variable approach where the level 1 variance is $\pi^2/3$.

Multi-level multivariable logistic regression model

Table 4 shows the final multilevel mixed effects model with sire and horse as the two hierarchical levels. Comparisons of the coefficients, odds ratios and 95% credibility intervals from this and a fixed effects only logistic regression model (not presented) showed that the estimates were very similar. This suggests that the effects of variables on the outcome did not vary greatly across these higher levels of clustering.

Horses wearing visors had a 3-fold decrease in the odds of falling compared to horses wearing no headgear. Horses that steeplechased before in the UK or outside the UK had lower odds of falling than horses that had never steeplechased before. The official British Horse racing Board (BHB) rating is effectively a measure of the horses ability (rating is given by the handicapper based on placing within races), and horses with a rating of 1-78 were associated with a decrease in the risk of falling compared to unrated horses. Winter racing appeared to be associated with an increased risk of falling. Soft and heavy track surfaces were associated with an increase in the risk of falling. Gender of the horse appeared to have no effect.

Assessing the fit of the model

The posterior distributions of the variables included in the mixed effects model presented in Table 4 are not shown. However, the fits were smooth and regular and all chains mixed well for all fixed-effect variables. Prohibitively long chain lengths seemed to be required to give certainty about the 97.5th and 2.5th quantiles of the posterior distributions for the random effect horse. However, according to the Brooks-Draper statistic, sufficient iterations were performed to give certainty about estimates for the means of both horse and sire.

When a cut-off probability of 0.06 (our data set's observed risk was~0.06) from this final mixed effects model was selected (i.e. if the predicted probability of falling is above 0.06, the horse is predicted to fall), the specificity was only 63% (i.e. 63% of non-fallers were correctly classified) and the sensitivity was 64% (i.e. 64% of fallers were correctly classified).

Table 4: A mixed effects, hierarchical, multivariable logistic regression model of risk factors associated with falling in steeplechase racing in the UK fitted using Markov Chain Monte Carlo methods.

	Median(β)	95% CI	P	Odds Ratio	95% CI
Random Effect	Variance estimate				
Sire	0.150	0.02, 0.3			
Horse	0.186	0.001, 0.68			
Fixed Effects	Coefficients				
Number runners	0.04	0.02, 0.06	<0.01	-	-
Age-years (cent)	-0.27	-0.35, -0.18	<0.001	-	-
Age-years $(cent)^2$	-0.005	-0.03, 0.02	0.70	-	-
Age-years $(cent)^3$	0.01	0.001, 0.01	0.03	-	-
Distance-furlongs (cent)	0.04	0.01, 0.07	0.01	-	-
Distance-furlongs $(cent)^2$	-0.01	-0.02, -0.003	<0.01	-	-
Distance-furlongs $(cent)^3$	0.001	0.00, 0.002	0.02	-	-
No. of runs last 12 months(cent)	-0.11	-0.14, -0.08	<0.001	-	-
No. of runs last 12 $months(cent)^2$	0.01	0.002, 0.01	<0.01	-	-
Gender					
Female	0.0	-		1.00	-
Male	-0.14	-0.42, 0.15	0.3	0.89	0.69, 1.16
Headgear					
None	0.0	-	-	1.00	-
Blinkers	0.15	-0.16, 0.46	0.3	1.15	0.85, 1.56
Visor	-1.10	-2.17, -0.26	0.02	0.34	0.13, 0.88
Official BHB rating					
Range 0 to 0	0.0			1.00	
Range 1-78	-0.36	-0.69, -0.04	0.03	0.69	0.51, 0.95
Range 79-98	-0.04	-0.29, 0.22	0.7	0.95	0.75, 1.22
Range 99-172	-0.22	-0.48, 0.04	0.1	0.80	0.62, 1.03
Track surface					
Firm	0.16	-0.60, 0.85	0.6	1.17	0.58, 2.41
Good to Firm	-0.13	-0.04, 0.14	0.3	0.88	0.67, 1.15
Good	0.0			1.00	
Good to Soft	0.19	-0.05, 0.43	0.1	1.20	0.96, 1.52
Soft	0.29	0.04, 0.54	0.03	1.33	1.03, 1.70
Heavy	0.21	-0.20, 0.59	0.3	1.22	0.82, 1.82
Steeplechased before?					
No	0.0			1.00	
Yes UK	-0.27	-0.53, -0.003	0.04	0.76	0.59, 0.86
Yes, outside UK only	-1.13	-2.01, -0.34	<0.01	0.36	0.15, 0.74
Season					
Winter (Dec-Feb)	0.0				
Spring (Mar-May)	-0.36	-0.58, -0.14	<0.01	0.69	0.56, 0.86
Summer (June-Aug)	-0.28	-0.67, 0.09	0.1	0.76	0.52, 1.10
Autumn (Sep-Nov)	-0.28	-0.53, -0.03	0.03	0.76	0.59, 0.97

CI- Bayesian Credibility Interval.
Cent - Indicates variables were centered

Discussion

This study has identified a number of variables associated with the risk of horse falls in steeplechasing in the UK. Race distance had a non-linear relationship with the risk of falling. There was a decreased risk of falling at shorter distances up to about 20 furlongs and then an increased risk of falling up to approximately 28 furlongs. This may be due to fatigue of the horse and/or jockey over longer distances or may be associated with an increase in the total number of jumping efforts required in longer distance races. There are least 12 fences in a 16-furlong race and in each succeeding 8 furlongs (1 mile), there must be at least an extra 6 fences (Jockey Club General Instructions 1997). Within the data set, races of 16 to 19 furlongs usually had between 12 and 15 fences compared to between 16 and 22 fences in races of 20 to 28 furlongs. In a study looking at horse falls in the sport of Horse Trials (eventing) in the UK (Singer et al 2003), the risk of falling was higher for courses with a greater number of jumps. Above 28 furlongs the risk appeared to decrease again; however, the confidence intervals are very wide here due to the small number of races run over distances greater than 28 furlongs.

Young horses (4-5 years) had the greatest risk of falling. The risk decreased steadily until the age of 12 when the risk started to increase again. The confidence intervals began to widen above the age of 13 years due to the small number of horses. Younger horses will be less experienced and this may account for the increased risk in falling. The increase at an older age might be due to sub clinical injury or fatigue but is surprising as a healthy-horse or talented-horse effect may have been expected (fit horses with ability are likely to continue racing past 12 years old). It would be interesting to ascertain at what point in the race younger and older horses are falling.

It could be that older horses fall later in the race if sub-clinical injury or fatigue is a factor.

Horses that had not raced at all in the previous 12 months were associated with a greater risk of falling. This might be due to decreased fitness of the horse or less recent experience of fence jumping under racing conditions. The risk then decreased steadily to 14 or 15 runs. Above 15 or 16 runs in the last 12 months the risk appeared to increase again, although the confidence intervals became very wide due to small numbers of horses racing this frequently.

Horses that had never raced before in a steeplechase races were at increased risk of falling when compared to those that had steeplechased before. This may due to inexperience of jumping steeplechase fences under racing conditions. Horses that had steeplechased before outside the UK were apparently less likely to fall. There might be a difference in the population of horses that are sent to race in the UK or different schooling methods may be used outside the UK. If greater experience reduced the risk of falling, this would also explain the lower risk for horses with an official rating compared to unrated horses. An intervention measure that could be explored to decrease falling risk would be to have specific schooling races where horses can race around a steeplechase course without the added pressure of race competition. Trainers are currently fined (by the authorities of racing) for "schooling" horses in scheduled races.

The greater the number of runners in a race, the greater the risk of falling. This may be due to interference between horses or may be due to greater speeds in the early parts of the race with jockeys aiming to get a good position. Speeds or sectional speeds for the races were not available in this data set.

Blinkers or visors are often used by trainers to try to enhance the concentration of horses that may have fallen before, or that are not racing at expected speeds. The effect of visors decreasing the risk of falling was not seen in horses wearing blinkers. Blinkers are a garment fitted over a horses head with holes for the eyes and ears with the eyeholes being fitted with cowls cutting out all vision to the rear but permitting full forward vision. A visor is a garment similar to blinkers in which the cowls have apertures in them permitting limited side or rear vision (The Jockey Club, Orders and Rules of Racing, Appendix 0, Rule 147(i)(b)). There are also half blinkers, which would allow greater side vision but no differentiation was made between half and full blinkers in this data set. Perhaps visors may be effective in enhancing horses concentration during jumping and this may be due to the limited side or rear vision permitted by visors.

Results from this year of data show that there was an increased risk of falling in winter (Dec, Jan, and Feb) that was independent of the condition of the track surface. When time of year was transformed into summer (May-September inclusive) and winter seasons which is consistent with the British racing seasons, summer jumping was protective (OR 0.8) in a multivariable model. These results suggest that the increased risk of injuries and fatalities reported in the summer may be due to factors other than falling such as fractures or soft tissue injuries on hard ground, or cardiovascular catastrophes. Soft and heavy track surfaces were associated with an increased risk of falling compared to good track surfaces. This was opposite to the effect observed in previous studies on falling in hurdle racing (Pinchbeck et al. 2002c), fatalities (Wood et al. 2001a) and injuries (Bailey et al. 1998; Williams et al. 2001) where softer ground was associated with a decreased risk. This suggests that falls on softer ground may be associated with less injuries and fatalities.

Estimating the proportion of variance due to levels of clustering has allowed targeting of areas in current research. All the models except the 1st order marginal quasi-likelihood estimates in MLWin gave similar variance estimates in the random effects models. The first order Taylor series expansion, was used as the second order expansion (which is considered to produce less biased estimates) would not converge. Previous studies (Rodriguez and Golmad 1995; Rabash et al. 2000) have shown that estimates from some of the iterative least squares algorithms for random effects models could be biased towards the null, particularly when the number of replications at the hierarchical level is small and the corresponding random effect is large, as was the case with horse and dam. A recent study by Dohoo et al (2000) found similar underestimations using second order penalised quasi-likelihood estimates in MLWin. MCMC estimation techniques were used for subsequent two and three level models as marginal quasi-likelihood estimates had already been shown to be unreliable in this data set and the maximum likelihood estimates were computationally slow and could not be used for models with greater than 2 levels.

The lack of variation due to trainer was in contrast to the prior beliefs of people involved in racing. Pre-project interviews conducted with trainers, jockeys and course clerks all indicated that they thought the trainer would have the greatest effect on influencing whether a horse fell or not (unpublished data). Gaining information from trainers about individual training and schooling practices might have proved difficult and results from our analysis indicate that finding ways to intervene at the trainer level would be unlikely to greatly influence falling rates. This was in contrast to the sources of variation reported in a study of mortality in flat and hurdle racing where a small (but significant) amount of variation was attributable to the trainer (Wood et al 2001a).

The large decrease in the variance estimate for dam when all levels are included suggests there was very little variation due to dam and most of the variation calculated using the 2-level models was due to horse. This is perhaps not surprising because of the small horse:dam ratio in the data set. However this highlights the problems that can arise in interpretation of results when levels of the hierarchy are omitted. The sire effect was only slightly reduced when horse was nested within sire, suggesting there is a small proportion of variation that is independently attributable to sire. This might be a reflection of the different breeding lines of Thoroughbreds used for jump racing. The variance estimate for track increased slightly when race was nested within track suggesting some of the variation seen between races was due the variation between the different racecourses.

The ICC's showed that although most of the variation occurs at the individual start or run (level-1), a significant proportion of variation can be attributed to the horse, race and sire. Although we presented ICC's using a latent variable approach (regarding a binary outcome as arising from an underlying continuous process) other methods may be more applicable with a true binary outcome. Comparative estimates using the methods described by Goldstein et al. (2000) were obtained and in all cases, the latent variable approach provided a higher estimate than the other 3 methods for all level 2 variables, hence the latent variable approach used in this paper may be over-estimating ICC's.

The results of the sensitivity and specificity of the model suggest that there was a significant proportion of unexplained variation within the model. This may be due to unmeasured (including unmeasurable) covariates.

Conclusion

This study has contributed to the understanding of the aetiology of equine falls, during racing on UK National Hunt racecourses. The variables with a significant effect on the risk of falling include the age of the horse, the number of runs a horse has had previously and if it has raced in a steeplechase race before, the number of runners in the race, distance of the race, the season and the going. The multilevel models explained some of the sources of variation in the risk of falling. Most of the variation was at the level of the run with significant proportions of variation due to horse and race and small proportions of variation due to track and sire. This has allowed us to target our future studies in areas where intervention would be likely to have the most impact.

Acknowledgements

We gratefully acknowledge the Jockey Club (in particular Dr Peter Webbon and Anthony Stirk) and Aintree and Cheltenham racecourses which funded this research. The RSPCA provided funding for the data from Weatherbys Ltd and Katherine Rogers kindly provided the data extract.

Appendix to Manuscript 1

In this appendix results from the estimation of random effects using different methods of model fitting are presented and the changes in variance estimates after the inclusion of fixed effects are also shown. Also presented are the ranks of the racecourses and alternative methods of calculating intra-class correlation coefficients.

Model fitting methods for random effects

A graphical representation of the level 2 variance estimates and credibility and confidence intervals for all seven random effects, using four different methods of model fitting is shown in Figure 1. All models except the MQL estimates using MLWin gave similar variance estimates.

Racecourse effects

Although the proportion of the total variation in the risk of falling attributable to racecourse was very small, plots of the ranked racecourse residuals (figure 2 and 3) showed that there was significant difference between the steeplechase courses with the highest and lowest ranks.

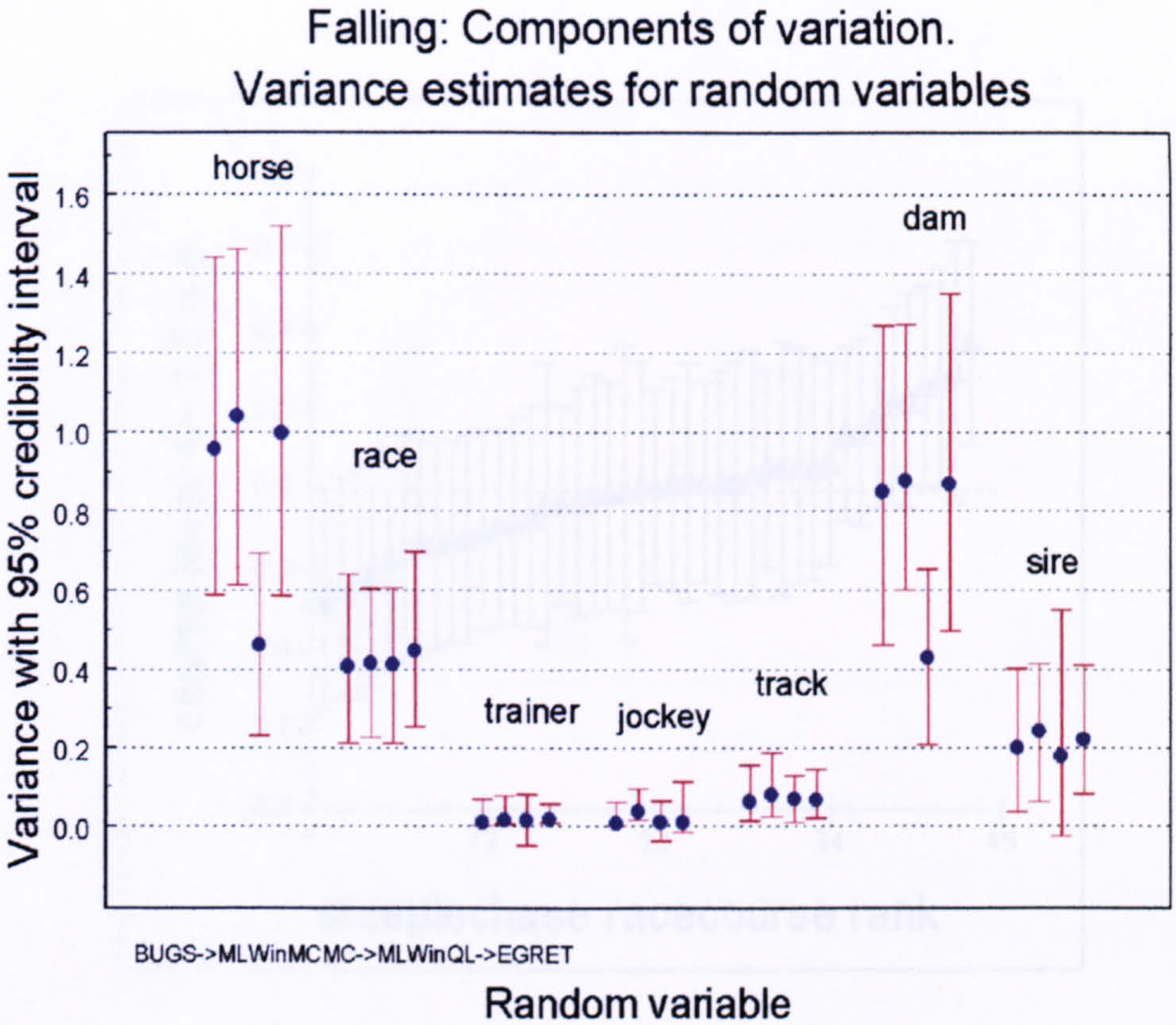


Figure 1. Variance estimates and credibility and confidence intervals for all seven random effects considered individually, using four methods of model fitting. The first fit represents Bayesian modelling via Gibbs sampling using WinBUGS, the second Markov Chain Monte Carlo with Bayesian inference using MLWin, the third represents 1st order marginal quasi-likelihood estimates using iterative weighted least squares using MLwiN and the fourth represents maximum likelihood estimates using Egret.

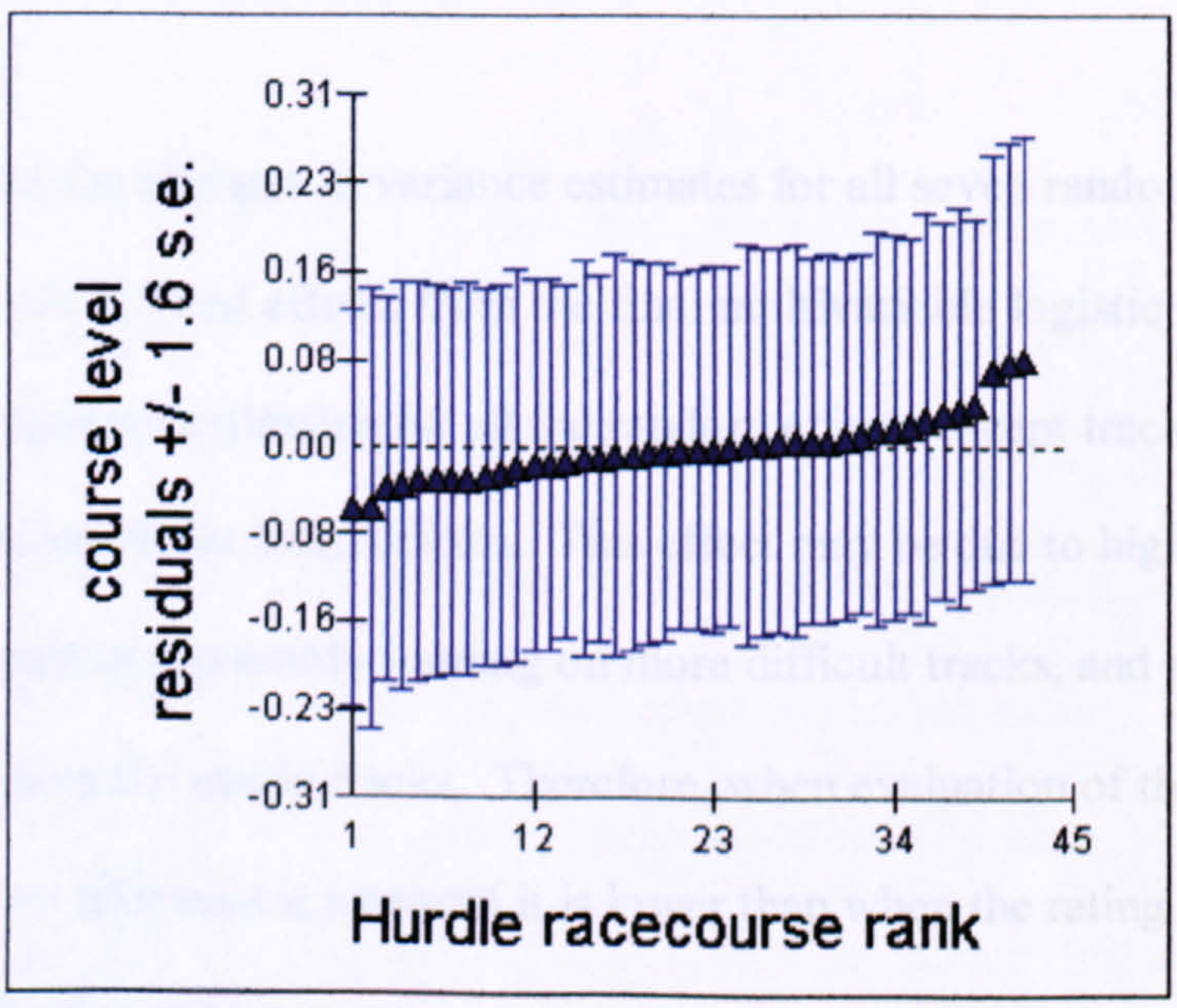


Figure 2: Ranked racecourse residuals (+/- 1.6 s.e. residual) for hurdle racing in a 2-level intercept only model

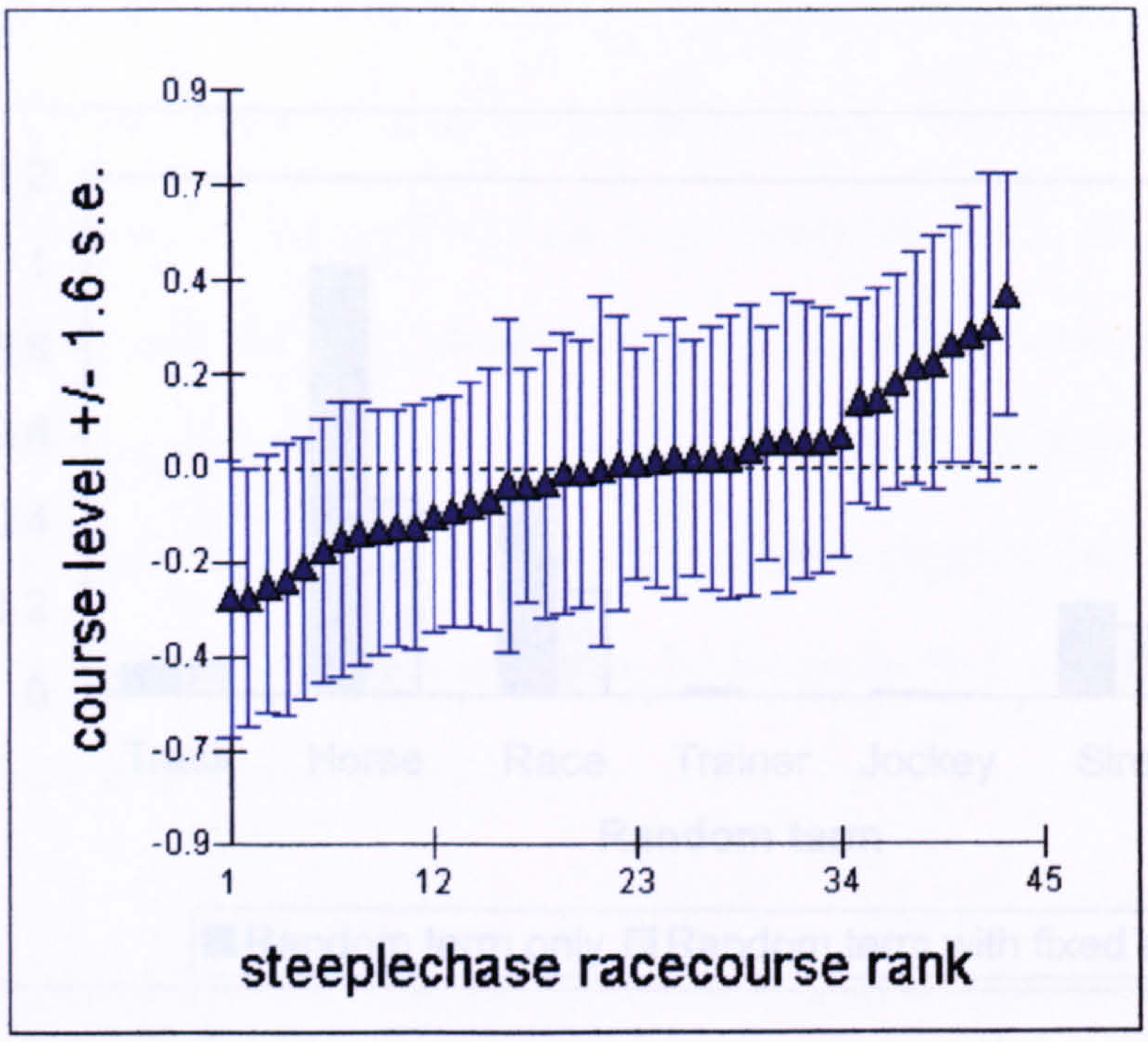


Figure 3: Ranked racecourse residuals (+/- 1.6 s.e. residual) for steeplechase racing in a 2-level intercept only model

Changes in variance estimates after inclusion of fixed effects

Figure 4 shows the changes in variance estimates for all seven random effects after the inclusion of the fixed effects from the final multivariable logistic regression model. The variance estimates for all the random effects except track decreased after the inclusion of the fixed effects. This effect may be due to higher rated horses with more experience possibly running on more difficult tracks, and poorer rated horses running on the easier tracks. Therefore, when evaluation of the variation in falling rate over all tracks is assessed it is lower than when the rating and experience of the horse is taken into account.

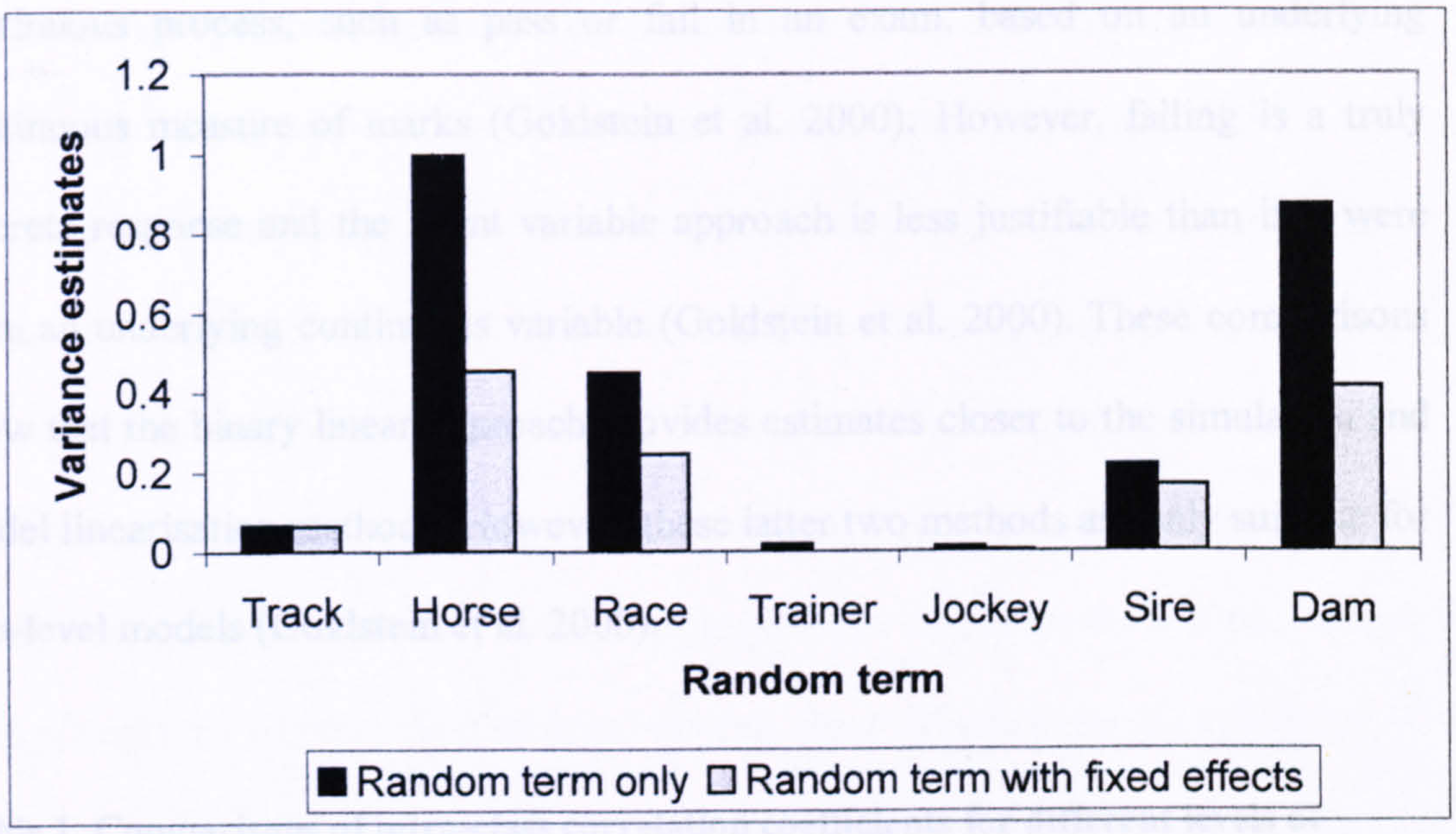


Figure 4. Changes in the variance estimates of all seven random variables after inclusion of significant fixed effects from the multivariable logistic regression model presented in manuscript 1.

Intra-class correlation coefficients

Table 1 shows the comparisons of intra-class correlation coefficients for horse, race, track, jockey, trainer and sire using the four different methods described. The largest proportion of variance by all methods was horse followed by race, track, jockey and trainer. In all cases the latent variable approach (which assumes constant level 1 variance of $\pi/3$) provided a higher estimate than the other 3 methods for all level 2 variables. However, each method may be subject to bias. The binary linear model approach would not be expected to fit well if the underlying probabilities are close to 1 or zero (as is the case in this study) (Goldstein et al. 2000). The latent variable approach assumes that the binary response is derived from an underlying continuous process, such as pass or fail in an exam, based on an underlying continuous measure of marks (Goldstein et al. 2000). However, falling is a truly discrete response and the latent variable approach is less justifiable than if it were from an underlying continuous variable (Goldstein et al. 2000). These comparisons show that the binary linear approach provides estimates closer to the simulation and model linearisation methods. However, these latter two methods are only suitable for two-level models (Goldstein et al. 2000).

Table 1. Comparisons of intra-class correlation coefficients for different levels of clustering using 2-level models. Four different methods of calculating ICC's are compared.

Level 2	Method Used			
	Latent Variable Approach	**Binary Linear Model**	**Simulation**	**Model Linearisation**
Race	11.1%	3.3%	3.7%	2.9%
Horse	22.8%	8.7%	8.4%	5.1%
Sire	5.9%	1.4%	1.6%	1.4%
Track	1.9%	0.47%	0.46%	0.48%
Jockey	0.5%	0.09%	0.1%	0.1%
Trainer	0.3%	0.1%	0.06%	0.06%

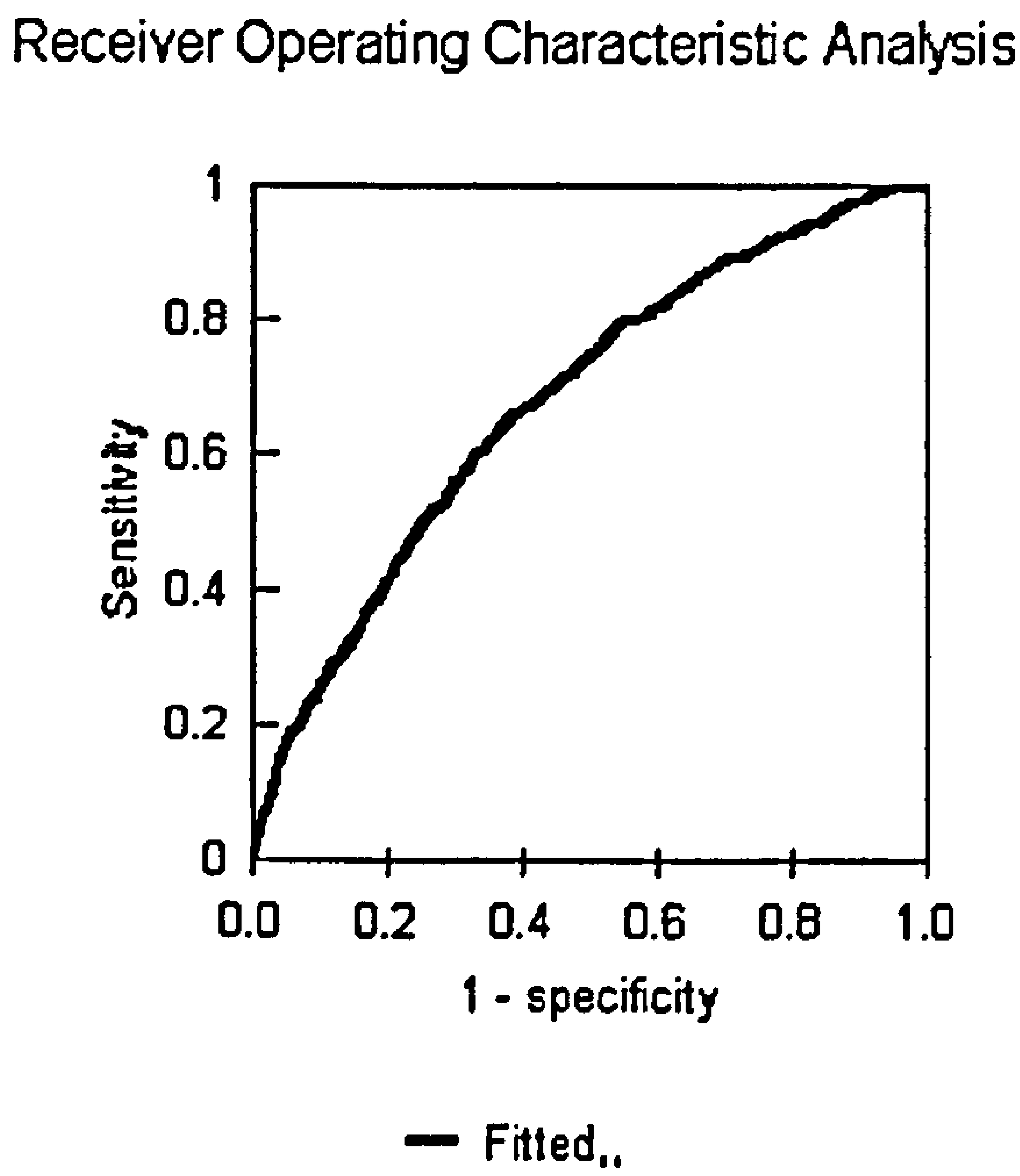
Assessing the fit of the model

The final fit of the model was assessed by calculating the sensitivity and specificity of the model for varying predicted-value cut-off points. The specificities and sensitivities at various cut-off points are presented in Table 2. For example when a cut-off of 0.06 was selected (i.e. if the predicted probability of falling is above 0.06, the horse is predicted to fall) the specificity was 63% (i.e. 63% of non-fallers were correctly classified) and the sensitivity was 64% (i.e. 64% of fallers were correctly classified). This method of assessing model fit uses estimated probabilities to predict group membership. If the model predicts group membership accurately then the model is assumed to fit well. However, this may not be a good test to use as the model may fit well but classification may be poor, as it reduces a probabilistic model to a dichotomous model where predicted outcome is binary, as well as depending on the distribution of probabilities in the sample (Hosmer and Lemeshow 2000). It also does not address whether the distances between observed and expected values are small and/or unsystematic. A more complete description of classification accuracy would be given by a Receiver Operating Characteristic curve (ROC) (Hosmer and Lemeshow 2000) which is a plot of sensitivity versus 1-specificity over possible cut-off points. The ROC curve for this data is shown in figure 5. The area under the curve was 0.68 (95% CI 0.65-0.70). An area under the curve of between 0.7 and 0.8 is considered to have acceptable discrimination (i.e. the likelihood that a case will have a higher probability than a non-case) (Homer and Lemeshow 2000).

Table 2. This table shows the values for specificity (non-fallers) and sensitivity (fallers) of the mixed effects, hierarchical, multivariable logistic regression model at various cut-off points.

Cut-off	Specificity (proportion of non-fallers predicted)	Sensitivity (Proportion of fallers predicted)
0.05	51	77
0.06	63	64
0.07	71	54
0.08	78	45
0.09	83	36
0.1	87	30
0.2	99	4

Figure 5. ROC curve for all possible cut-off values for the fitted probabilities from the final mixed effects, multivariable logistic regression model. (Area under curve = 0.68)



Manuscript 2

Horse falls in National Hunt racing in the UK; Risk factors and sources of variation

Pinchbeck, G.L.[1*], Clegg, P.D.[1], Proudman, C.J.[1], Morgan, K.L.[1], Wood, J.L.N[2], French. N.P.[1]

[1]*Epidemiology Group, Department of Veterinary Clinical Science and Animal Husbandry, University of Liverpool, Leahurst, Neston, CH64 7TE, UK.*

[2]*Epidemiology Unit, Animal Health Trust, Kentford, Newmarket, Suffolk, CB8 7UU, UK.*

[*]Corresponding Author. G.L.Pinchbeck

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Abstract

The fatality rate for horses in jump racing in the UK is significantly higher than for those racing on the flat, with falling over fences representing a major cause of the difference in death rate between these two types of racing. This study examines the determinants of falling in hurdling, and evaluates sources of variation in the risk of falling for targeting future research.

This analysis utilised retrospective data from all hurdle starts on UK National Hunt racecourses during 1999. The data consists of 14,595 starts with 367 horse falls. The falling risk per 100 starts was 2.1 in hurdling. The death risk among fallers was 7.1% and 35% of all deaths on the racecourse were associated with a fall.

The final models show that the risk factors for falling are different for hurdling compared to steeplechasing. For example, the age of the horse, field size, distance and racing experience were all significantly related to the risk of falling in steeplechasing. In hurdling, the gender of the horse, the jockeys experience and the age at which the horse started hurdling were all significantly related to the risk of falling. The highest proportion of variation resided at the horse and race level in steeplechasing, with very little clustering found at any level in hurdling.

Introduction

Injuries to horses whilst racing have a significant effect on animal welfare and the economics of racing. Furthermore, fatal or severe injuries can have a substantial negative impact on the public perception of racing. Falling during National Hunt racing in the UK contributes significantly to fatality in horses and injury in both horses and jockeys and often occurs in full view of the public.

The fatality and injury rate for racing over fences is higher than for flat racing (Williams et al 2001, Wood et al 2000, Bailey et al. 1998, McKee 1995) with around 74% of all fatalities on racecourses in the UK occurring in hurdle and steeplechase racing despite these races accounting for only 39% of all starts in the UK (Wood et al 2000). In the UK overall fatality rates of 0.1 per 100 starts for flat racing, 0.52 per 100 starts for hurdling and 0.71 per 100 starts for steeplechasing have been reported (Wood et al. 2000). A study by Bailey et al. (1998), conducted at 4 Australian racetracks, found incidence rates for fatal musculoskeletal injury of 0.06% for flat racing, 0.63% for hurdling and 1.43% for steeplechasing. This study identified harder track surfaces, older horses and one racecourse as significant risk factors although it did not differentiate between risks for flat and jump racing. In two descriptive studies of fatalities on UK racecourses falls were associated with between 50% (McKee 1995) and 55% (Vaughan and Mason 1975) of all fatalities in jump racing.

Previous studies on racetrack injuries have used different case definitions such as fatality, fatal musculoskeletal injury and non-fatal serious musculoskeletal injury

(Wood et al. 2000, Cohen et al. 1999, Bailey et al. 1998). To our knowledge there have not been any previous studies that specifically address risk factors for falling in National Hunt racing and risk factors may be very different for different causes of death. For example, 78% of fatal distal limb fractures in hurdle racing in the UK were not associated with a jumping episode whereas fatal fractures of the vertebrae most often occur due to falling (Parkin, personal communication, Vaughan and Mason 1975).

Analysis of these data sets had two main aims. Firstly, to identify risk factors associated with falling, secondly to estimate the contribution of various levels of clustering to the variation in falling so that levels that account for an important amount of the variability can be targeted for further research. Potential areas of clustering in jump racing include starts by the same horse, horses with the same sire, starts within the same race and on one particular track, and starts by horses trained by the same trainer or ridden by the same jockey. Allowing for these sources of variation, using multilevel mixed effects models, improves the estimation of regression coefficients.

Materials and methods

Data

The study utilised retrospective data from Computer Raceform, a commercially available electronic database, and data from the Jockey Club on fatalities recorded on UK racecourses. Weatherbys Ltd provided data on the previous racing history of the horses. Data from 1st January 1999 to 31st December 1999 were analysed providing information on every start in jump races on all racecourses in the UK during this period. Only data from the hurdle starts are presented in this paper and the results are compared to the findings of a previous study of steeplechase starts (Pinchbeck et al. 2002a). The variables available for analysis are shown in Table 1. The data were checked for validity against an independent data source (Racing Post online – www.racingpost.co.uk).

Table 1. Description of the variables available for analysis from computer Raceform and Weatherbys Ltd

Variable	Description
Horse identity	Name
Age of horse	Age at time of each start in years
Age at first race	Calendar age at first hurdle race under rules
Gender of horse	Gelding, colt or filly
Headgear	Blinkers or visors
Racing history	i) First race type
	iii) Number runs in the last 12 months
	iv) Number runs in the last 3 months
	v) Date of last run
Official rating	Official rating at each start
Weight carried	Weight carried by horse in pounds
Jockey identity	Name and whether professional or conditional
Trainer identity	Name of trainer
Dam identity	Name of dam
Sire identity	Name of sire
Race identity	Date and race form number
Racecourse	Name of course
Going	Hard-Heavy as recorded by clerk of the course
Distance	In furlongs
Number of runners	Number of horses starting in the race
Race class	Official class of race A-H

Statistical analysis

Fixed Effects:

Multivariable generalised additive models (GAMs) (Hastie & Tibshirani 1990) were used to explore the functional form of the relationship between the response (falling) and continuous variables (number of runners, age, distance of race, number of runners in last 12 months, weight carried, age started hurdling). When combined with other techniques, such as the fitting of equal number and equal interval categorised variables, these methods inform the choice of transformations that may be required to represent this relationship in generalised linear models (GLMs). The GAM model fits nonparametric functions to estimate the relationship between the response and the predictor variables. The advantage of GAMs is that individual variables are not assumed to have a linear relationship with the outcome. The response is modelled as a sum of smooth functions in the predictors. Two functions used for estimating the smooth relationships between the response and the predictors are the smoothing spline fit and the locally weighted least squares regression smooth (loess) (Hastie & Tibshirani 1990). Loess smoothers were used for the models presented in this paper. The loess smoother takes a proportion or "window" of the overall data and then fits a local regression model with nearest points given greater weight. The proportion in each window is set by the span. In these models the default span of 0.5 was used. In this way for each individual component fit, 50% of the overall data values are taken within a window set on the x-axis. The GAMs were fitted in S-Plus (S-plus 2000, Mathsoft Inc).

Variables considered for inclusion in multivariable logistic regression models included terms that had been shown to be important in previous studies, such as going and age of the horse, categorical variables with a p-value <0.25 on univariable analysis and polynomial terms identified using GAMs . A final model was built using backward elimination procedures where variables with a term-wise Wald test p-value<0.15 or variables that improved the fit (likelihood ratio chi squared statistic P<0.05) were left in the model. Biologically plausible interaction terms were tested. The critical probability throughout was 0.05. The logistic regression model was fitted initially using EGRET (Egret Application 2.0, Cytel Software Corporation).

Random Effects models:

Initially, intercept only, 2 level models were fitted to assess individually the contribution at each level of clustering. The levels included horse, sire, racetrack, race, trainer and jockey. The models were fitted using a residual generalised iterative least squares (RIGLS) algorithm. Modelling was attempted initially using second order penalised quasi-likelihood (PQL) but in two cases (horse and race) these would not converge so first order PQL was used. Comparative estimates using Markov Chain Monte Carlo (MCMC) simulations were attempted, however prohibitively long chain lengths (up to $9x10^6$) were required to give reliable estimates of both the mean and tails (2.5 and 97.5 centiles) of the posterior distributions of regression coefficients. Comparative estimates were derived from full maximum likelihood models using EGRET. To estimate the proportion of variation attributable to each level of clustering, intra-class correlation coefficients were calculated using four different methods as described by Goldstein et al (2000). Mixed effects two level models were then fitted including fixed effects from the final logistic regression model to assess the change in variance in these models. Subsequently the 3 level model, which accounted for the most variation, was extended to include significant fixed effects (from the logistic regression model). The random effects models were fitted using MlwiN (MlwiN 1.10,0006, IOE, London). The final fit of the model was assessed by calculating the sensitivity and specificity of the model for varying predicted-value cut off points.

Results

Descriptive Statistics

There were 14,595 hurdle starts available for analysis with 367 horse falls. Runners that did not complete the race for reasons other than falling were not included in the analysis. The falling risk was 2.1 per 100 starts and 7.1% (26) of the fallers died. Of all deaths recorded on the racecourse from these starts 35% were associated with a fall. Table 2 shows the numbers at each hierarchical level and the maximum starts at each hierarchical level.

Table 2. Hierarchical structure of the data showing the numbers at each level and the maximum number of starts by those in each level.

Hierarchical level	Numbers at each level	Maximum starts per level
Horse	4887	25
Race	1666	30
Trainer	656	609
Jockey	439	492
Track	42	637
Sire	1046	234

Generalised Additive Models

Results from the GAMs are shown in the plots in Figure 1. Outliers of age (>13 years) and number of runs in the last 12 months (>30) were omitted from this analysis to allow better interpretation of the curves at the points where most of the data lie. None of the variables demonstrated a significant non-linear ($p<0.05$) relationship with the log odds of falling and so only linear terms were considered in subsequent logistic regression model.

Random effects

Table 3 compares the intra-class correlation coefficients (ICC's) for horse, race, track, jockey, trainer and sire, using the four different methods described by Goldstein et al (2000). The results show that there was very little variation at any level of the hierarchy and only jockey showed 'significant' variation. In all cases the latent variable approach provided the highest estimate for all level 2 variables.

Table 3. Comparison of intra-class correlation coefficients using four different methods. The variance estimates used are from 2-level intercept only models using 1st or 2nd order PQL models.

Level 2	Latent variable approach	Model linearisation	Simulation	Binary linear model
Horse*	4.4%	0.4%	0.4%	0.6%
Race*	2.9%	0.2%	0.3%	0.3%
Trainer	2.6%	0.2%	0.2%	0.2%
Track	0.2%	0.03%	0.03%	0.01%
Jockey	3.2%	0.3%	0.3%	0.3%
Sire	2.4%	0.2%	0.2%	0.1%

* 1st order PQL

Changes in the variance estimates for each hierarchical level after inclusion of fixed effects from the final multivariable model are shown in Figure 2. The variance estimate for trainer increased after inclusion of the fixed effects whilst the variance estimates for all other levels decreased.

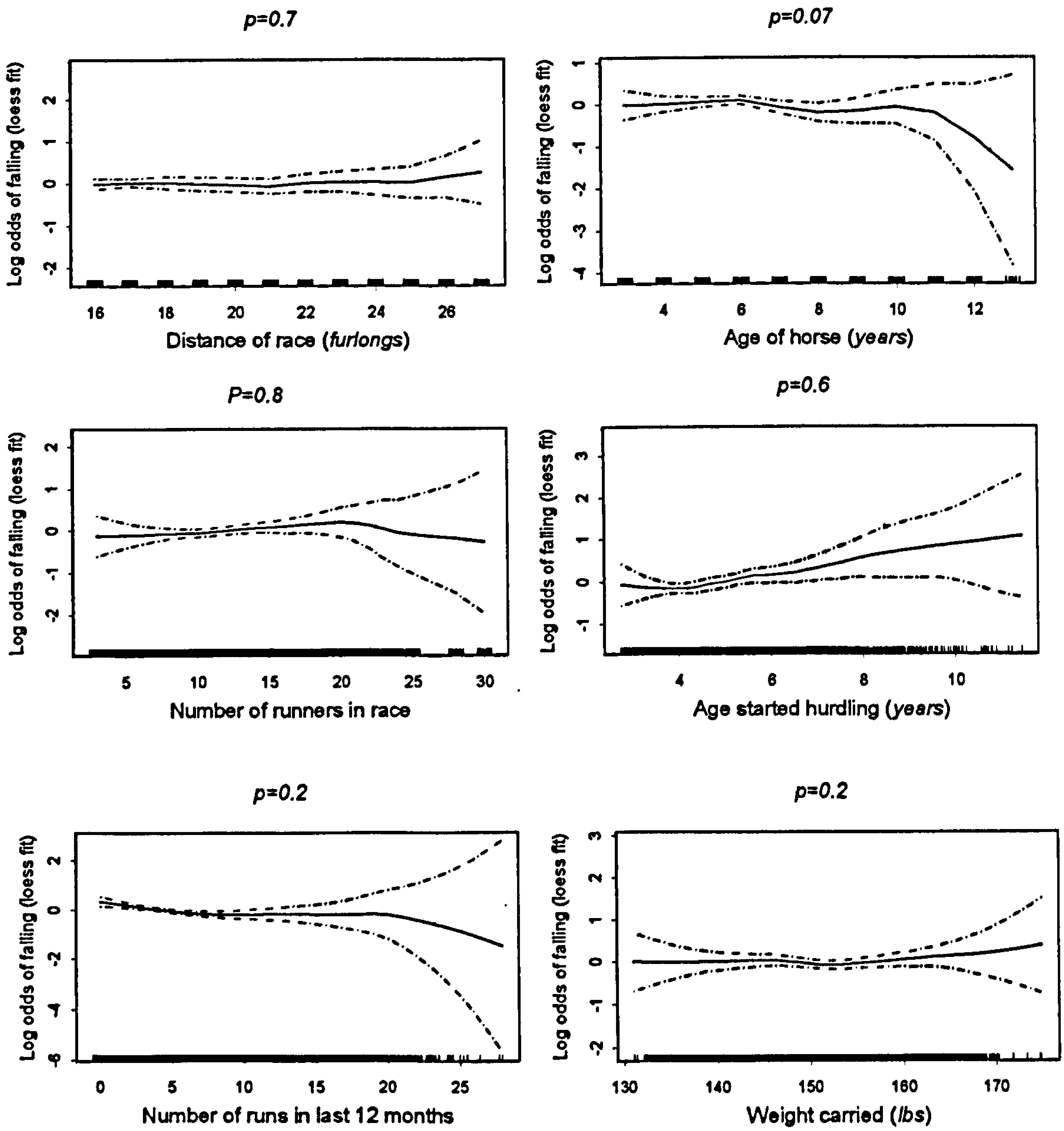

Figure 1. Graphical representation of the functional form of the continuous variables modelled in a multivariable gam. The plots show the smoothed, fitted means and the 95% confidence intervals, with rug plots to represent the number of data points along the x-axis.

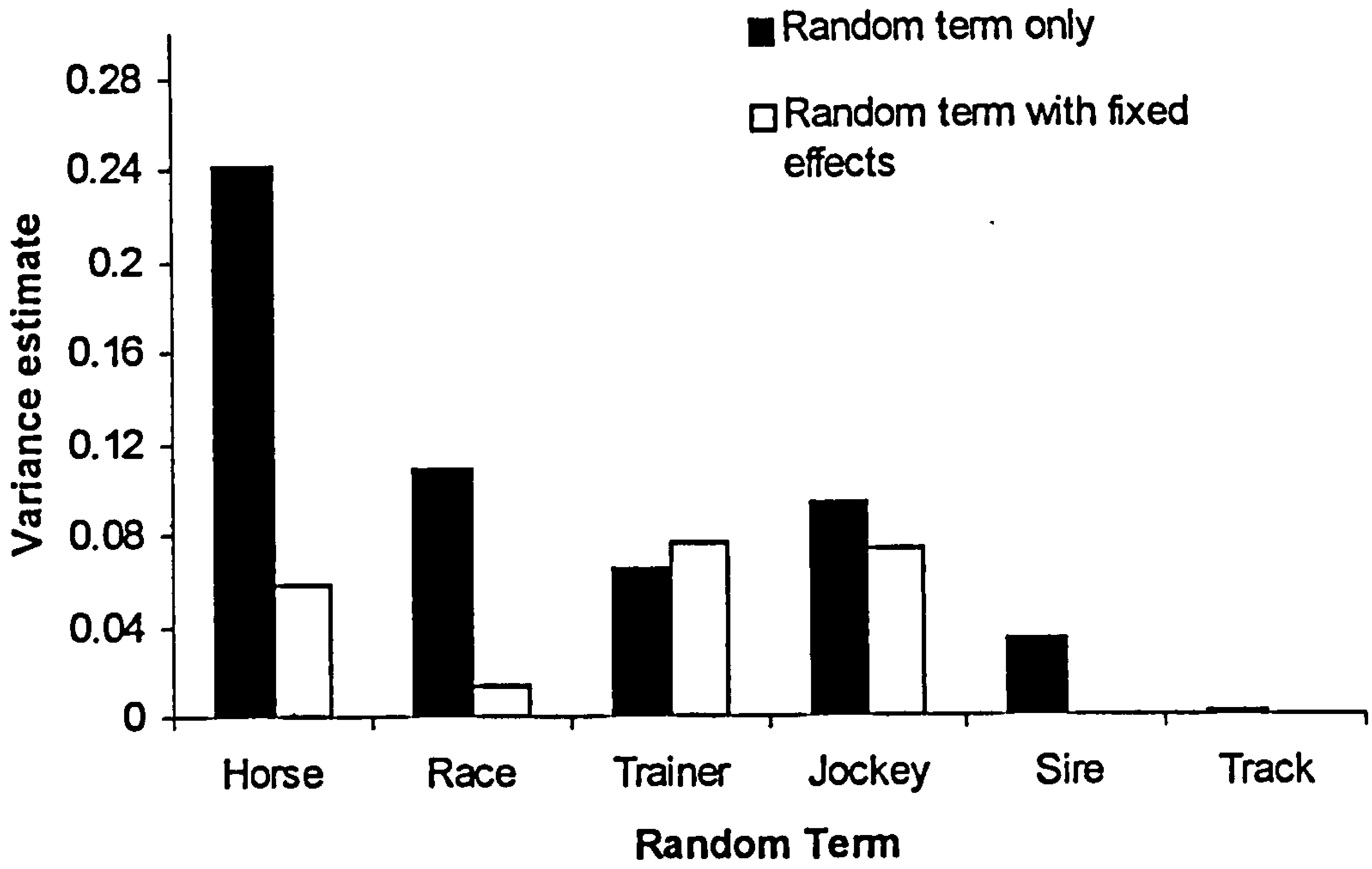

Figure 2. Variance estimates for each level with and without fixed effects. The latter were obtained using estimates from the intercept only PQL models (for horse and race 2nd order PQL models would not converge so 1st order PQL models were used so estimates may be biased)

Multi-level multivariable logistic regression model

The results from the final multilevel mixed effects model (using a 1st order PQL model) are shown in Table 4. The three levels used were jockey, horse and the start (level 1). The nested model of jockey-horse was used as this accounted for the largest proportion of variance (although horse within jockey will not be entirely nested). Two-level models with horse, trainer or jockey as the 2nd level and the three level model trainer-horse-start were also considered. When the three level models were fitted the horse variance was reduced to zero in both cases. The coefficient estimates for the fixed effects did not vary substantially between these three level and two level models. Most coefficients were identical to 2 decimal places, except for the estimates for jockeys claiming weight, which decreased in the models including the level jockey by between 0.01 and 0.04.

To reduce collinearity, the continuous variables were centered by subtraction of the sample mean from all observations (age mean=6.97, weight mean =152, number runs in the last 12 months mean=5.96, age started hurdling mean=5.6). From the model it can be seen that the continuous variables, weight carried, the age the horse started hurdling and the number of runs the horse had in the last 12 months were all significantly related to falling, and their relationship with the log odds of falling were best described by single linear terms. The older the horse began its hurdling carreer the more likely it was to fall and greater the weight carried was associated with an increased odds of falling. A greater number of runs by the horse in the last 12 months was associated with a decreased odds of falling. Horses that had hurdled before in the UK were also at decreased odds of falling when compared with horses that had never hurdled before. Horses ridden by a professional jockey had a lower odds of falling compared to horses ridden by conditional jockeys (entitled to a weight allowance) and starts on soft or heavy going were associated with a lower odds of falling. Male horses (geldings and entire males) were also at decreased odds of falling.

Table 4. Multi-level multivariable logistic regression model of risk factors associated with falling in hurdle racing fitted using 1st order PQL

Regression terms	Estimates	S.E.	Odds Ratio	95% CI	P-value
Random effect	*Variance estimate*				
Jockey	0.072	0.05			
Horse	0.000	0.000			
Fixed effects	*Coefficients*				
Age (cent)	0.005	0.036			0.9
Age started Hurdling (cent)	0.116	0.052			0.02
No. runs last 12 months (cent)	-0.028	0.014			0.05
Weight carried (cent)	0.019	0.008			0.02
Gender					
-female			1.00ª		
-male	-0.390	0.124	0.68	0.53 – 0.86	<0.01
Going					
-firm/good to firm	-0.126	0.140	0.88	0.67 – 1.16	0.4
-good			1.00ª		
-good to soft	-0.177	0.145	0.84	0.63 – 1.11	0.2
-soft/heavy	-0.459	0.153	0.63	0.47 – 0.85	<0.01
Hurdled before					
-No			1.00ª		
-Yes UK	-0.534	0.152	0.59	0.44 – 0.79	<0.01
-Yes Outside UK	0.120	0.371	1.13	0.54 – 2.33	0.7
Jockey					
-Professional			1.00ª		
-Claiming 3lbs	0.375	0.182	1.45	1.02 – 2.08	0.04
-Claiming 5lbs	0.291	0.190	1.34	0.92 – 1.94	0.1
-Claiming 7 lbs	0.389	0.180	1.48	1.04 – 2.10	0.03

ªIndicates reference category.
Cent – Indicates variables were centered.

Assessing the fit of the model

The fitted probability values calculated from this final model ranged from 0.006 to 0.13. The specificity and sensitivity at various cut-off points are shown in Table 5. For example when a cut off of 0.025 is selected (i.e. if the predicted probability of falling is above 0.025, the horse is predicted to fall) the specificity is 62% (i.e. 62%

of non-fallers were correctly classified) and the sensitivity was 54% (i.e. 54% of fallers were correctly classified)

Table 5. Sensitivity and specificity of the model presented in Table 4.

Cut-off	Specificity (proportion of non-fallers predicted)	Sensitivity (proportion of fallers predicted)
0.02	38%	76%
0.025	62%	54%
0.03	77%	38%
0.05	96%	12%
0.1	99%	5%

Discussion

This study, combined with a similar study of steeplechasing (Pinchbeck et al. 2002a), has contributed to our understanding of the aetiology of equine falls during racing on National Hunt racecourses in the UK. The two studies have identified markedly different risk factors and sources of variation. The only significant level of clustering detected in the hurdling model was at the jockey level, and this only explained a very small amount of variation. This suggests that modification or intervention of start (level 1) variables would be likely to have the most impact on reducing the risk of falling in hurdling. However, in the steeplechase model significant clustering was found at the horse, race, sire and racetrack level and this helped to focus further research in these areas. Few previous studies on racehorse injuries have taken into account levels of hierarchy and clearly race starts may not be independent. A study by Wood et al (2001a) looking at deaths on UK racecourses from 1990 to 1999 detected small but significant clustering at the trainer and race level in hurdling. The use of multilevel models also provides more robust estimates of regression coefficients for fixed effects and assessment of whether or not the effects of these change within different levels of clustering.

Although only two-level-intercept-only models are presented above, 3 level nested models (e.g. start, horse and sire) were also fitted but, possibly because of small variance estimates, only marginal quasi-likelihood models (MQL) would converge and these did not reveal any contribution from higher levels. This is in contrast to the steeplechase study (Pinchbeck et al. 2002a) where, for example, the sire remained a 'significant' source of variation, having accounted for horse and start. Inclusion of the fixed effects decreased the variance estimates at all levels except trainer where the estimate increased. This may be due to some trainers having more horses with less experience or using claiming jockeys more often than other trainers, so when evaluation of the variation in the risk of falling is assessed over all trainers it is lower than when experience of the horse and/or jockey is taken into account.

All random effects models were fitted using 2^{nd} order PQL models if possible as the second-order Taylor series expansion provides the most unbiased estimates of regression terms and variance estimates. However, 1^{st} order PQL models were used when 2^{nd} order would not converge. All iterative least squares algorithms may have inherent bias (Dohoo 2001, Rodriguez & Golmad 1995) and confirmation of estimates was attempted using MCMC techniques, however very long chain lengths of between 1 and 9 million (according to the Brooks-Draper statistic) were needed which were too computationally (and time) intensive. The need for long chain lengths may be because of the small variance estimates at all levels and was not the case in the study of steeplechase starts. The final model shown in Table 4 (2 levels only-jockey and start) was also fitted using MCMC simulation with Metropolis-Hastings sampling, diffuse priors, a burn in of 50,000 and a run of 10^6 iterations, to provide comparative estimates of the regression coefficients. The coefficients of the fixed effects were the same to 2 decimal places. However the estimate for jockey decreased to 0.058. A comparison of four different methods of estimating variance (marginal quasi-likelihood, MCMC with metropolis Hastings sampling, MCMC using Gibbs sampling and maximum likelihood estimates) was performed when analysing the steeplechasing data and all except the MQL models gave similar estimates.

The ICC's showed that the contribution to the variation at any level other than level 1 (the start) was very low. The simulation method and the model linearisation methods both provided similar estimates. Calculations using a latent variable approach provided higher estimates and this pattern was also seen in the steeplechase data analyses. This approach assumes that the binary response is derived from an underlying continuous variable and is possibly a less justified approach for a truly discrete response such as falling or not falling.

The generalised additive models provided a means of exploring the functional form of the relationship between continuous variables and the risk of falling and also graphically assessing the contribution by each variable. In the hurdle model none of the variables had a significantly non-linear relationship with the outcome of falling and for some variables single linear terms provided the best fit in the final multivariable logistic regression model. The graphs of weight carried and number of runs in the last 12 months appear almost flat and close to zero because of the small odds ratios associated with these variables (1.02 and 0.97 respectively), which were detectable due to the high power of the study. Age was not significant, but was forced into the model, and was considered both in a quadratic form and as a piece-wise fit, neither of which improved the fit of the model. In the steeplechase data 3 variables had a significantly non-linear relationship with the risk of falling. Distance and age of the horse were best described by a cubic relationship and the number of runs the horse had in the last 12 months by a quadratic relationship with the risk of falling. When combined with the alternatives such as variable categorisation, GAMs provide a powerful way of representing, potentially complex, functional relationships parsimoniously in regression models.

Although age at the time of start was not significant in hurdling, the age at which a horse began its hurdling career was significantly related to the odds of falling. This was best described by a linear term giving an OR of 1.12 per yearly increase, so for example, a horse that started its hurdling career at 8 years old would be estimated to have an increased odds of falling of 1.8 times compared to a horse that started its hurdling career at the age of 3 years old (3 years is the minimum allowed age for hurdle racing in the UK). The age at which horses began their hurdling career ranged from 3 years to 11 years old. This may be due to enhanced learning responses in younger horses, or it may be that horses starting their hurdling career at a later age have had more runs on the flat. Such horses are likely to have been specifically bred for flat racing, and therefore less suitable for jumping in hurdle racing. There was no information in this data set on the number of previous flat races a horse had over its career. There was information on the number of runs (of any type) that a horse had in the last 12 months and this had a small but significant relationship with the odds of falling with a greater number of runs associated with lower odds of falling. This relationship was different to that observed in steeplechasing where the odds of falling started to increase with greater than 17-18 runs in the previous 12 months. This may be due to gaining jumping and racing experience and increasing fitness levels. This is backed up by the results of comparing horses that had hurdled before with those having their first ever hurdle race. Horses that had hurdled before in the UK had decreased odds of falling. Interestingly this effect was not seen in horses that had hurdled only outside of the UK and this is in contrast to steeplechasing where a previous steeplechase race anywhere decreased the odds of falling. This may be due to different fences used overseas or may reflect the population of horses sent to race in the UK.

In hurdling male horses were less likely to fall than females. Males may have a better natural athletic ability for jumping compared to females, or may be of an average greater height than females although this effect was not seen in steeplechasing where there was no significant difference between the gender of the horses.

In contrast to steeplechasing the jockey was associated with the risk of falling in hurdling and this was seen both in the variance estimates and in the fixed effects. When professional jockeys were compared with conditional jockeys claiming three different weights the odds of falling were almost 2 fold for horses ridden by a conditional jockey. A conditional jockey is an inexperienced jockey under 26 years of age and the weight they are allowed to claim is dependent on the number of races they have won (e.g. 7lb until won 15 races, 5lb up to 30 races and then 3 lb). Once a jockey has won 65 races he is classed as professional. Increasing weight carried by the horse also had a small but significant increase on the odds of falling. It may be that extra weight does affect the horses jumping ability or may contribute to fatigue but this really needs to be assessed taking into account whether the race is a novice or a handicap and what the handicap (or horses rating were) weights were.

The effect of going in hurdling was opposite to that seen in steeplechasing with softer and heavy going significantly decreasing the odds of falling in hurdling. In steeplechasing these types of going appeared to be associated with an increase risk of falling. This does suggest different mechanisms for falling in the two different types of racing and speed (which will be affected by going) may have also have an effect.

The results of the sensitivity and specificity of the model suggest that there is a significant proportion of unexplained variation within the model. This may be due to unmeasured covariates or unmeasurable biological variability.

To summarise, this study has identified a number of variables associated with the risk of horse falls in steeplechasing and hurdling in the UK and will help to identify high-risk horses and races. The random effects models have suggested in which areas further research and intervention studies would be likely to have the most impact.

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Manuscript 3

Journey time, behaviour and weather and their association with the risk of horse falls in hurdling and steeplechasing: The results of a prospective cohort study

Pinchbeck, G.L. Clegg, P.D., Proudman, C.J., Morgan, K.L., French. N.P.

Department of Veterinary Clinical Science and Animal Husbandry, University of Liverpool, Leahurst, Neston, CH64 7TE, UK.

Corresponding Author. G.L.Pinchbeck

Key words: Horse falls; steeplechase; hurdle; cohort; journey time

Abstract

A prospective cohort study was conducted on 2879 starts in hurdle and steeplechase races on 6 UK racecourses to identify and quantify risk factors for horse falls. There were 124 falling cases (32 in hurdling and 92 in steeplechasing) identified. The injury risk of fallers was 8.9% and the fatality risk was 6.5%. Multilevel multivariable logistic regression models allowing for clustering at the level of the track were used to identify the relationship between variables and the risk of falling. Duration of journey to the racecourse, behaviour in the parade ring and weather at the time of the race were associated with falling in both hurdling and steeplechasing. Age, amount of rainfall and going were also associated with falling in steeplechasing.

Introduction

It has been well documented that the fatality rates in hurdle and steeplechasing racing are significantly higher than those in flat racing (Bourke 1995; McKee 1995; Wood et al. 2000). In the UK, average equine fatality rates of 0.1 per 100 starts for flat racing, 0.52 per 100 starts for hurdling and 0.71 per 100 starts for steeplechasing have been reported between 1990 and 1999 (Wood et al. 2000). Despite the differences in death rates and the profound differences in the nature of the races and training in National Hunt racing there have been few published studies specifically addressing risks for injuries or accidents in jump racing (Bailey et al. 1998; Wood et al. 2000; Williams et al. 2001). The nature of injuries sustained in jump racing differ from those sustained in flat racing (Williams et al. 2001) and some injuries, such as vertebral fractures are almost unique to horse racing over jumps (Vaughan and Mason 1975). Previous studies have reported that between 42% (Pinchbeck et al. 2002b) and 55% (Vaughan and Mason 1975) of jump racing fatalities were associated with falls at fences and falling during National Hunt racing in the UK contributes significantly to fatality in horses and injury to both horses and jockeys. The falling risk for National Hunt jockeys has been quoted as between one in every 10 rides with an injury rate of 4.3% (Allen 1992) to one in every 12 rides with an injury rate of 2.1% (Pritchard, Racing Post 2001). Horse falls often occur in full public view and fatal injuries in particular are likely to have a very negative impact on the public's perception of racing welfare and evoke strong reaction from groups concerned with animal welfare.

In this study we follow a cohort of horses starting in races at 6 UK racecourses to identify and quantify risk factors associated with horse falls in hurdling and steeplechasing and to report on the frequency of falling and of any risk factors identified.

Materials and Methods

Study Design

A prospective cohort study was conducted on hurdle and steeplechase racing on six UK racetracks (Aintree, Bangor-on Dee, Cartmel, Cheltenham, Haydock and Huntingdon) for approximately two years. The racecourses were selected due to their membership of the Racecourse Holding Trust Ltd and their willingness to co-operate with the study. Based on Jockey Club estimates of 2 falls per race day and 60 starts per race day a falling risk of 3.3% was assumed. Sample size estimates showed that with 95% confidence and 80% power to detect odds ratios of 2.5 or more a sample size of 1506 would be needed for more common exposures and a sample size of 2350 would be need for rarer exposures (ratio of non exposed per exposed 9:1). It was estimated that a cohort using 50% of races on all race days at the six tracks during the study period (possible 127 race days) would achieve a sample size of 3810. These estimates would allow for some loss of race days due to abandonment. Fifty percent of the races on a race day were randomly selected using randomised blocking of pairs of races. In other words one from every two consecutive races was randomly selected. This meant that two but not three consecutive races could be selected, avoiding difficulties in data collection. Hunterchase races were excluded from this study due to the different nature of these horses (amateur trained and ridden) and due to difficulties encountered in tracing of the carers, and therefore in questionnaire administration, of horses taking part in these races during a pilot study (unpublished data).

Identification of cases

The cohort consisted of all starts in selected races and starters were followed from the start of the race until they finished the race, fell or did not compete for another reason. Cases were defined as any horse in any start that suffered a fall at a steeplechase or hurdle fence during the study. Cases were verified by the author who attended the races and were checked against an independent data source (Racing Post online-www.racingpost.co.uk). Horses that were brought down by another horse were not included in the case definition. Non-cases were all horses that started in the race and did not suffer a fall regardless of whether they completed the race or not.

Data Collection

Horse, race and jockey information were collected from the race cards on the day of racing and from Racing Post on-line and a commercial disc-based database (Raceform Ltd.). A questionnaire was designed for the study to collect information on the individual horses' pre-race routine. The questionnaire was piloted at racetracks prior to the study from November 1999. Only seventy percent of the starters were selected for questionnaire administration due to time constraints, resulting in decreased power for questionnaire variables. The starters to receive the questionnaire were randomly selected from all starters in the selected races using random number generation (Epi-Info 6.04). The questionnaire was then administered by interview, prior to races starting, to the trainer or the carer of the horse who travelled to the racetrack that day. Two interviewers administered all questionnaires.

Data on all starters in the selected races were also obtained from observations by the first author in the parade ring before the race commenced. Horses generally entered the parade ring between 5 and 30 minutes before race time. All observations were made on entry to the parade ring and repeated on the horse's last circuit of the parade ring. Data were recorded using a focal sampling method (sampling each horse over a set distance in the parade ring) (Martin and Bateson 1993). Information relating to the horses' behaviour, tack and shoeing and variables relating to the weather and rainfall on the racecourse that day were also recorded. All variables collected from existing databases, the questionnaire and from parade ring observations are shown in Table1.

Table 1: Variables collected in a cohort study of 2879 race starts on 6 UK racecourses from 1st January 2000 to 24th December 2001.

Variable	Description
Variables from racing post and race cards	
Racecourse	Good to firm, good, soft, good to soft, soft, heavy
Race type	Steeplechase or hurdle
Race date and ID	Month of race and ID for that race
Race time	Time of start of race
Going	Condition of track surface. (good-to-firm, good, good-to-soft, soft, heavy)
Distance	Distance of race in furlongs
Speed	Winning time divided by distance.
Race classification	Handicap, novice, maiden, selling, juvenile
Race class	Official race class (A-H)
Horse ID	Horse name and identification number
Horse age	Age in years at time of start
Horse gender	Male or female
Horse Official rating	Official BHB rating at the time of the race
Days since last ran	Number of days since horse last raced
Weight carried	Weight carried by horse in pounds
Weather	Weather at the start of the race (cloud, sun, rain)
Time until sunset	Time from race to sunset.

Rainfall	Race course rainfall measurement on morning of racing for previous 24 hours (millimetres)
Jockey ID	Jockey name and identification number
Trainer ID	Trainer name and identification number
Variables from questionnaire	
Entered stables	Entered racecourse stables or raced from the horse box
Time since last shod	Time in days/weeks since horse was last shod
Schooling frequency	Number of times horse was schooled over fences in the previous month
Exercise yesterday	Exercise or not and type - walk, trot, canter, work, schooled, turned out
Exercise today	Exercise or not and type - walk, trot, canter, work, schooled, turned out
Journey time*	Time from leaving yard to arrival at the race course
Time from arrival to race*	Time from arrival at the racecourse to the start of the race
Travelling behaviour	How the horse travelled-calm, slightly sweaty, very sweated up and excitable
Box behaviour	Horses behaviour in the box at the racecourse
Feed times	Number of hours from last concentrate feed and hay/haylage feed
Water withdrawal	Was water withdrawn before racing and if yes how many hours before?
Interviewees position	Interviewee's employment position. E.g. trainer, assistant, head person, stable person.
Variables from parade ring observation	
Number of handlers	Number of people leading the horse
Sweating	Degree of sweating (neck, between hindlimbs, whole body)
Behaviour	Any head tossing, tail swishing or other abnormal behaviour
Locomotion	Walking, trotting, jogging
Boots and bandages	Presence of boots or bandages on fore or hind limbs
Blinkers/visor	Presence of blinker or visor
Tongue tie	Presence of a tongue tie
Tracheostomy	Presence of a tracheostomy tube
Shoeing	Shod or unshod
Foot conformation	Normal, long toe, long toes and low heel, boxy foot.
Fired	Presence of tendon firing

* Validated from Jockey Club records

Statistical analysis

The outcome was a binary variable where a start that resulted in a fall was a case and starters that did not fall were non-cases.

Intercept only 2 and 3-level random effects models were fitted to assess the contribution of each possible level of clustering. The levels included track, race, horse, jockey and trainer. The models were fitted using Markov Chain Monte Carlo

(MCMC) simulations with Metropolis-Hastings sampling with diffuse priors. The number of iterations used was determined by the Brooks-Draper Nhat statistics (Rasbash et al. 2000). To estimate the proportion of variance attributed to each level, approximations of the intra-class correlation coefficients were calculated using a latent variable approach which assumes the binary outcome arises from an underlying continuous distribution and that the level 1 variance on the logit scale is $\pi^2/3$.

Univariable screening of all variables was performed using chi-squared test for categorical variables and univariable logistic regression model for continuous variables. The functional form of the relationship between the continuous variables and the risk of falling was explored using generalised additive models (GAM) replacing the usual linear function of a covariate with a cubic spline smoothing function (Hastie and Tibshirani 1990). The GAM models were fitted in S-Plus (S-plus 2000, Mathsoft Inc.). The functional form of the continuous variables was then used to inform the polynomial fits in a subsequent multivariable logistic regression model.

Variables with a p-value<0.25 were considered for inclusion in a multilevel multivariable model which was built using backward elimination procedures where variables remained in the model if they significantly improved the fit if the model (assessed by the change in deviance) or if removal resulted in substantial change to the effect of other variables. Interaction terms were tested between all biologically plausible terms. The critical probability throughout was 0.05. The fit of the model was assessed by examination of the posterior distributions of the fixed and random variables.

Statistical analyses were done with the software packages EGRET (Egret Application 2.0, Cytel Software Corporation), Minitab (Minitab 13.1, Minitab Inc.) and MlwiN (MlwiN 1.10,0006, IOE, London).

Results

Information was collected on 2879 starts of which 124 resulted in a fall (32 in hurdling and 92 in steeplechasing). The distribution of fallers as a percentage of starts at each racecourse are shown in figure 1. Only 2.3% of horses did not enter the stable yard at the racecourse. The overall response rate to the questionnaires was 95.8%. The remaining 4.2% refused to answer due to concerns about confidentiality or lack of time. Within the questionnaires there were questions where a proportion of the respondents did not know the answer, and these ranged from 2% (questions relating to the horses exercise that day) to 6% (number of days since last shod). Over half (57%) of the questionnaires were answered by the stable person responsible for that particular horse. The remainder were answered by the head person, trainer or assistant trainer. There were 18 fatal injuries in the cohort and 44% of these were associated with a fall. The injury risk of fallers was 8.9% and the fatality risk of fallers was 6.5%. Further information on injuries is provided in manuscript 4.

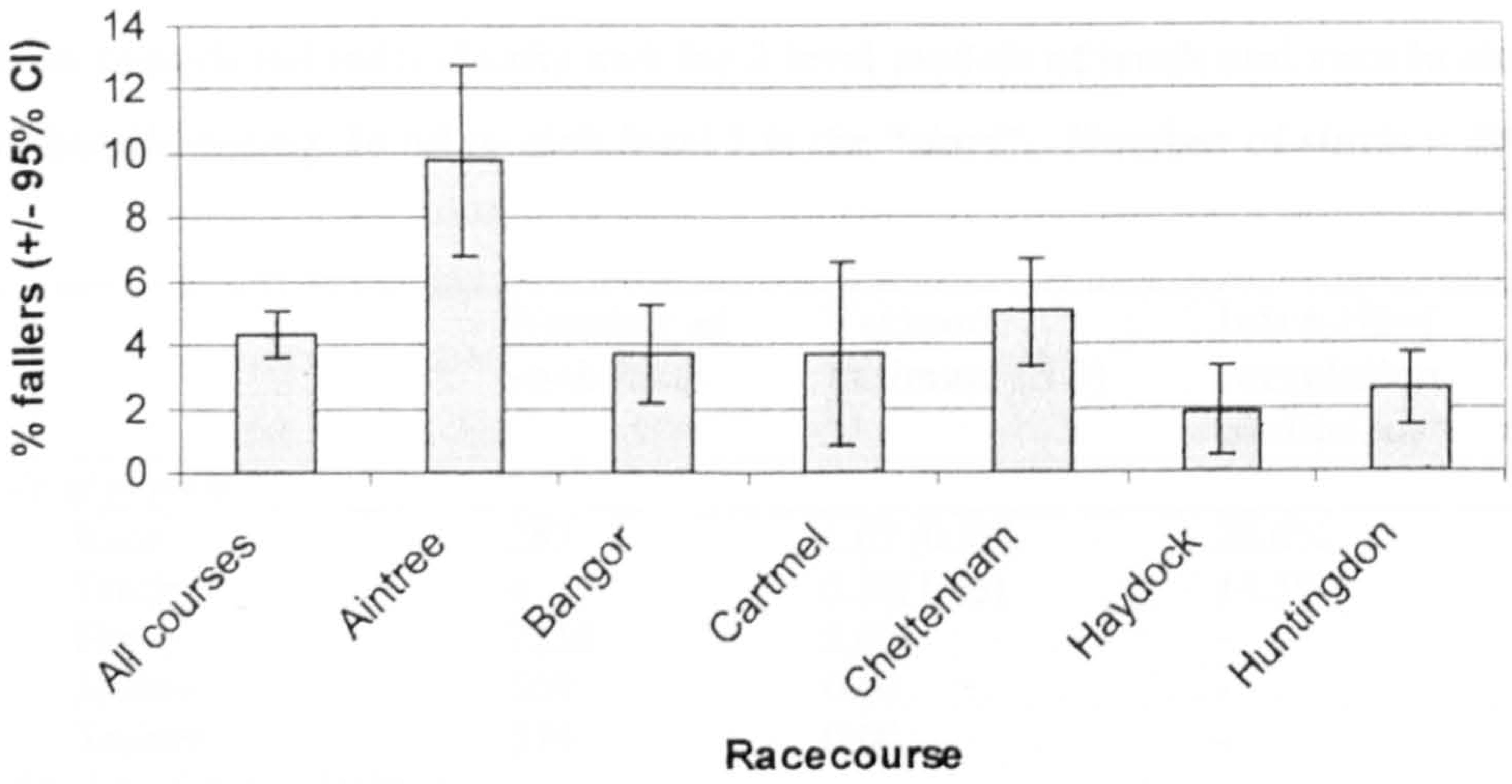


Figure 1: The distribution of fallers as a percentage of starts at 6 UK racecourses from Jan 2000-Dec 2001.

Random effects

The variance estimates show that there was very little variation at the level of the horse, the trainer or the jockey (table 2). In two-level intercept only models the largest proportion of variation appeared to be due to race and to track. Subsequent 3-level models, in hurdling and steeplechasing, and allowing for the clustering of race within track (table 3) showed that much of the clustering at the level of race was accounted for by the different race types. There was very little variation at the level of track in hurdle racing.

Table 2: Variance estimates and intra-class correlation coefficients for all 5 random effects considered individually and for 3 level models of track and race in steeplechase and hurdle racing. In all models level 1 is the "start". Number of starts = 2879.

	Number at each level	Variance Estimate (SD)	Intra-class correlation coefficient*
2-level models			
Race	283	1.07 (0.36)	24.6%
Track	6	0.56(1.06)	14.5%
Horse	2216	0.00	-
Jockey	509	0.00	-
Trainer	334	0.00	-
3-level model steeplechase			
Track	6	0.52 (0.32)	12.7%
Race	142	0.27 (0.25)	6.7%
3-level model hurdle			
Track	6	0.00(0.00)	-
Race	141	0.07(0.15)	2.1%

* Calculated using a latent variable approach where the level 1 variance is $\pi^2/3$

Multivariable models

Model 1

Model 1 (Table 3) used data from both race types and the questionnaire (70% of the cohort). Track was allowed for by inclusion as the level 2 random effect. Steeplechasing was associated with increased risk compared to hurdling (OR 3.5). Journey time was also significantly associated with the risk of falling and was best described by a quadratic relationship as shown in figure 2. The risk of falling increased up to a journey time of around 7.5 hours and then decreased.

Table 3: A multilevel, multivariable logistic regression model of risk factors associated with falling in hurdle and steeplechase racing on 6 UK racecourses fitted using Markov Chain Monte Carlo methods.

Variable	Median(β)	95% CI of β	P-value	Odds Ratio	95% CI of OR
Random Effect	*Variance estimate*				
Track	0.15	0.001, 0.79			
Fixed Effects	*Coefficients*				
Journey time	0.62	0.29, 0.99	0.001	1.85	1.29, 5.65
Journey time squared	-0.04	-0.071, -0.013	0.01	0.96	0.93, 0.99
Steeplechase	1.26	0.75, 1.8	<0.001	3.50	2.09, 5.90

CI – Credibility intervals

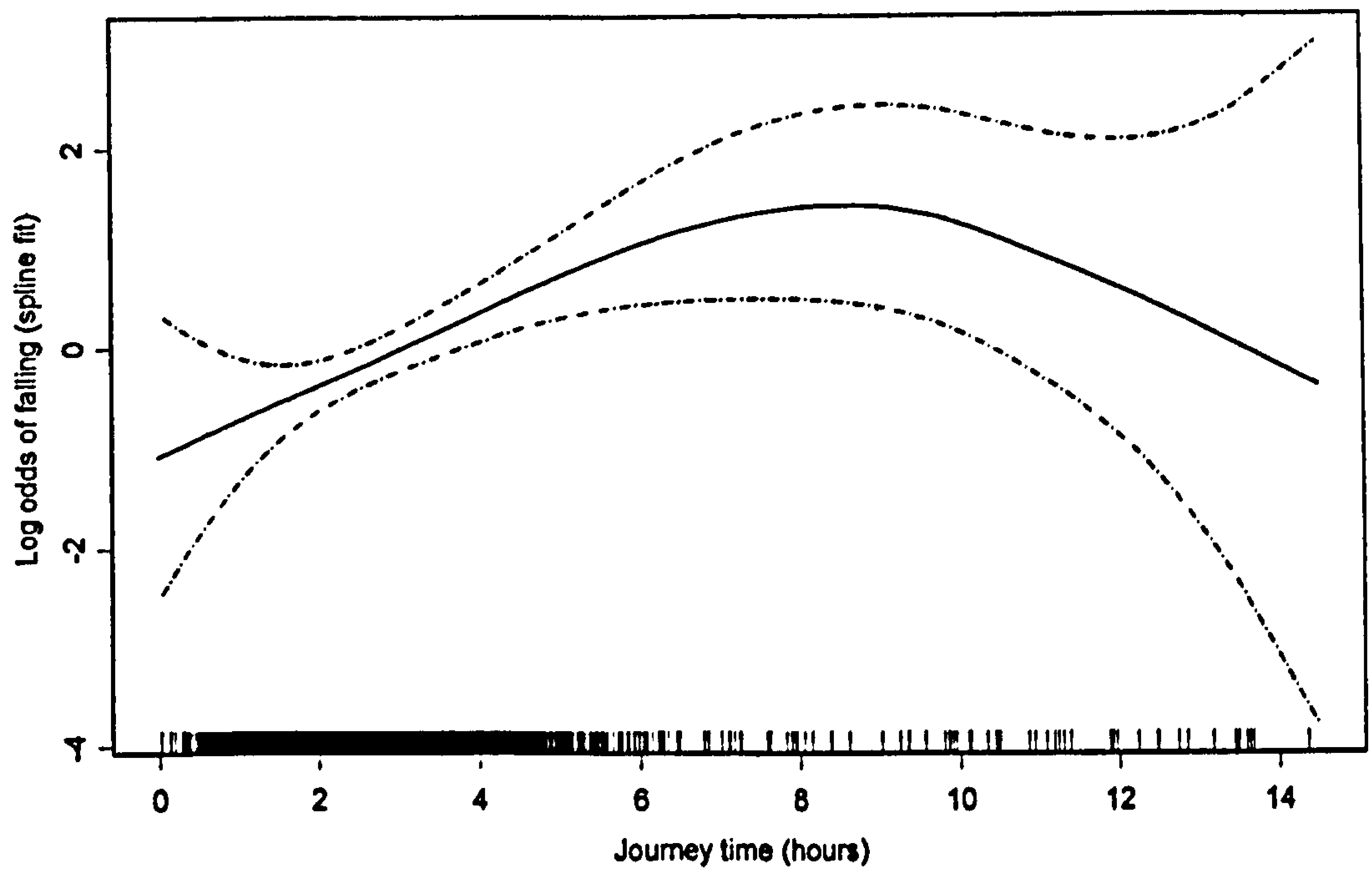


Figure 2: Functional form of the relationship between journey time and the log odds of falling modelled using a multivariable generalised additive model (including the covariates race type and track). The plot shows the fitted curves with 95% confidence intervals and a rug plot on the x-axis representing the number of data points.

Models 2 and 3 (Table 4 and 5) used data from the steeplechase starts and hurdle starts respectively as some of the variables had effects in opposite directions in the different race types. Track was allowed for by inclusion as a level 2 random effect in the steeplechase model.

The horse's locomotion was associated with falling. Horses that were walking calmly in the parade ring were less likely to fall than those that were trotting or cantering. Although the confidence intervals crossed one, if the data from both race types were combined then the association was significant (OR=1.7, 95% CI= 1.01, 3.00).

In steeplechasing increasing age was associated with decreasing risk and novice races were associated with increased risk of falling even after allowing for the effects of age. Good to soft and soft/heavy going were associated with decreased risk when compared with good or good to firm going. Sunny weather was associated with an increased risk of falling compared to cloudy weather and increasing rainfall in the previous 24 hours was associated with increasing risk. Increasing distance of the race was also associated with an increased risk. Further analysis with the Grand National 2001 omitted from the data set showed that the effects of rainfall and distance were skewed by the inclusion of this race. With this single race omitted from analysis the odds ratio for rainfall (OR=1.05, 95% CI=0.98, 1.13) and distance (OR=1.05 , 95% CI=0.97, 1.13) decreased and the confidence intervals crossed 1.

In contrast to steeplechasing, novice hurdle races were associated with a protective effect. Sunny weather was associated with an increased risk of falling, similar to that seen in steeplechasing. Although not significant the effect of rainfall was opposite to that seen in steeplechasing (OR=0.9, 95% CI= 0.78, 1.06). Going was not significantly associated with falling in hurdling, however the trend was similar to that seen in other studies and that seen in steeplechasing (i.e. softer going was associated with a decreased risk compared to good going).

Table 4: A multilevel, multivariable logistic regression model of risk factors associated with falling in steeplechase racing on 6 UK racecourses fitted using Markov Chain Monte Carlo methods.

Variable	Median(β)	95% CI β	P-value	Odds Ratio	95% CI OR
Random Effect	*Variance estimate*				
Track	0.20	0.001, 1.09			
Fixed Effects	*Coefficients*				
Horse age (years)	-0.24	-0.40, 0.10	0.002		
Distance (furlongs)	0.08	0.01, 0.14	0.02		
Rainfall (mm)	0.07	0.01, 0.13	0.02		
Going					
Good	Ref.			1	
Good to firm	-0.22	-1.22, 0.67		0.8	0.3, 2.0
Good to soft	-0.79	-1.50, -0.01		0.5	0.2, 1.0
Soft/heavy	-0.72	-1.37, 0.04	0.02	0.5	0.3, 1.0
Weather					
Cloudy	Ref			1	
Sunshine	0.59	0.09,1.10		2.0	1.1, 3.0
Rainfall	0.46	-0.33, 1.21	0.04	1.6	0.7, 3.4
Novice race					
No	Ref			1	
Yes	0.68	0.18, 1.18	0.01	2.0	1.2, 3.2
Locomotion in the parade ring					
Walking calmly	Ref			1	
Trotting/Other	0.48	-0.26,1.16	0.18	1.6	0.8, 3.2

CI – Credibility intervals

Table 5: A multivariable logistic regression model of risk factors associated with falling in hurdle racing on 6 UK racecourses fitted using maximum likelihood methods.

Variable		Coefficients	Standard error	LRS P-value	Odds Ratio	95% CI
Locomotion in parade ring						
	Walking calmly	Ref.				
	Trotting or other	0.87	0.5	0.06	2.4	0.89, 6.4
Weather						
	Cloudy	Ref.			1	
	Sunshine	0.74	0.37		2.11	1.03, 4.31
	Rainfall	-1.07	1.04	0.03	0.34	0.05, 2.63
Novice race						
	No	Ref.				
	Yes	-0.98	0.46	0.03	0.43	0.15, 0.93

Discussion

This study has identified journey time and horses behaviour as risk factors for falling in both hurdling and steeplechasing. Journey time was best described by a quadratic relationship with the risk of falling. As journey time increased the risk of falling increased until around 7.5 hours when the risk appeared to decrease again. The finding that the risk appeared to decrease after greater than 7.5 hours travelling time is likely to be confounded by the time from arrival at the racecourse to the start of the race. The majority of horses that travelled greater than 7.5 hours stayed overnight at the racecourse and journey time was correlated with arrival time (Pearson correlation coefficient 0.64). Track had a small effect on the coefficients of journey time and this suggests a difference in the journey time to particular tracks. In fact the two race courses with the highest rates of falling had the highest mean travel times, the highest maximum travel times and also had the greatest proportion of horses staying over night. It is unclear why long journey times had an association with the risk of falling in jump racing but this was a prior hypothesis, based on previous observations by the people within the racing industry. It has been shown that horses have increased heart rates and energy expenditure whilst travelling (Waran et al 1995; Doherty et al. 1997). In a study of horses during long distance commercial transport, travel for longer periods without water caused dehydration and fatigue (Friend 2000). However, these horses were transported over much longer periods (up to 30 hours) and in hot conditions whilst the majority of jump racing in the UK is during the cooler months. There is evidence that even horses that are used to travelling still experience changes in heart rate (Waran 1997) and in transport tests undertaken on donkeys there was no evidence of habituation in terms of cortisol responses (Forhead et al. 1995). An interaction term between journey time and time from arrival at the racecourse until racing was tested and, after allowing for the quadratic shape of journey time, was not significant. This suggested that allowing longer rest periods before the race after long journey times was unlikely to have an effect except when rested overnight. This is perhaps not surprising as the majority of horse are not fed or watered when they arrive at the racecourse unless they are staying overnight (see manuscript 4). Furthermore a study by Matlina et al. (1980) also showed that sympathetic stimulation occurred in response to racetrack noise.

Horses that were not walking calmly in the parade ring were at greater risk of falling, although other variables measuring behaviour, including those after travel and in the box, or sweating in the parade ring showed no association with the risk of falling. It is possible that horses that are excited before racing may lack concentration at the beginning of the race or they may set off faster at the start. A study by Hutson et al. (1997) on pre-race behaviour as a predictor of finishing position found that winners tended to be more relaxed and losers tended to be more aroused. Evaluation of the horses' behaviour at the start of the race and where in the race these horses are falling would be useful and this area may warrant further investigation.

In steeplechase racing, novice races and younger horses were associated with an increased risk of falling and this is consistent with previous studies on falling (Pinchbeck et al. 2002a). In contrast, in hurdling age had no effect on falling and novice races were associated with a decreased risk. This finding may also explain why in a study on injuries and fatalities by Williams et al. (2001) increasing age was associated with increasing risk of death for flat and hurdle racing but not for steeplechasing.

Softer going was associated with a decreased risk compared with good and good to firm going in steeplechasing. This is consistent with many previous studies on injuries and fatalities (Bailey et al. 1998; Williams et al. 2001; Wood et al. 2000) and falling in hurdling (Pinchbeck et al. 2002b) but is in contrast to a retrospective study on falling in steeplechasing on all UK racecourses (Pinchbeck et al. 2002a). However due to the retrospective nature of that study the analysis did not allow for the effect of the amount of rainfall that fell on the course on the day of racing. In the present study after allowing for the increased risk associated with increased rainfall in steeplechasing, softer going was associated with a decreased risk. In hurdling softer going, amount of rainfall and rain at the time of racing all had the trend of decreasing the risk of falling. These results combined with those from previous studies on injuries and fatalities in the UK (Williams et al. 2001; Wood et al. 2000) suggest that aims should be made to hurdle and steeplechase race on good to soft, or soft going to decrease injury rates. At present the technology to water racecourses to achieve this whilst maintaining an even surface during racing, does not exist. Also there may be some objection from trainers to this proposal as certain horses race better over good or good to firm ground.

The results showed that the effects of rainfall and distance of the race were slightly skewed by the inclusion of the Grand National 2001 in the steeplechase cohort. The Grand National is run over 36 furlongs and by its nature has a higher proportion of horses that fall and in 2001 the Grand National had an exceptionally large amount of rain. Although the proportion of fallers in this race was high there were no fatalities in this year and the type of fall and type of ground may influence the fatality rates of fallers.

Sunny weather was associated with an increased risk of falling in both steeplechasing and hurdling even after allowing for going (which obviously may be affected by weather). In a previous study on falling in hurdle racing in the UK (Pinchbeck et al. 2002c) the last race of the day was found to be associated with an increased risk of falling. We hypothesised that this may be due to deteriorating ground conditions, a horse effect, or related to either lack of light at the end of the day or due to low setting sun affecting visibility of the fences. In the current study we examined the effect of racing in the sun on falling and found that sunny weather was associated with an increased risk at any time of the day. In a study by Saslow (1999), examining factors affecting visibility for horses, a stripe encountered on a sunny day was less visible than on an overcast day suggesting that bright conditions may be less favourable to the equine eye. Time from the start of the race to the time of sunset and its interaction with the weather was not significant in this study but this may be due to low study power. A study using weather station variables by Clanton et al. (1991) did not find any association between weather and patterns of horse injuries and breakdowns. However, like the majority of studies on racehorse injuries and fatalities in the USA this involved flat racing only which is likely to have very different risk factors compared to jump racing in the UK. These results suggest that a further study examining in more detail the effects of the angle and intensity of the sun on jumping mistakes by horses may be warranted. A possible future intervention would then be to omit fences or hurdles when the sun is compromising their visibility.

There was very little clustering at any level of the hierarchy within racing. Track was allowed for by inclusion as a random effect in all models except the hurdle model where the variance for track was zero. There was some clustering within race but the fixed effects in the models such as race type, journey time and going explained most of this variation. These results are in contrast with those from a previous larger study of falling in steeplechase racing on all UK racetracks in 1999 (Pinchbeck et al. 2002a) where a proportion of clustering was attributable to horse. This was a much larger data set (674 cases of falling). There may be a degree of informed censoring in the current study where, once a horse has fallen on a particular track, the owners or trainers are reluctant to race the horse again over the same track. However the proportion of fallers that had more than one start within the data set (0.27) was very similar to the proportion of non-fallers that had more than one start (0.23). Another possible explanation may be that horses are less likely to fall on a racetrack that they have previously raced around (whether they fell or not). In a case-control study on steeplechase racing on 6 UK racetracks (see manuscript 7) having previously raced on that racecourse was found to be associated with decreased risk of falling.

A study on fatalities, in both flat and hurdle racing, on all UK racecourses from 1990-1999 also found that a proportion of variation was due to race track and race although a large part of the variance was attributable to the effects of track surface (going) (Woods et al. 2000).

The intra-class correlation coefficients in this current study were calculated using a latent variable approach where the level 1 variance is $\pi^2/3$, however this method has been shown to over estimate ICC's (Christley et al. 2002; Pinchbeck et al 2002b; Goldstein et al 2000) so these values should be used for comparative purposes only.

This study forms part of a larger project to identify and quantify risk factors for horse falls and injuries in National Hunt racing in the UK and it is hoped that information from this project may be used in future interventions to improve horse and jockey safety in racing.

Appendix to Manuscript 3

In this appendix a copy of the questionnaire used in the cohort study is shown and descriptive statistics and results from the univariable analysis of all categorical and continuous variables in the cohort are presented. There is an also an example of generalised additive models representing the functional form of the relationship between continuous variables and the risk of falling.

Further work on the multilevel modelling is also shown with results from different methods of estimating variation. Finally the Markov Chain Monte Carlo (MCMC) diagnostics for the fit of the model are presented.

Univariable analysis

Tables 1, 2 and 3 show the univariable relationship derived from chi-square tests between categorical variables from racing records, the questionnaire and the parade ring observations, and the risk of falling in hurdle or steeplechase racing. Table 4 shows the results from univariable logistic regression analyses of the continuous variables and their relationship with the risk of falling. All continuous variables were checked for linearity using generalised additive models. If significant non-linearity was found then the appropriate polynomial terms (e.g. quadratic cubic) were used in the logistic regression analysis. An example of the output for four of the continuous variables is shown in Fig 1.

THE UNIVERSITY
of LIVERPOOL

NATIONAL HUNT FALLERS PROJECT

RACK and RACE:

TRAINER: **Arrival time:**

HORSE: **Box Number:**

Interview Time:

Hello. Do you work for Mr/Ms_______________?

My name is Gina Pinchbeck. I am a veterinary surgeon from Liverpool University, working on a scientific project looking at falling injuries in National Hunt horse racing, which is sponsored by Aintree and Cheltenham racecourses. All trainers have been contacted about the study. Would you mind answering a short questionnaire about your horse in the ____ race? Any information will be confidential. There are only twelve questions; it will only take 4 minutes.

1. When was the horse last shod?

Within Last 2 days ☐ Within last Week ☐
1-4 Weeks ago ☐ > 4 Weeks ago ☐

I am now going to ask you about exercise.

2. How many times in the last month has the horse been schooled over fences or hurdles? -

3. Did the horse have any exercise yesterday? **Yes/None**

If yes ⇒ **Which of the following did he/she do?** (Read out options)(Tick all activities done)

Walked/Horse Walker ☐ Trotted Out ☐
Cantered ☐ Worked at a gallop ☐
Turned out in field ☐ Schooled ☐
Other ☐

If Cantered or galloped **-What distance did the horse do yesterday?_______**

4. Did the horse have any exercise today? **Yes/None**

If yes ⇒ **Which of the following did he/she do?**(Read out options) (Tick all activities done)

Walked/Horse Walker ☐ Trotted Out ☐
Cantered ☐ Worked at a gallop ☐
Turned out in field ☐ Other ☐

5. What time did the horse leave the yard to go to the racecourse? _______am/pm
6. What day did the horse leave the yard to go to the racecourse? _______

Track and Race:
Horse:

7. Which of the following best describes the state of the horse immediately after travelling to the racecourse (read out options)

Very excited/difficult to control	☐	Sweating and Excited	☐
Slightly Sweated up	☐	Alert	☐
Calm	☐		

8. Which of the following best describes the horses behaviour since arrival at the racecourse (read out options)

Calm and resting	☐	Bright, with head over door	☐
Box walking,weaving or crib biting	☐	Excited and sweating	☐

I am now going to ask you about feeding

9. When was the horses' last hard feed? Today/Yesterday ____am/pm

10. When did the horse last have hay or haylage Today/Yesterday _____am/pm

Was this a Normal/ SlightlyReduced/ Greatly Reduced **ration ?**

11. Does the horse have access to water now? YES/NO

***If yes*⇒Will water be withdrawn before racing?** YES ☐

- < 4 hours before race ☐
- 4-8 Hours before race ☐
- >8 hours before race ☐

NO ☐

***If no* ⇒ When was it withdrawn?**

- <4 hours before race ☐
- 4-8 hours before race ☐
- >8 hours ☐

And finally

12. What is your position with Mr_________?

Thank you very much for your time.

Table 1: Descriptive statistics and chi squared analyses of the categorical variables investigated in the cohort for their association with falling in hurdle and steeplechase racing on 6 UK racetracks

Variable	Controls % (n)	Cases %(n)	Odds Ratio	P-value
Racecourse				
Aintree	90(349)	10 (38)	1	
Bangor	96(547)	4(21)	0.35	
Cartmel	96(155)	4(6)	0.36	
Cheltenham	95(627)	5(33)	0.48	
Haydock	98(368)	2(7)	0.17	
Huntingdon	97(709)	3(19)	0.25	<0.001
Race month				
Jan	96(102)	4(4)	1	
Feb	98(235)	2(5)	0.54	
March	97(314)	3(10)	0.81	
April	92(425	8(35)	2.1	
May	96(480)	4(18)	0.96	
August	98(170)	2(4)	0.6	
September	96(125)	4(5)	1.02	
October	93(281)	7(21)	1.91	
November	97(400)	3(14)	0.89	
December	96(223)	3(8)	0.91	0.9
Race type				
Steeplechase	92(1131)	8(92)	1	
Hurdle	98(1624)	2(32)	0.24	<0.001
Hurdle padded				
No	98(846)	2(17)	1	
Yes	98(778)	2(15)	0.9	0.9
Novice				
No	96(1737)	4(72)	1	
Yes	95(1018)	5(52)	1.23	0.2
Handicap				
No	95(1055)	5(50)	1	
Yes	96(1700)	4(74)	0.92	0.6
Maiden				
No	96(2629)	4(121)	1	
Yes	98(126)	2(3)	0.52	0.3
Selling				
No	96(2686)	4(124)	1	
Yes	100(69)	0(0)	0	0.07
Claiming				
No	96(2748)	4(123)	1	
Yes	88(7)	12(1)	3.19	0.3
Race class				
A	92(289)	8(24)	1	
B	95(395)	5(19)	0.58	
C	93(241)	7(17)	0.85	
D	96(758)	4(31)	0.49	
E	96(545)	4(20)	0.44	
F	97(450)	3(13)	0.35	
G	100(68)	0(0)	0	
H	100(9)	0(0)	0	<0.001

Variable	Controls % (n)	Cases %(n)	Odds Ratio	P-value
Track surface(going)				
Good to firm	97(309)	3(11)	1	
Good	95(1024)	5(59)	1.62	
Good to soft	97(527)	3(18)	0.96	
Soft	97(661)	3(21)	0.89	
Heavy	94(234)	6(15)	1.8	0.04
Going changed on race day?				
No	96(2129)	4(92)	1	
Yes	95(626)	5(32)	1.18	0.4
Horse gender				
Female	98(374)	2(9)	1	
Male	95(2381)	5(115)	2.00	0.04
Jockey changed on day of race?				
No	96(2613)	4(120)	1	
Yes	97(142)	3(4)	0.61	0.3
Weather				
Cloud	97(1501)	3(49)		
Sun	94(919)	6(56)	2.8	
Rain	95(335)	5(19)	3.1	0.005
Season				
Summer	97(775)	3(27)		
Winter	95(1980)	5(97)	1.4	0.1
Speed c.f. the average for that race				
Slow	96(1933)	4(83)	1	
Medium	94(101)	6(7)	1.61	
Fast	96(721)	4(34)	1.1	0.5

Table 2: Descriptive statistics and chi squared analyses of the categorical variables from the questionnaire investigated in the cohort for their association with falling in hurdle and steeplechase racing on 6 UK racetracks.

Variable	Controls %(n)	Cases %(n)	Odds ratio	P-value
Entered racecourse stables				
No	96(45)	4(2)	1	
Yes	96(1910)	4(81)	0.95	0.9
Days since last shod				
Less than 2	96(909)	4(36)	1	
3-7	95(603)	5(31)	1.3	
7-28	96(246)	4(9)	0.92	
>28	75(3)	(1)	8.42	0.1
Exercise day prior to racing				
No	94(34)	6(2)	1	
Yes	96(1784)	4(76)	0.72	0.7
Walked yesterday				
No	96(1454)	4(61)		
Yes	96(352)	4(16)	1.1	0.8

Variable	Controls %(n)	Cases %(n)	Odds ratio	P-value
No	96(1632)	4(70)	1	
Yes	96(174)	4(7)	0.94	0.9
Cantered yesterday				
No	96(661)	4(29)	1	
Yes	96(1149)	4(48)	0.95	0.8
Galloped yesterday				
No	96(1391)	4(62)	1	
Yes	96(418)	3(15)	0.81	0.5
Turned out yesterday				
No	96(1666)	4(72)	1	
Yes	97(143)	3(5)	0.81	0.6
Schooled yesterday				
No	96(1681)	4(72)	1	
Yes	96(128)	3(5)	0.91	0.8
Exercise today				
No	96(1170)	4(48)	1	
Yes	96(658)	4(30)	1.11	0.7
Walked today				
No	96(1276)	4(56)	1	
Yes	96(551)	4(21)	0.87	0.6
Trotted today				
No	96(1799)	4(77)	1	
Yes	100(28)	0(0)	0	0.3
Cantered today				
No	96(1756)	4(71)	1	
Yes	92(71)	8(60)	2.09	0.08
Galloped today				
No	96(1822)	4(77)	1	
Yes	100(5)	0(0)	0	0.5
Turned out today				
No	96(1801)	4(77)	1	
Yes	100(26)	0(0)	0	0.3
Behaviour after travel				
Excited and sweating	98(108)	2(2)	1	
Bright and alert	97(223)	3(8)	1.94	
Calm	95(1116)	5(55)	2.66	
Slight sweating	97(377)	3(13)	1.86	0.4
Behaviour in box				
Calm	96(1258)	4(51)	1	
Bright and alert	96(486)	4(22)	1.12	
Box walking, weaving	100(23)	0(0)	0	
Sweating and excited	95(56)	5(3)	1.32	0.7
Size last hay ration				
Normal	97(1091)	3(39)	1	
Less than normal	96(693)	4(32)	1.15	0.3
Water withheld				
No	96(256)	4(11)	1	
Yes	96(1572)	4(67)	0.99	0.9
Time before racing water withheld				
Zero hours	96(256)	4(11)	1	
Less than 4 hours	96(1135)	4(48)	0.98	
4-8 hours	96(431)	4(17)	0.92	
Greater than 8 hours	86(6)	14(1)	3.88	0.6

Table 3: Descriptive statistics and chi squared analyses of the categorical variables from parade ring observations investigated in the cohort for their association with falling in hurdle and steeplechase racing on 6 UK racetracks

Variable	Controls %(n)	Case%(n)	Odds Ratio	P-value
Sweating on entry to parade ring				
No	96(2524)	4(114)	1	
Yes	96(186)	4(8)	0.9	0.9
Sweating on exit from parade ring				
No	96(2171)	4(93)	1	
Yes	95(244)	7(13)	1.2	0.5
Locomotion on entry to parade				
Walking calmly	96(2571)	4(119)	1	
Other	97(155)	3(5)	0.7	0.4
Locomotion on exit from parade ring				
Walking calmly	96(2198)	4(90)	1	
Other	93(216)	7(16)	1.82	0.03
Abnormal behaviour on entry to parade ring				
None	96(2579)	4(114)	1	
Head shaking	94(145)	6(10)	1.56	0.9
Abnormal behaviour on exit from parade ring				
None	96(2126)	4(89)	1	
Head shaking	95(294)	5(17)	1.38	0.4
Bandages fore				
No	95(2547)	4(121)	1	
Yes	98(181)	2(3)	0.35	0.06
Bandages hind				
No	96(2665)	4(123)	1	
Yes	98(65)	2(1)	0.33	0.23
Boots fore				
No	95(876)	5(42)	1	
Yes	96(1854)	4(82)	0.92	0.7
Boots hind limbs				
No	96(2198)	4(10)	1	
Yes	96(531)	8(21)	0.84	0.5
Head gear				
None	96(2431)	4(106)	1	
Blinkers	94(208)	6(14)	1.54	
Visor	97(113)	3(4)	0.81	0.3
Tongue strap				
No	96(2565)	4(114)	1	
Yes	95(188)	5(10)	1.2	0.6
Shod behind				
Yes	96(2112)	4(94)	1	
No	97(320	3(1)	0.7	0.7
Abnormal shoeing				
No	96(1764)	4(79)	1	
Yes	96(380)	4(16)	0.94	0.8

Variable	Controls %(n)	Case%(n)	Odds Ratio	P-value
Hoof conformation				
Normal	96(1773)	4(79)	1	
Long feet/low heels	96(327)	4(13)	1.13	
Boxy feet	94(44)	6(3)	1.53	0.4
Tendon fired				
No	96(2130)	4(93)	1	
Yes	88(14)	12(2)	3.27	0.1
Number handlers				
One	96(2703)	4(121)	1	
Yes	94(44)	6(3)	1.52	0.5

Table 4: Descriptive statistics and univariable logistic regression analyses of the continuous variables investigated in the cohort study for their association with falling in hurdle and steeplechase racing on 6 UK racetracks.

	Univariable Log Reg.		Controls				Cases			
Variable	OR	p-value	Mean	St Dev	Min	Max	Mean	St Dev	Min	Max
Race Distance	1.1	<0.001	20.7	3.6	16	36	22.8	5.3	16	36
Horse age	1.1	0.04	7.1	2.1	3	15	7.5	1.9	3	12
Race speed (furlongs/minute)	0.2	<0.001	4.0	0.3	3.1	4.5	3.9	0.3	3.2	4.5
Horses rating	1.002	0.2	77.3	49.6	0	175	83.2	50.9	0	168
Days since last ran	1.0	0.5	87.1	156.7	1	2751	76.1	138.7	1	1143
Weight Carried	1.0	0.9	151.9	8.3	133	175	151.9	7.7	133	168
Rainfall	1.04	0.02	2.0	4.2	0	17	2.9	5.4	0	17
Schooling freq	0.9	0.7	2.6	2.6	0	25	2.5	2.5	0	12
Distance exercised yesterday	0.9	0.2	6.3	4.8	0	36	5.6	4.0	0	16
Journey time(hours)	1.2	<0.001	180.1	114.7	0	960	226.4	126.8	55	750
Time from arrival to race	1.02	0.004	327.4	527.5	0	6480	515.3	787.6	50	3855
Last hard feed (hours)	1.02	0.6	10.0	4.1	1.0	46.0	10.3	4.1	1.0	22.0
Last access to hay	0.9	0.5	20.5	4.4	0.0	36.0	20.3	5.0	6.0	27.0

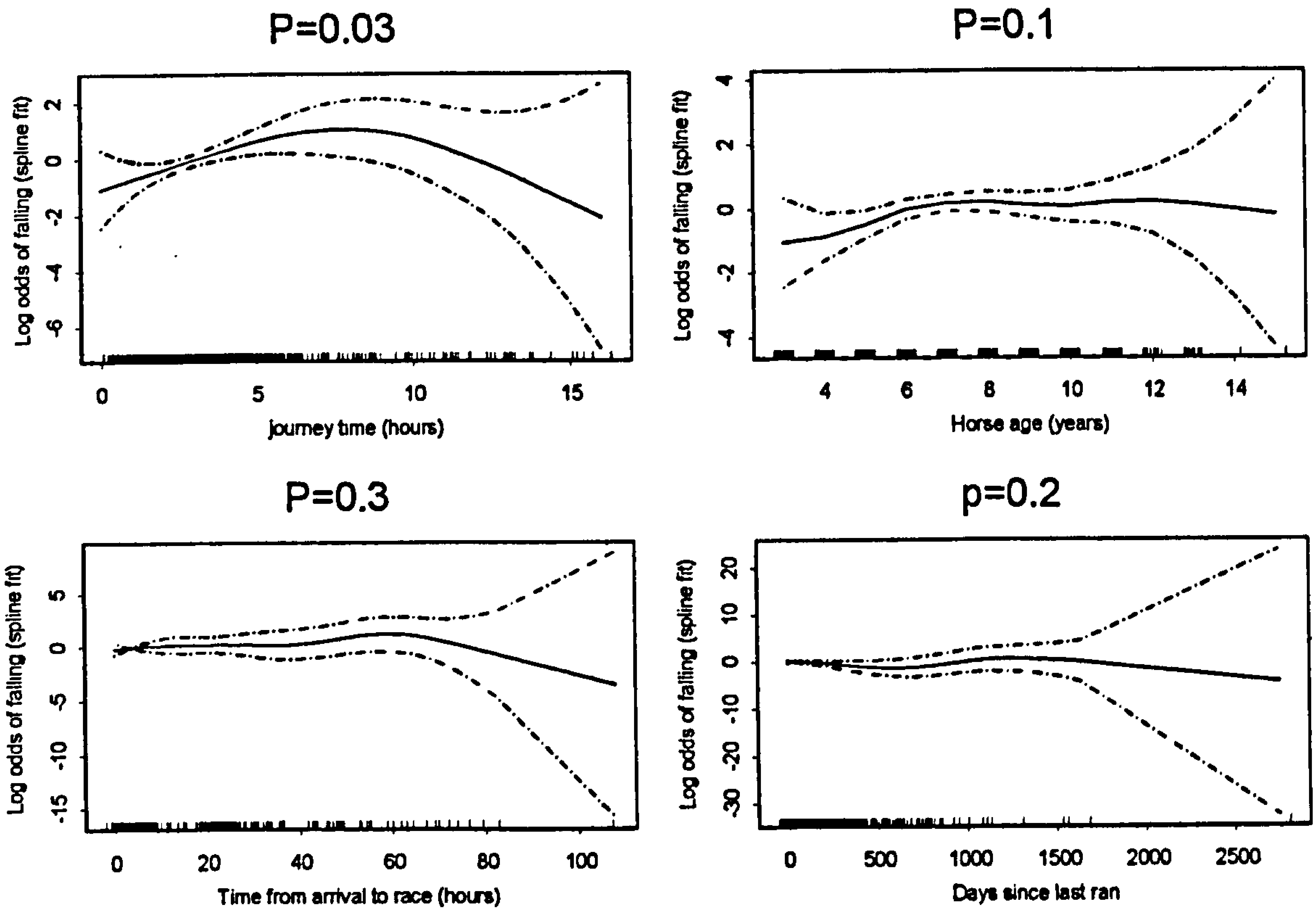


Fig 1: Graphs representing the functional forms of the continuous variables modelled using generalised additive models (where the continuous fixed effects are fitted using smoothers) to determine the shape of the relationship between the predictor variable and the outcome (log odds of falling during a steeplechase race). The plots show the fitted curves with 95% confidence intervals (dashed lines). The rug plots along the x-axis represent the number of data points. The P value is a chi-square for non-linearity (e.g. for journey time chi-square 8.88 on 3 degrees of freedom).

Multilevel modelling

Variance estimates presented in manuscript 3 were obtained using MCMC estimation techniques. Comparative estimates using maximum likelihood estimates in Egret and penalised quasi-likelihood techniques were also obtained. Where possible second-order Taylor series expansion was used as this provides the most unbiased estimates of regression terms and variance estimates. However, 1st order PQL models were used when 2nd order would not converge. An earlier study (Rodriguez and Golmad 1995) showed that estimates from some of the iterative least squares algorithms for random effects models could be biased towards the null and a more recent study by Dohoo et al (2000) found similar underestimation's using second order predictive quasi-likelihood estimates in MLWin. Therefore MCMC estimation techniques were used for subsequent two and three level models as quasi-likelihood estimates can be unreliable and the maximum likelihood estimates were computationally slow and could not be used for models with greater than 2 levels.

To estimate the proportion of variation attributable to each level of clustering, intra-class correlation coefficients were calculated. Although intra-class correlation coefficients presented in the manuscript were calculated using a latent variable approach this method, which assumes that the binary response is derived from an underlying continuous variable, may be less justified for a truly discrete response such as falling or not falling. Comparative estimates using three other methods as described by Goldstein et al. (2000) are presented in Table 5. The simulation method, the model linearisation methods and binary linear model all provided similar estimates. Calculations using the latent variable approach provided higher estimates, which is consistent with results from previous studies (Christley et al. 2002; Pinchbeck et al. 2002b)

Table 5. Comparison of variance estimates using three different methods and intra-class correlation coefficients using four different methods for all five random effects for both race types and for race for steeplechasing only.

	Variance estimate			Intra-class correlation coefficient			
	Estimate Egret	Estimate PQL	Estimate MCMC	Model linearisation	Simulation	Latent variable approach	Binary linear model
Race	1.06	0.72	1.07	2.8	5.3	24.6	4.9
Track	0.64	0.26	0.558	2.1	3.1	14.5	2.4
Horse	0	0	-	-	-		
Jockey	0	0	-	-	-		
Trainer	0	0	-	-	-		
Chase race	0.62	0.44*	0.62	3.2	4.8	15.8	4.4

* 1st order PQL

Journey times at different racecourses

Track and race did have a small effect on the coefficients of journey time and this suggests a difference in the journey time to particular tracks and for particular races. Table 6 shows the mean and range of journey time for each race tack. Aintree, which has a higher risk of falling than the other tracks, also has the highest mean travel times. It may be that trainers are prepared to travel further for higher prize money races.

Table 6: Mean and range of journey times to the six different racecourses

Track	Mean journey time	Range of journey times
Aintree	4.0	0.2-13
Bangor-On-Dee	2.9	0.5-10
Cartmel	3.0	0.0-8.0
Cheltenham	3.1	0.1-16.0
Haydock	3.0	0.7-11.2
Hunt	2.6	0.3-10.1

Assessing the fit of the models

When models were fitted using Markov Chain Monte Carlo (MCMC) simulations with Metropolis-Hastings sampling the fit of the final model was assessed by examination of the posterior distributions of the fixed and random variables. The number of iterations used was determined by Brooks-Draper Nhat statistic which estimates the number of iterations required to give certainty about estimates for the means and the 97.5th and 2.5th quantiles. All fits were smooth and regular and all chains mixed well for all fixed-effect variables. An example of the output from the multivariable model presented in manuscript 3 of the steeplechase data (table 4) is shown below.

Figure 2: Example of output from MCMC model of steeplechasing (including fixed and random effects) in Mlwin with a burn-in of 100000 and 500000 iterations. The first figure shows the model output, the second figure the intervals and tests and the remaining figures show the MCMC diagnostics for each variable. (The upper left-hand cell is the whole trace for the parameter and a healthy sampling trace should look like white noise. The upper right hand cell gives a kernel density estimate of the posterior distribution which should have an approximately Normal distribution. The second row of boxes plot the auto-correlation (ACF) and the partial auto correlation (PACF). For example distance has a first order auto-correlation of 0.7. In the third row the left-hand box is the plot of the estimated Monte Carlo standard error (MCSE) of the posterior estimate of the mean against the number of iterations. The right hand box shows two accuracy diagnostics. The Raferty Lewis diagnostic (Raferty and Lewis 1992) is based on particular quantiles of the distribution. The diagnostic Nhat is used to estimate the Markov chain length required to estimate the 2.5% and 97.5% quantiles. The Brooks Draper diagnostic is a diagnostic based on the mean of the distribution and estimates the length of Markov chain required to produce mean estimate to K significant figures (2 in the example s below) with a given accuracy (.05). The bottom box has numerical summaries of the data such as mean and the 95% central intervals (Bayesian credible interval)).

$$\mathrm{casecon}_{runid,\,track} \sim \mathrm{Binomial}(\mathrm{denom}_{runid,\,track},\ \pi_{runid,\,track})$$

$$\mathrm{casecon}_{runid,\,track} = \pi_{runid,\,track} + e_{0runid,\,track}\mathrm{bcon}^{*}_{runid,\,track}$$

$$\begin{aligned}\mathrm{logit}(\pi_{runid,\,track}) = {} & \beta_{1track}\mathrm{cons} + -0.224(0.487)\mathrm{goodtofirm}_{runid,\,track} + \\ & -0.793(0.357)\mathrm{goodtosoft}_{runid,\,track} + -0.720(0.345)\mathrm{soft/heavy}_{runid,\,track} + \\ & 0.675(0.255)\mathrm{novyes}_{runid,\,track} + 0.591(0.259)\mathrm{sun}_{runid,\,track} + \\ & 0.464(0.400)\mathrm{rain}_{runid,\,track} + 0.076(0.032)\mathrm{racedist}_{runid,\,track} + \\ & -0.241(0.077)\mathrm{horseage}_{runid,\,track} + 0.072(0.032)\mathrm{rainfall}_{runid,\,track} + \\ & 0.476(0.358)\mathrm{trotting}_{runid,\,track}\end{aligned}$$

$$\beta_{1track} = -2.865(0.939) + u_{1track}$$

$$\left[u_{1track}\right] \sim \mathrm{N}(0,\ \Omega_u) \ :\ \Omega_u = \left[0.197(0.433)\right]$$

$$\mathrm{bcon}^{*}_{runid,\,track} = \mathrm{bcon}_{runid,\,track}[\pi_{runid,\,track}(1 - \pi_{runid,\,track})/\mathrm{denom}_{runid,\,track}]^{0.5}$$

$$[e \quad] \sim (0,\ \Omega_e) \ :\ \Omega_e = [1.000(0.000)]$$

Model output

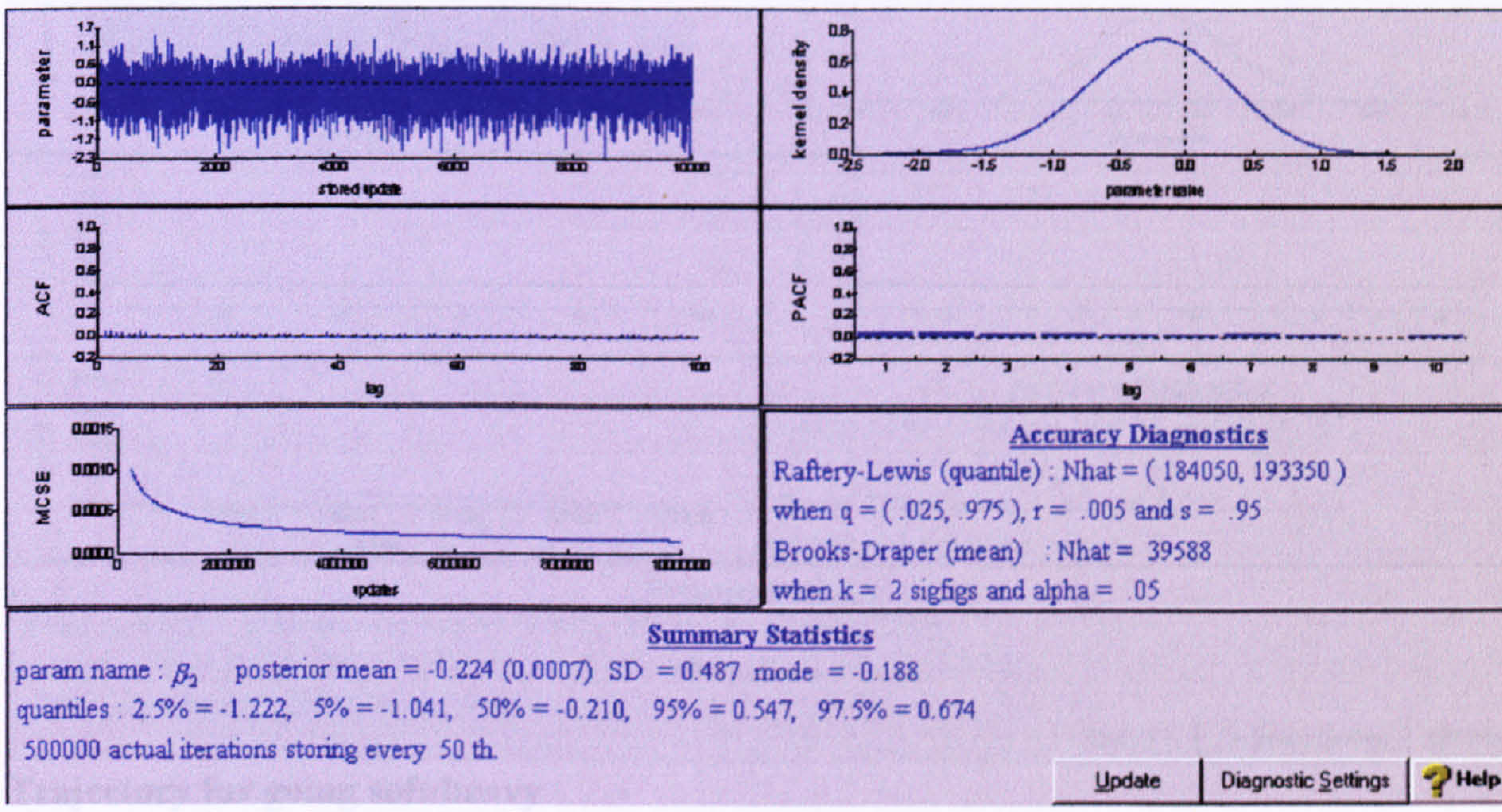
Intervals and tests

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
fixed : cons	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
fixed : goodtofirm	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
fixed : goodtosoft	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
fixed : soft/heavy	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
fixed : novyes	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
fixed : sun	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
fixed : rain	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
fixed : racedist	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
fixed : horseage	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
fixed : rainfall	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
fixed : trotting	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
constant(k)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
function result(f)	-0.224	-0.793	-0.720	0.675	0.591	0.464	0.076	-0.241	0.072	0.476
f-k	-0.224	-0.793	-0.720	0.675	0.591	0.464	0.076	-0.241	0.072	0.476
chi sq, (f-k)=0. (1df)	0.211	4.921	4.359	6.983	5.203	1.345	5.762	9.783	5.162	1.767
+/- 95% sep.	0.954	0.700	0.676	0.501	0.508	0.784	0.062	0.151	0.062	0.702
+/- 95% joint	2.084	1.529	1.475	1.093	1.108	1.712	0.136	0.330	0.136	1.532

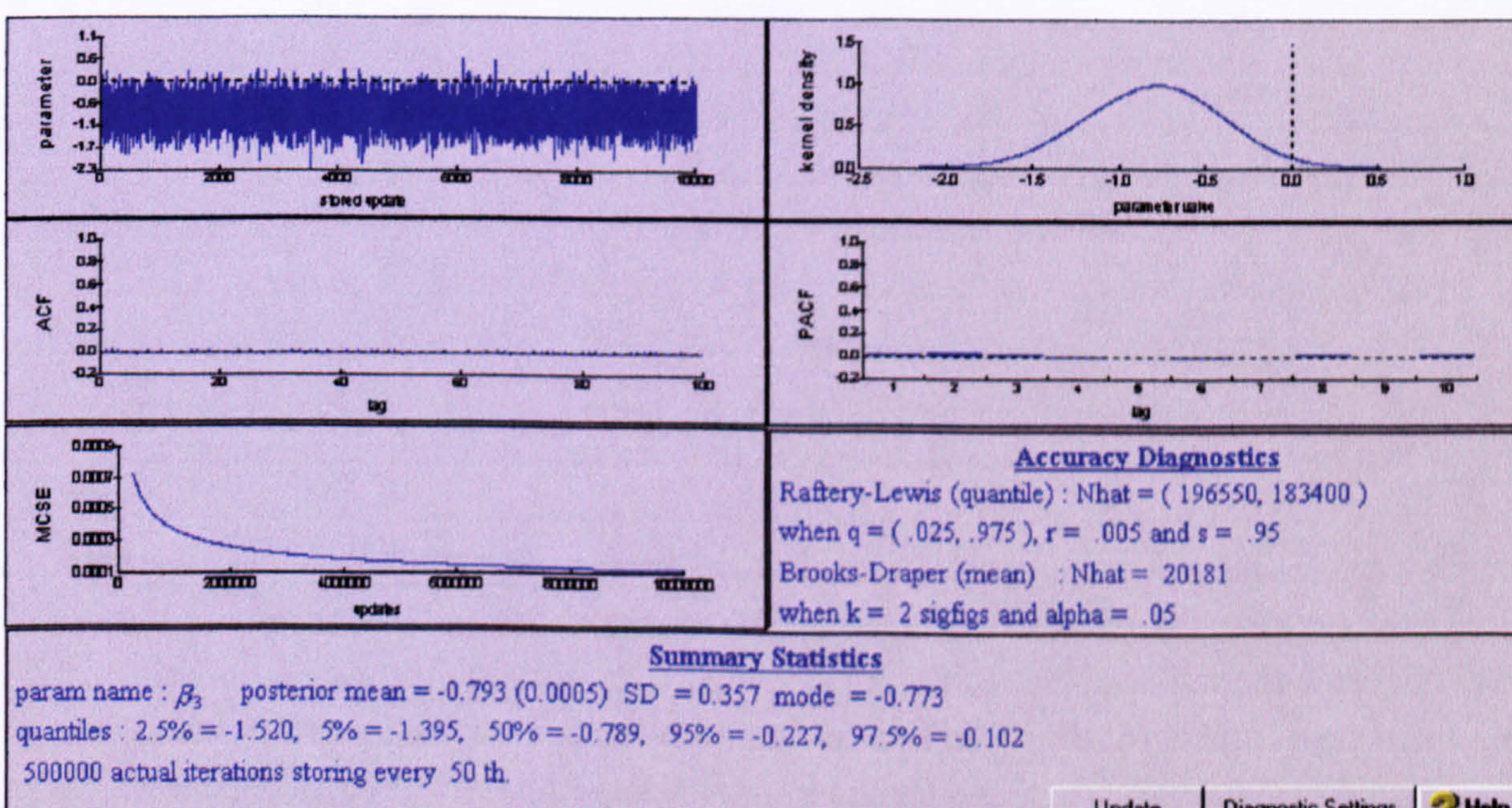
joint chi sq test(10df) = 45.496

random / fixed # of functions 10

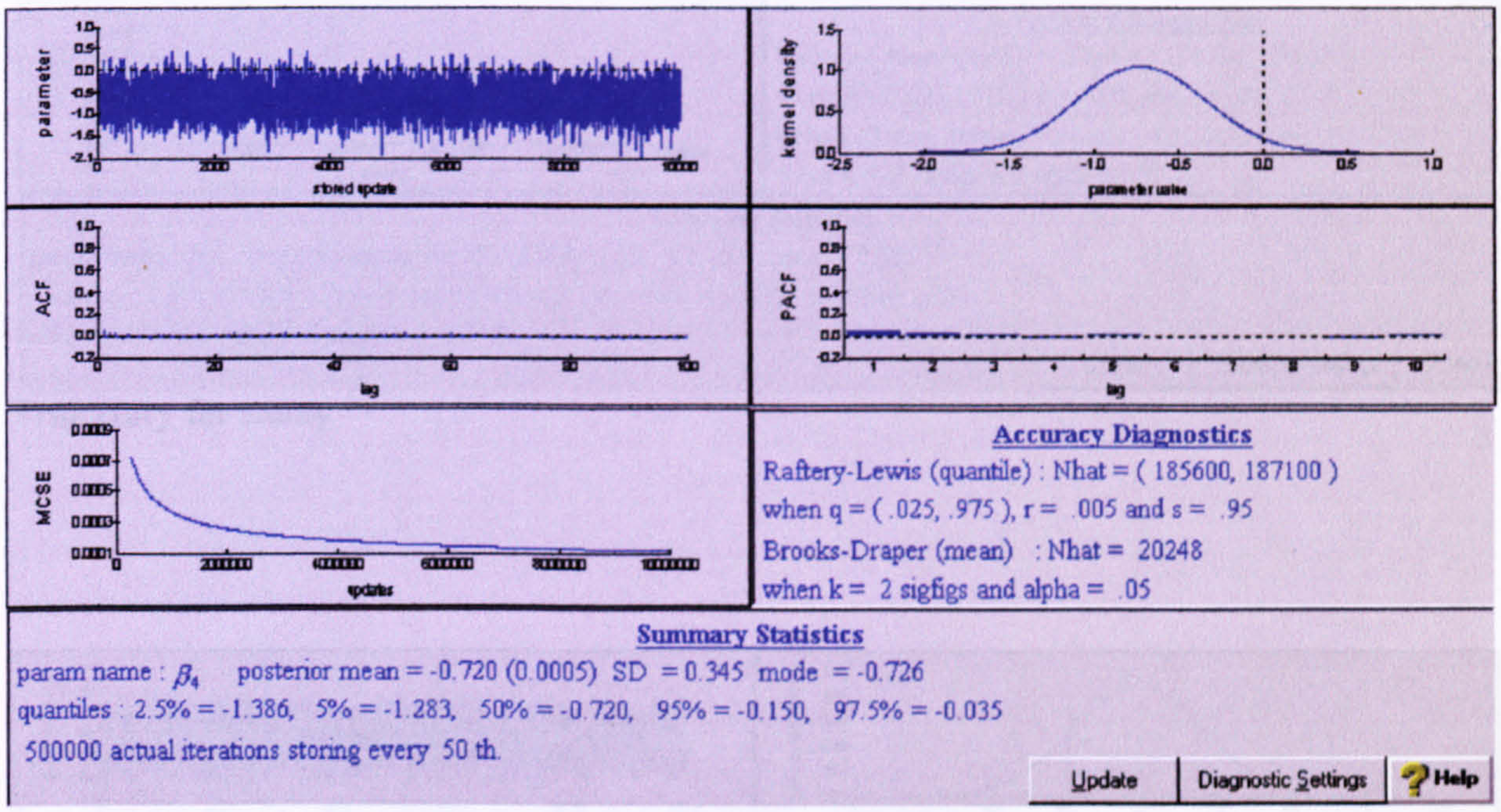
Intervals and tests



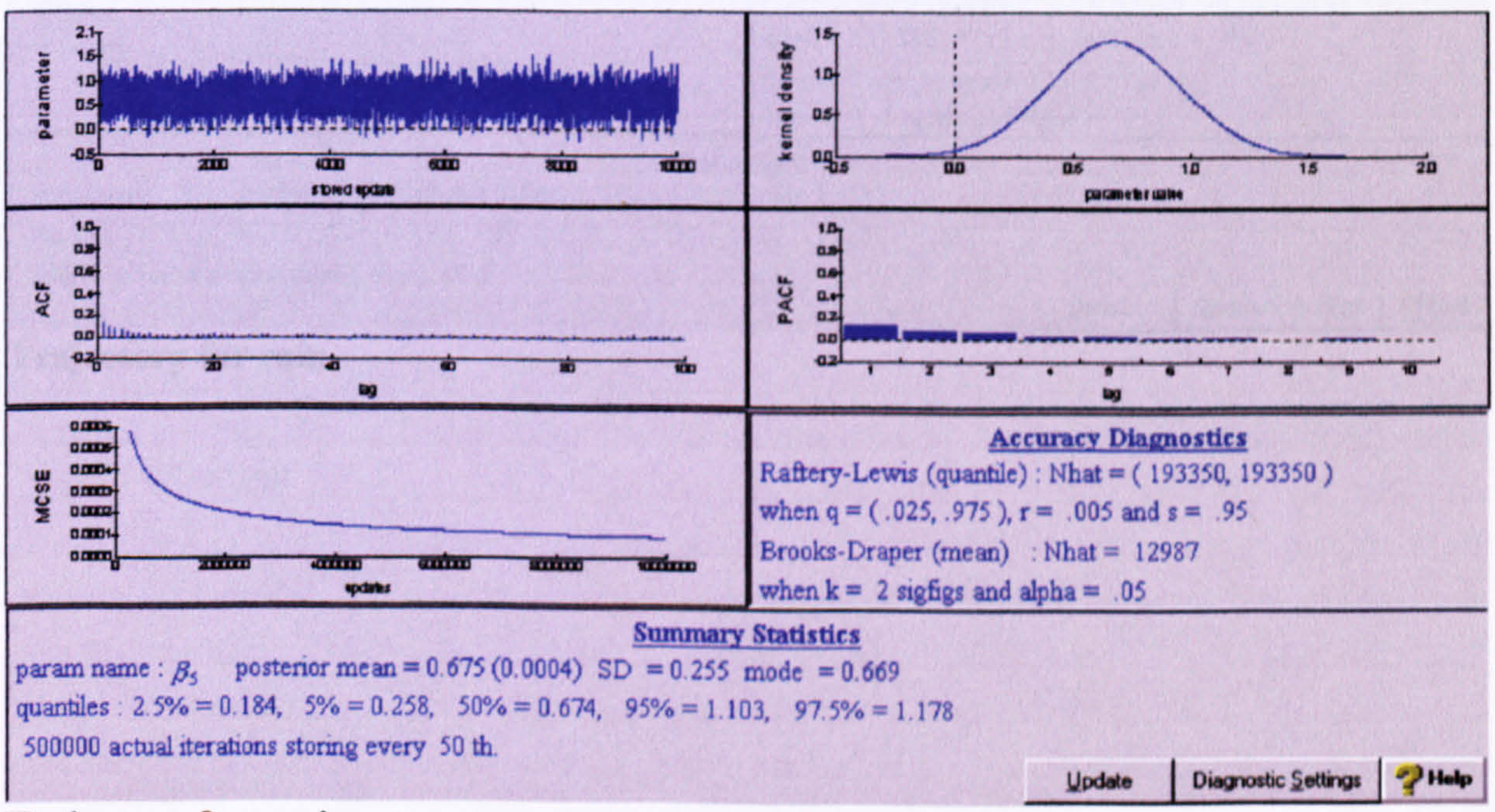
Trajectory for going good to firm



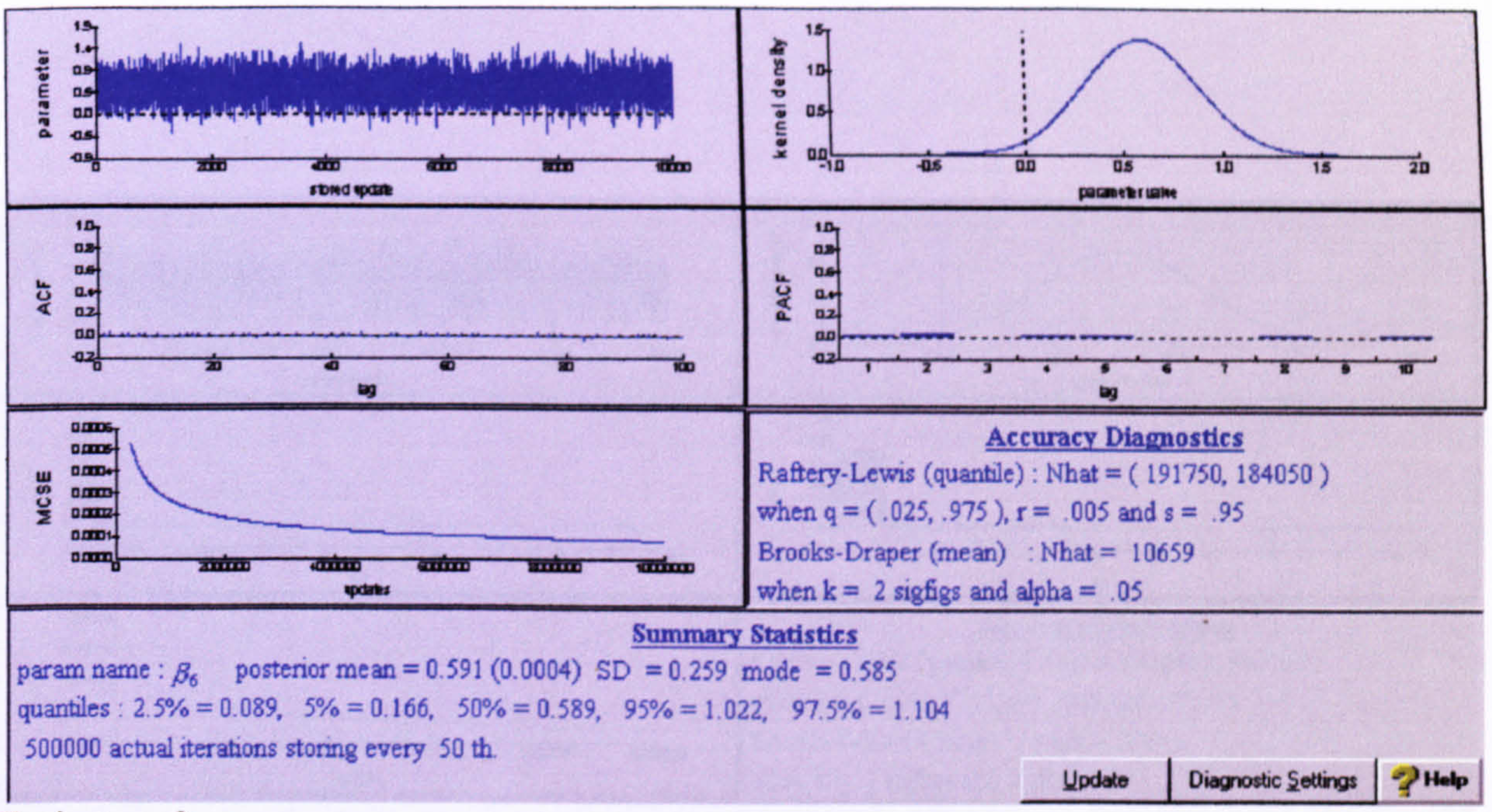
Trajectory for going good to soft



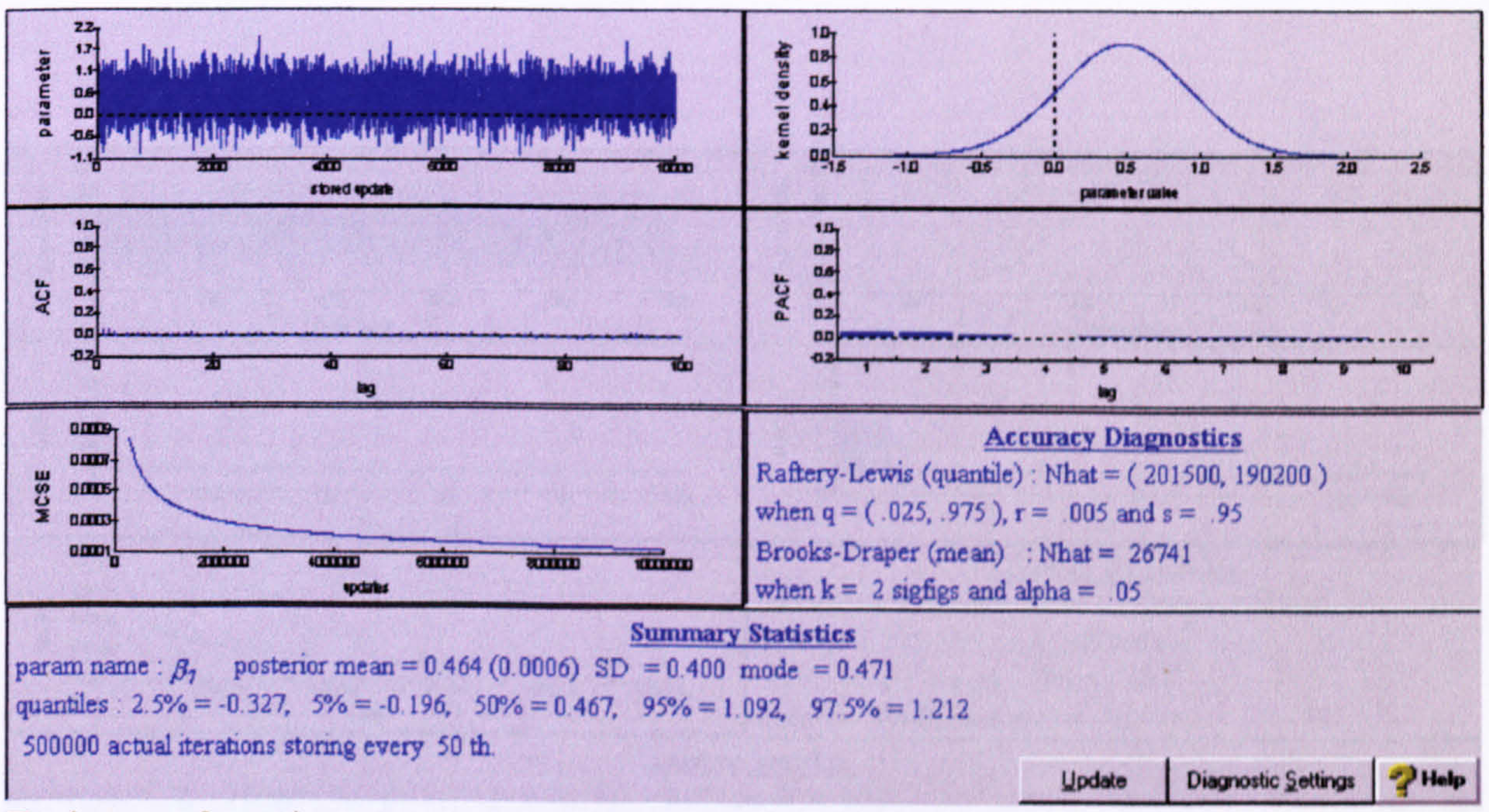
Trajectory for going soft/heavy



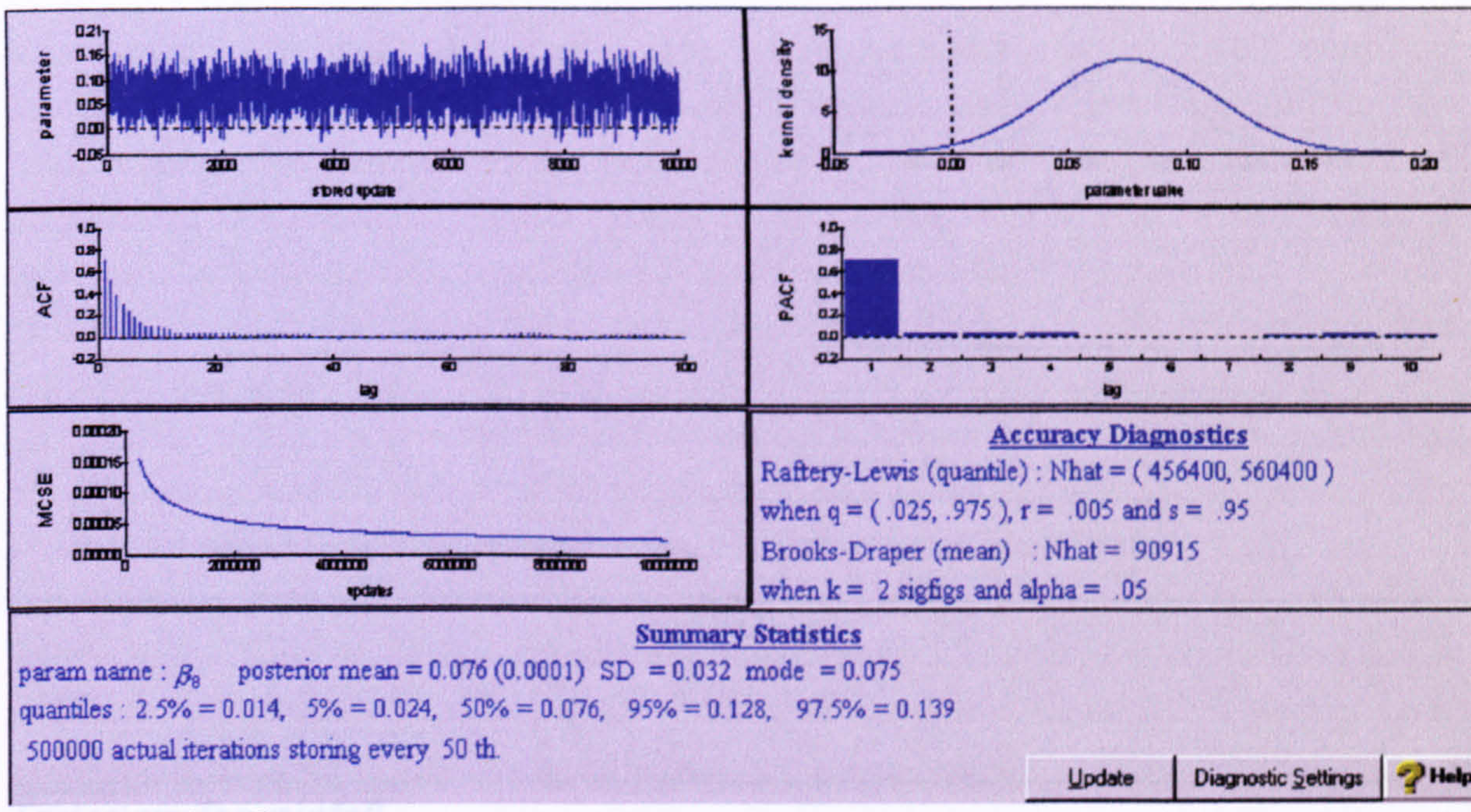
Trajectory for novice



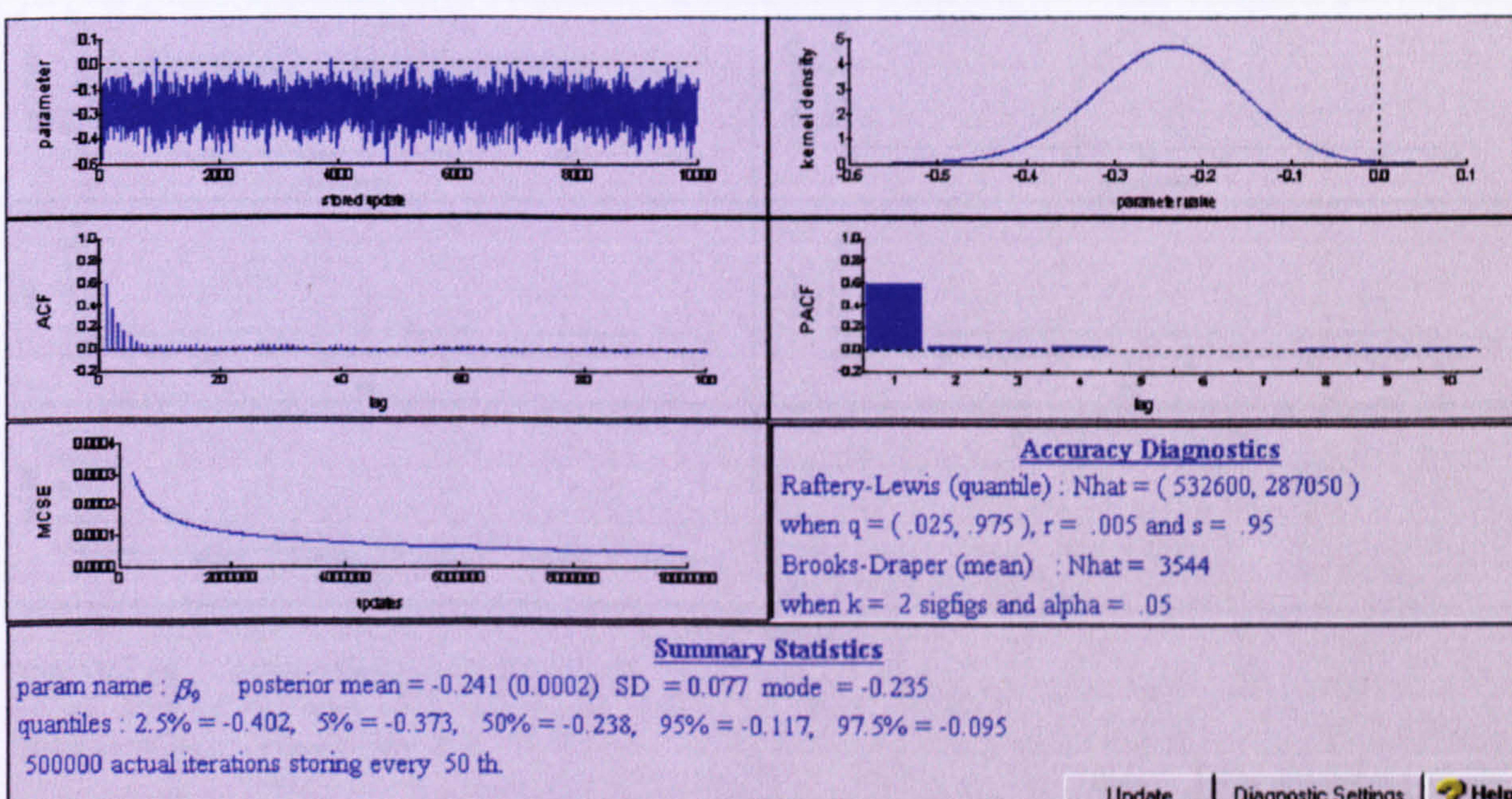
Trajectory for sunny



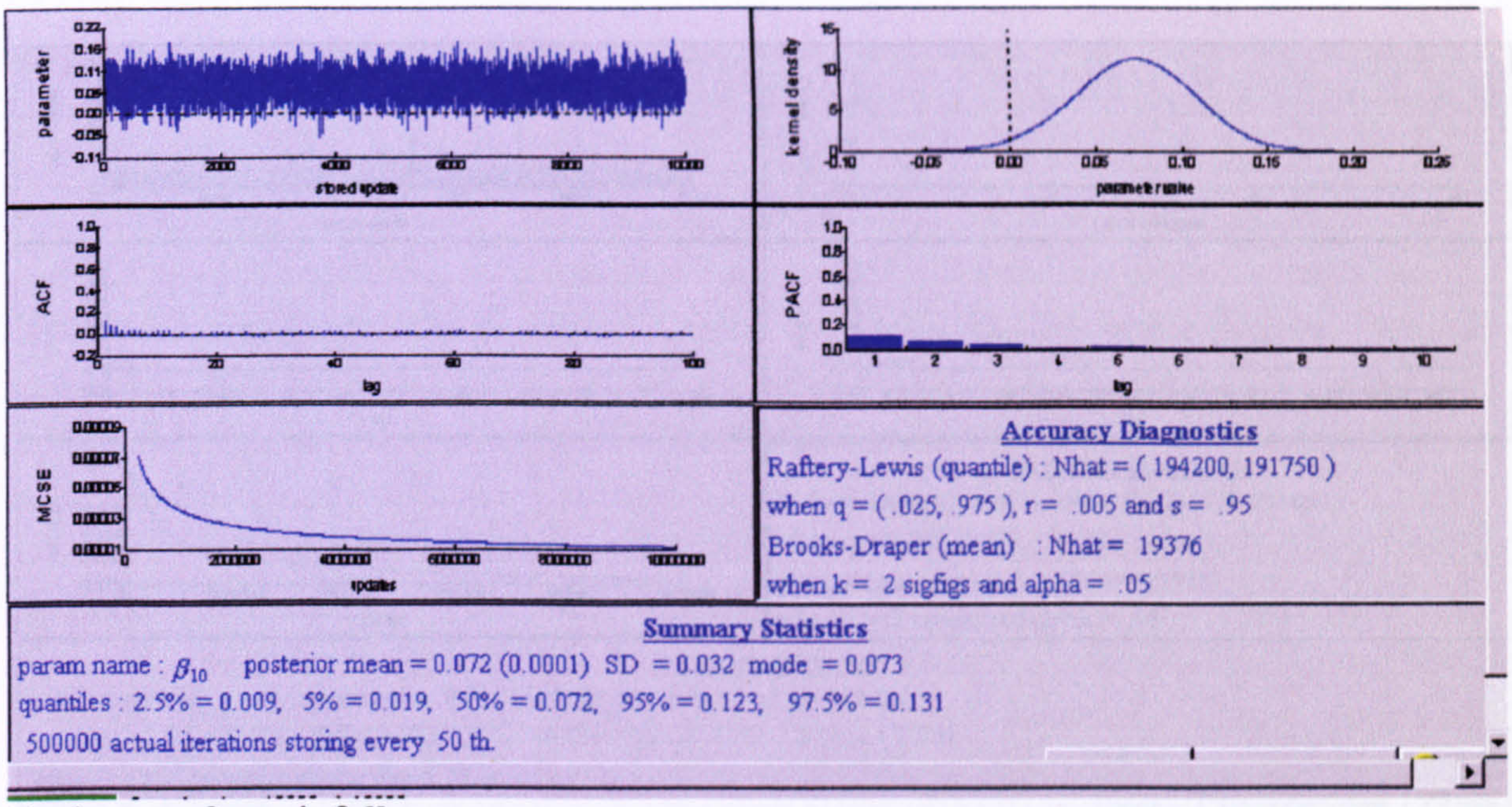
Trajectory for rain



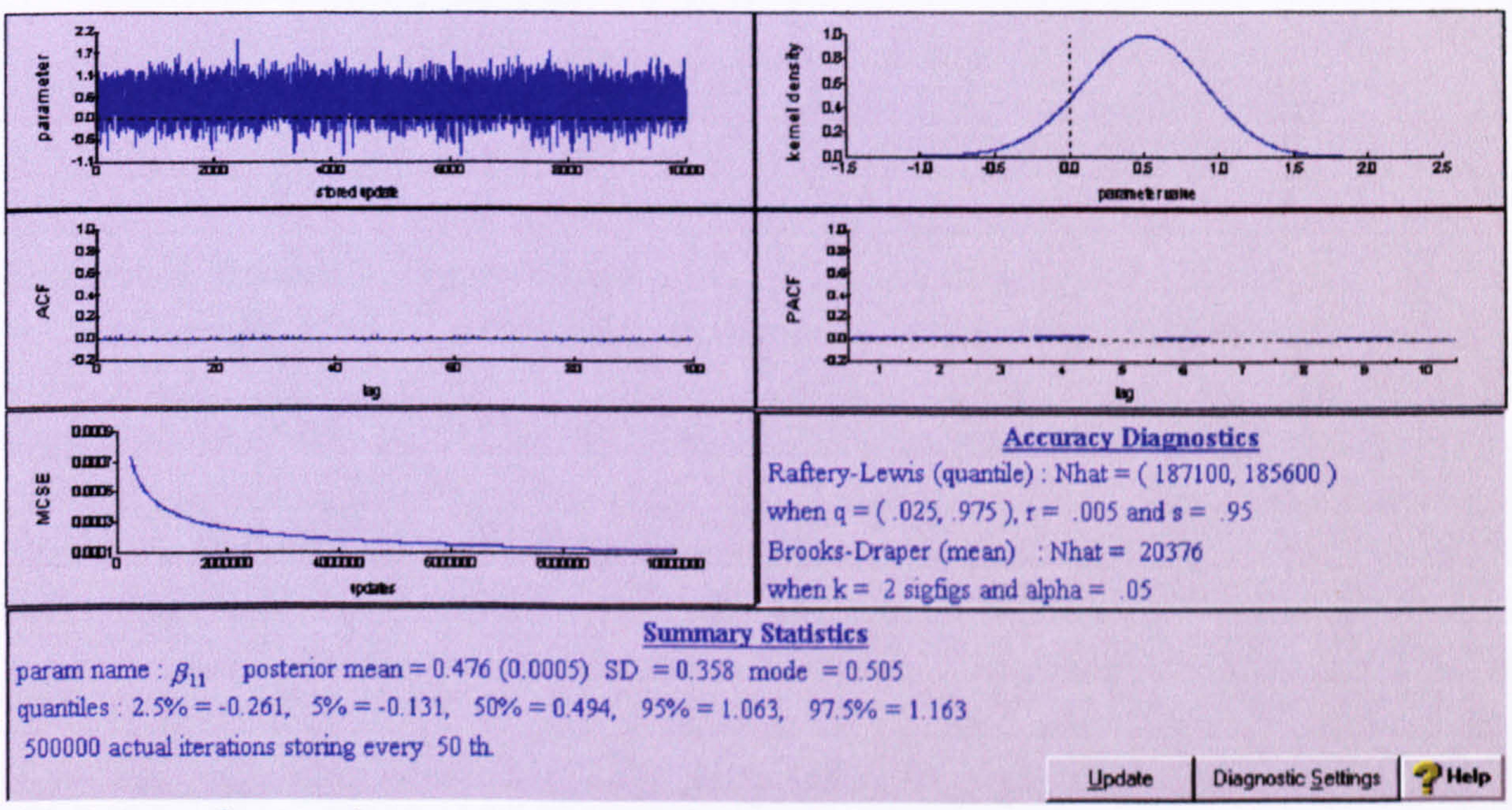
Trajectory for distance



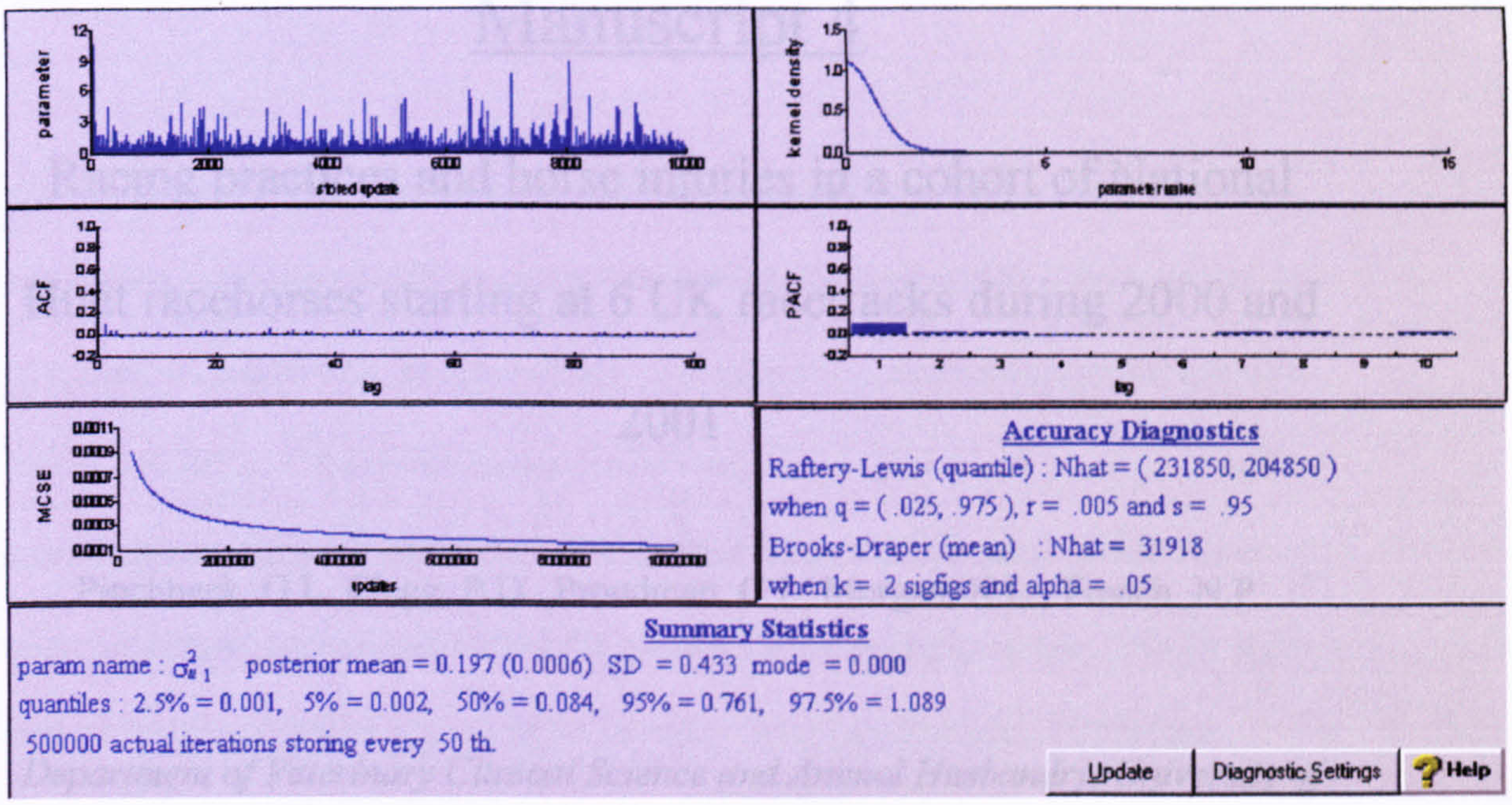
Trajectory for age



Trajectory for rainfall



Trajectory for trotting



Trajectory for track (random effect)

Manuscript 4

Racing practices and horse injuries in a cohort of National Hunt racehorses starting at 6 UK racetracks during 2000 and 2001

Pinchbeck, G.L. Clegg, P.D., Proudman, C.J., Morgan, K.L., French. N.P.

Department of Veterinary Clinical Science and Animal Husbandry, University of Liverpool, Leahurst, Neston, CH64 7TE, UK.

Corresponding Author. G.L.Pinchbeck

Key words: Racehorse; Injury; Cohort

Abstract

A prospective cohort study was conducted on horses starting in hurdle and steeplechase races on 6 UK racecourses during 2000 and 2001. Trainers or carers were questioned on the horses' pre-race routine and observational data were collected in the stables and parade ring. Some practices were common to many starters, such as withholding food and water before racing, whereas other practices, such as schooling frequency, were more variable. There were a total of 2879 starts and a total of 83 injuries or medical events (28.8/1000 starts). The commonest types of injury were tendon/suspensory injuries and lacerations/wounds. There were also total of 23 medical events. Multivariable logistic regression models were used to identify the relationship between predictor variables and the risk of injury. Risk of injury including medical event was associated with distance of the race, weight carried and access to water. The risk of injury, excluding medical events, was associated with the speed of the race and hoof conformation.

Introduction

Numerous studies have been performed in the USA and Australia to investigate risk factors for injuries, particularly musculoskeletal injuries, in racing Thoroughbreds (Mohammed et al. 1991, Peloso et al. 1994; Kane 1996; Bailey et al. 1997; Bailey et al 1998; Cohen et al. 2000). These studies identified a number of potential risk factors including age, number of previous starts, race distance, race class, track surface, shoe type and exercise intensity. However, there have been limited studies on injuries sustained by horses racing in the UK. Wood et al. (2000) and Wood et al. (2002) performed a comprehensive study to describe risk factors for fatalities in all race types in the UK over a 10-year period. This study of over 2000 fatalities and over 700,000 starts identified various risk factors for fatality in hurdling and steeplechasing such as age and age at first start, the track surface condition (going), racing frequency and speed. However this study did not seek to identify risks for particular causes of fatality and it excluded non-fatal injuries. Williams et al. (2001) described injuries sustained on UK racecourses over a 3-year period but did not attempt to identify risk factors using multivariable techniques. However they did highlight many differences in injury rates between flat racing and jump (hurdling and steeplechasing) racing in the UK. For example, the frequencies of carpal and pelvic injuries were much higher in horses racing on the flat whereas the frequency of both tendon injuries and spinal injuries were higher in hurdlers and steeplechasers. This suggests a different aetiology for injuries in horses racing over jumps, which warrants investigation. Current studies are seeking to gain information regarding training practices and exercise intensity particularly in relation to the development of stress fractures (Boston and Nunamaker 2000, Verheyen et al. 2001, Parkin et al 2002).

In this study we report frequencies of management practices immediately prior to racing and of observations at the racecourse in a cohort of horses racing on 6 UK National Hunt racecourses. We also report on the frequency of types of injuries and the findings from multivariable logistic regression analyses to identify risk factors for these injuries.

Materials and methods

Study design and data collection

The prospective cohort used for this study was the same as that described in manuscript 3 and data and variable collection was identical to that described in manuscript 3

Identification of cases and controls

Cases were defined as any horse in any start that suffered an injury or medical event that was recorded by the Veterinary Officer (veterinary surgeon employed by the Jockey Club) attending the race meeting. Veterinary officers completed standardised report forms (see appendix to Manuscript 4) for all injuries, accidents and medical events observed or attended by them, or veterinary surgeons employed by the racecourse, on the day of racing. The information was then entered onto a central database. There is likely to be some under-reporting especially of particular conditions. For example horses with cardiac abnormalities (e.g. atrial fibrillation) would not be examined unless there was a specific request from the trainer. Also horses that did not show clinical signs of, for example, lameness until after leaving the racing yard would not be recorded. Non-cases were all horses that started in the races and did not suffer an injury or medical event recorded on the racetrack.

Statistical analysis

Univariable screening of all variables and their association with injury was performed using the chi-squared test for categorical variables and the univariable logistic regression model for continuous variables. Variables with a p-value<0.25 were considered for inclusion in multilevel multivariable models which were built using backward elimination procedures where variables remained in the models if they significantly improved the fit if the model (assessed by the change in deviance) or if removal resulted in substantial change to the effect of other variables. The critical probability throughout was 0.05. The goodness-of-fit of the models was assessed using the Hosmer-Lemeshow test statistic (Hosmer and Lemeshow 2000). The software packages EGRET (Egret Application 2.0, Cytel Software Corporation) and Minitab (Minitab 13.1) were used for all statistical analyses.

Results

Data were collected on 2879 starts by 2216 horses, trained by 334 trainers.

Racing Practices

A small proportion (2.3%) of horses racing did not enter the stable yard at the racecourse and went from the transport box directly to the parade ring. Approximately half the horses (51.4 %) were shod within 2 days prior to racing and only 0.2% of carers reported that it was greater than 4 weeks since the horse was last shod. Almost all horses (98%) received some exercise the day before racing and 82 % cantered or did gallop work on the day before racing. Only 8% reported that their horses were turned out the day before racing and only 7% of horses were schooled over either hurdles or fences the day before racing. The frequency of schooling (number of schooling sessions) in the previous month varied with 15% of horses receiving no jump schooling in the previous month. Figure 1 shows the distribution of schooling frequency for 1771 respondents to the question. Approximately one third of horses (36%) received some exercise other than travelling on the day of racing and the majority of these were walked. Journey times ranged from 0 to 16 hours with a mean journey time of 3 hours. Figure 2 shows the distribution of journey times. Approximately one quarter (26.3%) of horses sweated up to some degree during travelling and 62 % were described as travelling calmly. The time from arrival at the racecourse to race start time ranged from 0 hours to 108 hours (4.5 days). The horses staying overnight tended to be those arriving from overseas and for festival meetings (i.e. two or more consecutive days of racing at the course). The mean time from arrival to race was 5.6 hours. If horses staying overnight were excluded the mean time from arrival to race start was 3.4 hours. The majority of horses (96%) were calm or alert in the stable yard at the racecourse with only 4 % sweating, box walking or weaving.

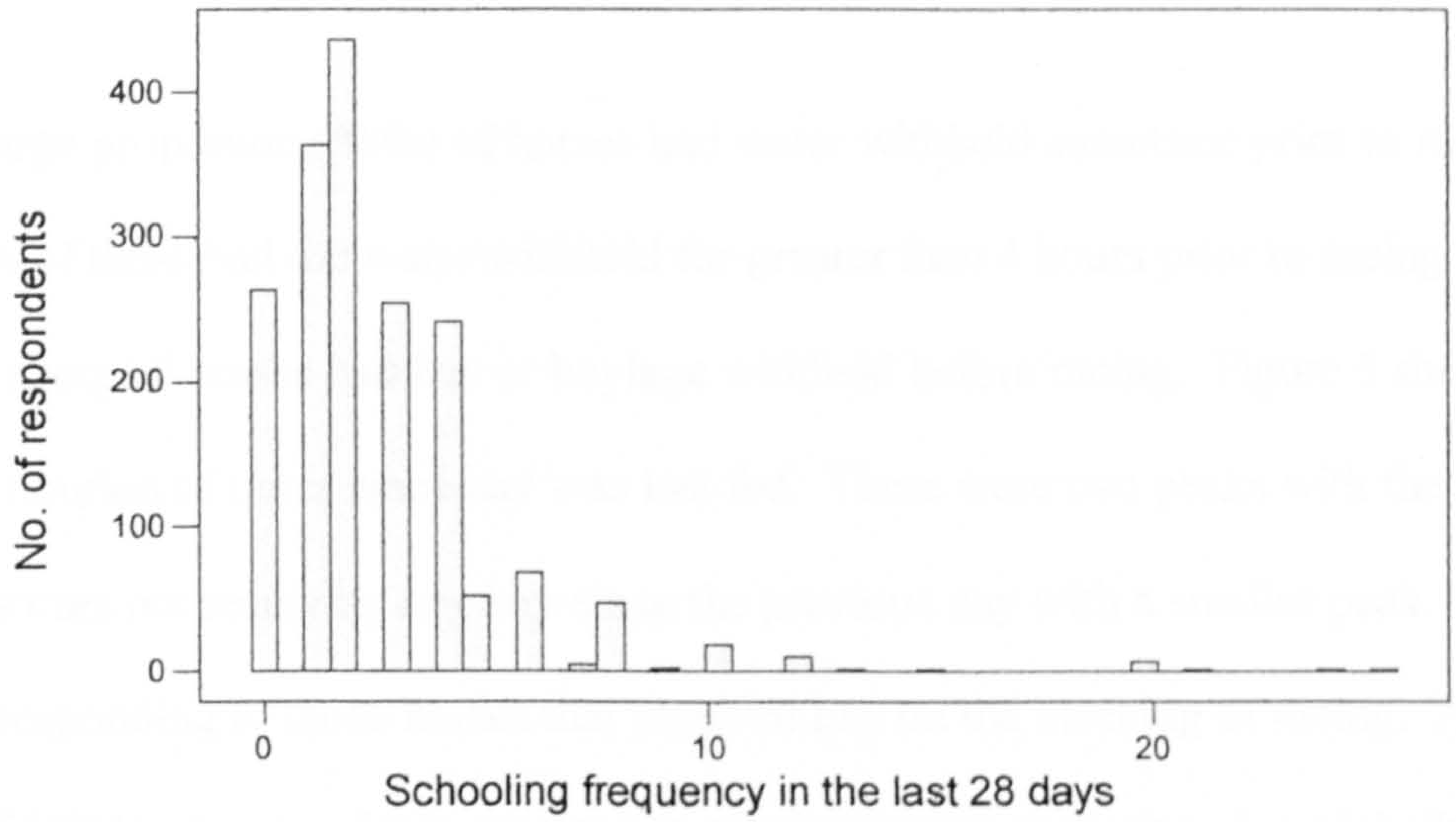


Figure 1: Histogram of schooling frequency (the number of times a horse schooled over fences or hurdle in the 28 days prior to the race start) for horses racing at 6 UK racecourses from Jan 2000-Dec 2001.

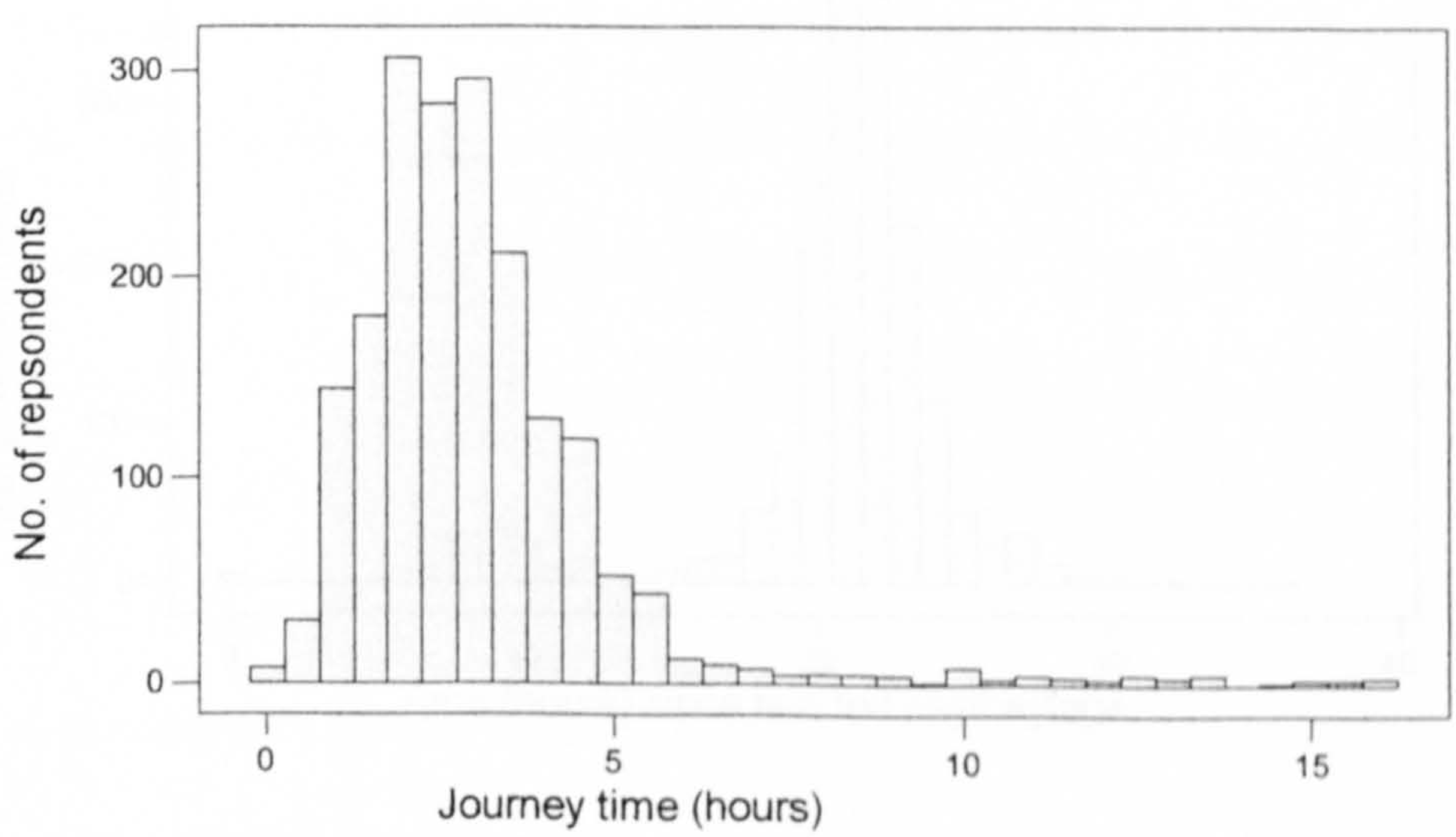


Figure 2: Histogram of duration of journey times to the racecourse, for horses racing at 6 UK racecourses from Jan 2000-Dec 2001.

A large proportion (86%) of horses had water withheld sometime prior to racing and 24% of these had the water withheld for greater then 4 hours prior to racing.

All except 6 horses had hay or haylage withheld before racing. Figure 3 shows the distribution of times since hay was last fed. There were two peaks with the majority of horses not receiving any hay since the previous day with a smaller peak corresponding to those horses that received hay on the morning of racing. Almost half (40%) of respondents reported that before racing the ration size of the hay was be reduced. Figure 4 shows the distribution of time since last cereal or hard feed prior to racing. The majority of horses received a hard feed on the morning of racing with a second peak corresponding to those horses that received the last hard feed the night before racing.

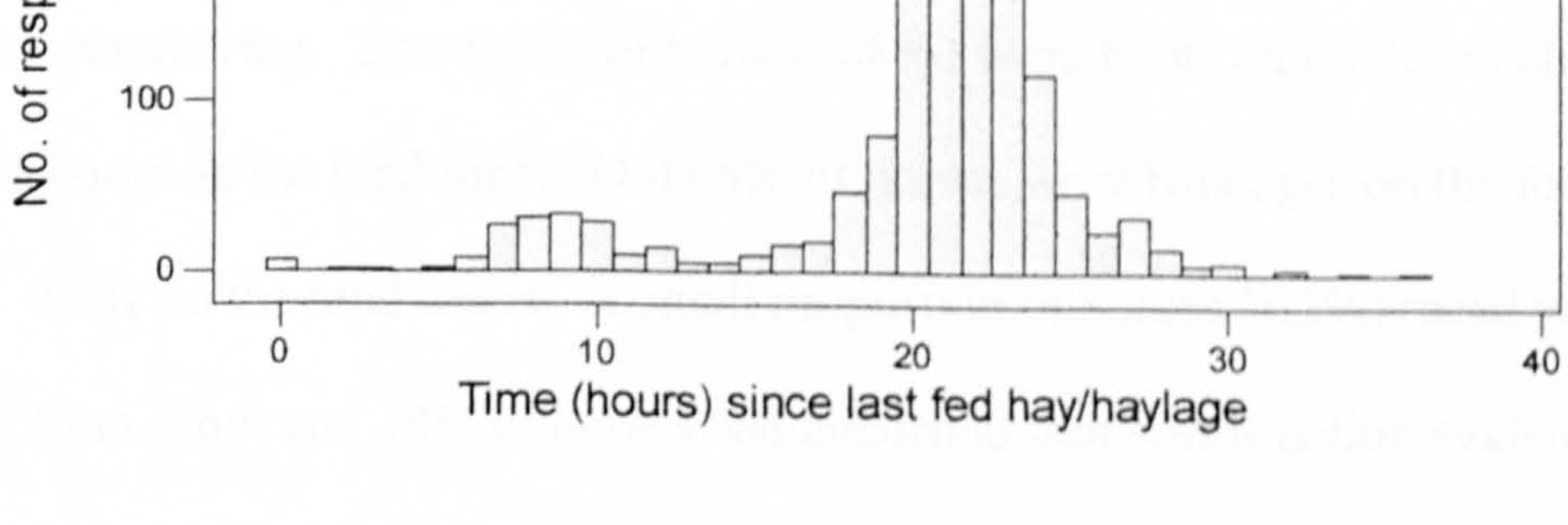


Figure 3: Histogram of the time since horses were last fed hay or haylage prior to racing, for horses racing at 6 UK racecourses from Jan 2000-Dec 2001.

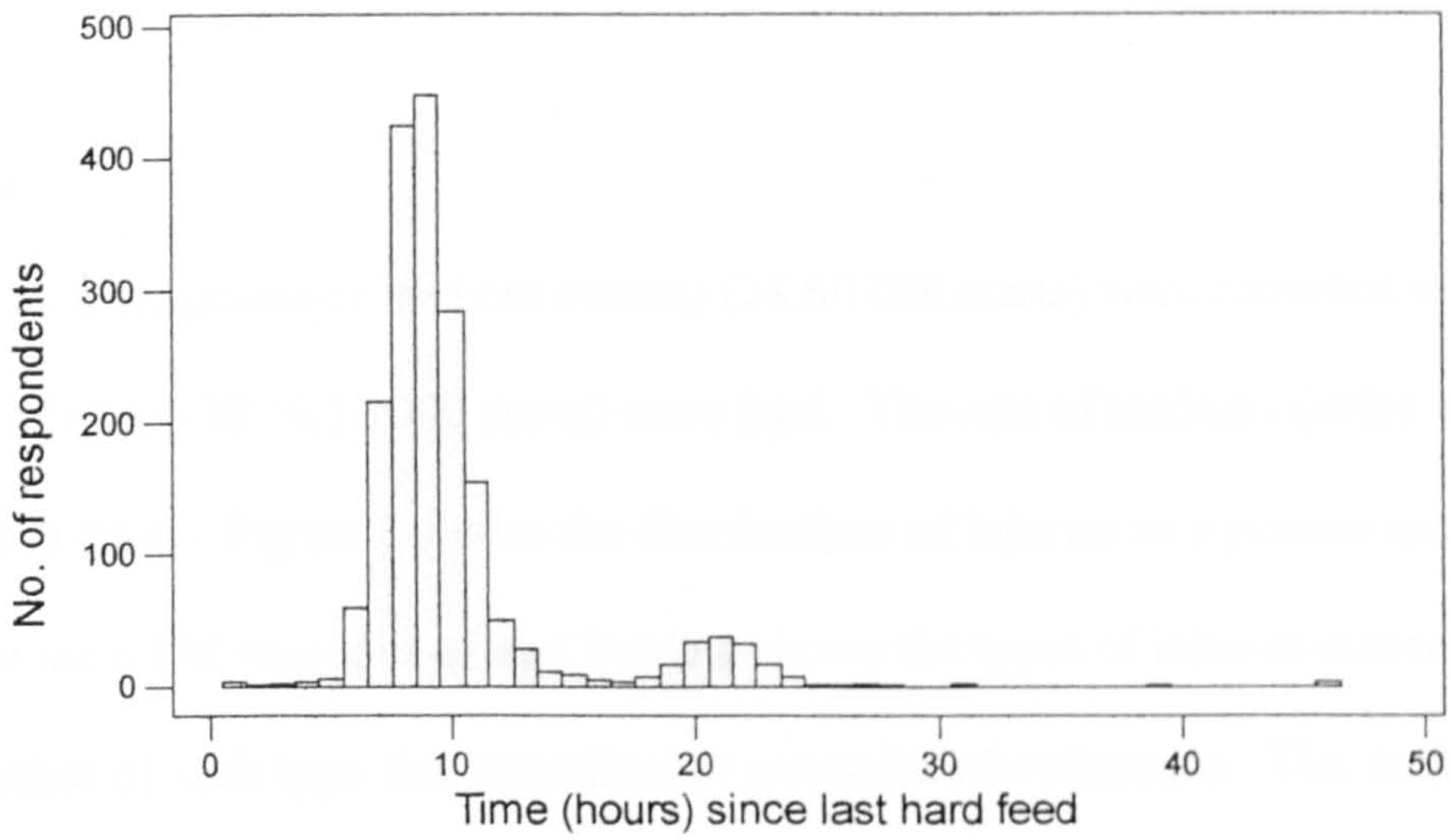


Figure 4: Histogram of time since the horses last cereal or hard feed prior to racing, for horses racing at 6 UK racecourses from Jan 2000-Dec 2001.

Parade ring observations

A small proportion of horses (10.2%) showed signs of sweating in the parade ring although the percentage of horses sweating was higher in the warmer months (e.g. May -18%) so this may not be a good measure of behaviour. Another measure of behaviour used in the parade ring was the horse's locomotion (whether the horse was walking calmly, trotting or cantering). Only 8.5% of horses did not walk calmly in the parade ring. Two thirds of horses (68%) wore boots on the forelimbs and 19% wore boots on the hind limbs. Only 6% of horses wore bandages on the forelimbs and 2.3% on the hind limbs. A small proportion of horses (1.5%) raced without hind limb shoes and 18% of horses had abnormal foot confirmation evident on visual observation in the parade ring. The majority of the abnormalities (86%) were long toes or a combination of long toes with low heels. Only 1 % of horses were fired, however this is likely to be an underestimation considering the proportion of horses that wore boots or bandages on the forelimbs.

Injuries

A total of 83 injuries (or medical events) (28.8/1000 starts) were recorded in the cohort of which 18 (6.3/1000 starts) were fatal. The rate of tendon injuries was (6.9/1000 starts). Figure 5 shows the distributions of injuries as a percentage of starts at the 6 UK racecourses and Table 1 shows the types of injuries sustained and the number of each type that were fatal or necessitated euthanasia. The medical event category was an all-encompassing category consisting of cardiovascular, respiratory, heat exhaustion and other medical problems.

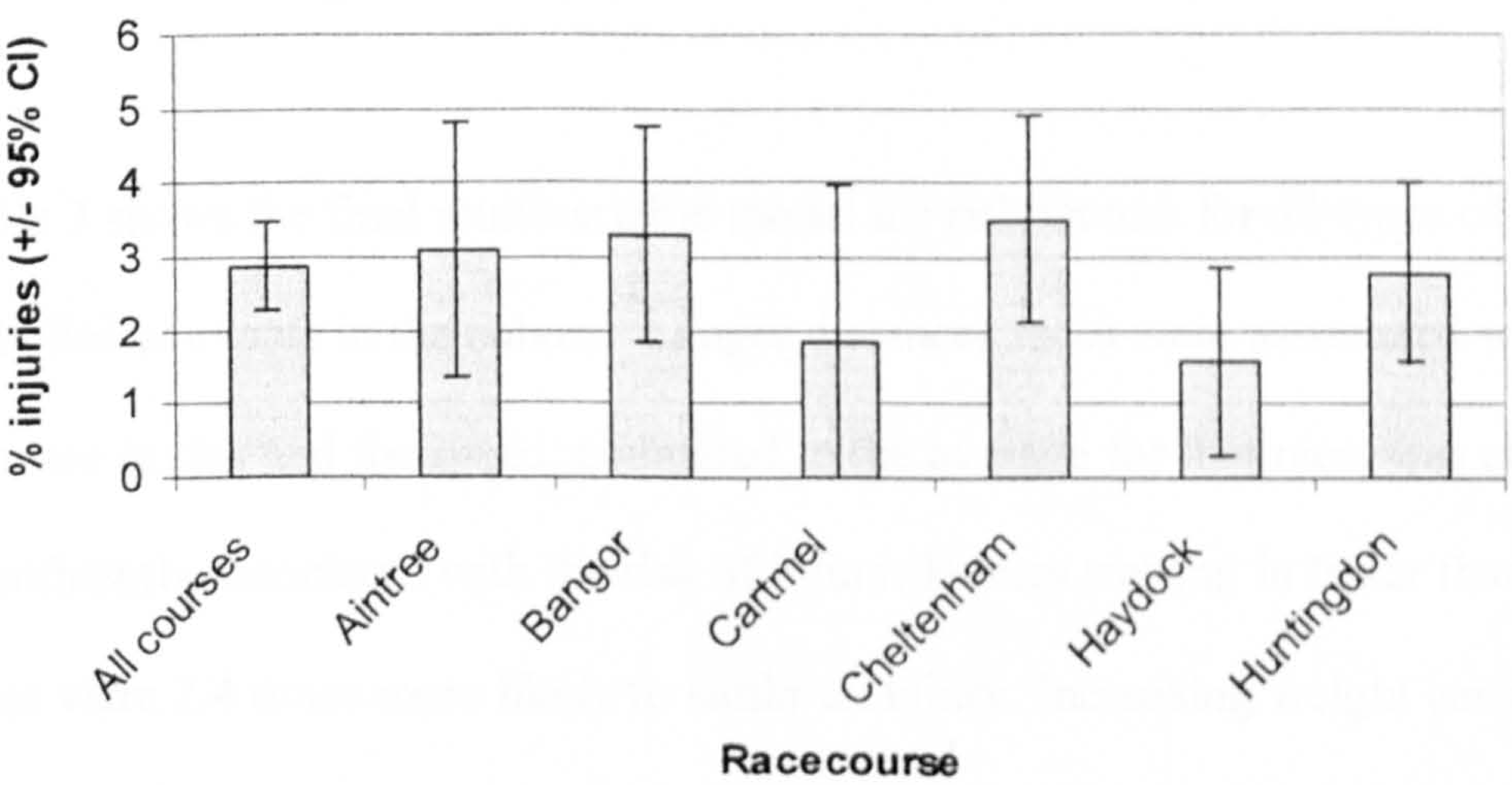


Figure 5: The distributions of injuries as a percentage of starts at 6 UK racecourses from Jan 2000-Dec 2001.

Table 1: Types and number of injuries sustained at six UK racecourses from Jan 2000-Dec 2001

Type of injury	Number	Number fatal
SDFT[a]/DDFT[b]/ Suspensory ligament strain	20	4
Distal limb fracture (carpus/ tarsus distally)	5	5
Upper limb fracture	2	2
Pelvis/vertebral injury or fracture	4	3
Lameness	7	1
Laceration/wound	18	0
Medical event	27	3

[a] Superficial digital flexor tendon
[b] Deep digital flexor tendon

Risk Factors for injuries in the cohort study

Table 2 shows the univariable relationship between age and the risk of injury in steeplechasing and hurdling. There was an increased risk of injury with increasing age in hurdle racing.

Table 3 shows the final multivariable model for risk factors for all types of injuries and clinical events in the cohort. Longer distances races were associated with an increase in risk and the speed, compared to the average for that race, was also significantly associated with the risk of injury. Horses starting in faster than average races were 2.4 times more likely to suffer an injury. Increasing weight carried was also associated with increasing risk. Withholding water was also significantly associated with an increase in the risk of injury. Horses shod greater than 1 week ago had a greater risk of suffering an injury compared to those shod within the last week. The Hosmer-Lemeshow statistic for this model was 6.97 (P =0.54, 8 degrees of freedom) indicating a good fit.

When the medical event category was excluded from the analysis, weight carried and withholding water were no longer significant (Table 4). The foot conformation observed in the parade ring was associated with the risk of injury (excluding medical events) with horses with long feet and low heels being more likely to suffer an injury. The relationship between distance and speed was similar to that seen in the model of all injuries. The Hosmer-Lemeshow statistic for this model was 6.24 (P =0.4, 6 degrees of freedom) indicating a good fit.

When the relationship between the 20 tendon/suspensory injuries only and the effect of foot conformation was examined there was a greater increase in risk (OR 5.8, 95% CI 1.3, 26.8) suggesting that this effect is influenced by the tendon injuries.

Table 2: Univariable relationship of age with injuries in hurdling and steeplechasing on 6 UK racecourses

Age	Both race types		Hurdling		Steeplechasing	
	Odds ratio	Chi square P-value	Odds Ratio	Chi square P-value	Odds ratio	Chi square P-value
4-5	1					
6-7	1.6		2.1		0.5	
8	2.1		-		1.1	
9	2.3		2.2		0.8	
10-15	3.0	0.002	4.0	0.03	0.9	0.3

- Zero cell at this level.

Table 3: Multivariable logistic regression model of risk factors for all types of injuries reported in hurdle and steeplechase racing on 6 UK racecourses. The table shows coefficients, standard errors and P-values for all variables and odds ratios and 95% confidence intervals (CI) of odds ratios for categorical variables.

Variable	Coefficient	Std. Error	LRS P-value	Odds ratio	Lower 95% CI	Upper 95% CI
Continuous						
Distance (furlongs)	0.09	0.04	0.01			
Weight carried (lbs)	0.05	0.02	0.01			
Categorical						
Water withdrawn						
No	Ref.					
Yes	1.47	0.73	0.02	4.3	1.0	18.1
Race speed c.f average						
Slow/medium	Ref.					
Fast	0.88	0.29	0.01	2.4	1.4	4.3
Time since shod						
< 1 week	Ref.					
> 1 week	1.08	0.34	0.003	3.0	1.5	5.8

LRS=Likelihood ratio test statistic

Table 4: Multivariable logistic regression model of risk factors for all injuries, excluding medical events, reported in hurdle and steeplechase racing on 6 UK racecourses. The table shows coefficients, standard errors and P-values for all variables and odds ratios and 95% confidence intervals (CI) of odds ratios for categorical variables

Variable	Coefficient	Std. Error	LRS p-value	Odds ratio	Lower 95% CI	Upper 95% CI
Continuous						
Distance (furlongs)	0.08	0.04	0.05			
Categorical						
Race speed c.f average						
Slow/medium	Ref.			1.0		
Fast	1.29	0.63	<0.001	3.6	1.0	7.1
Foot conformation						
Normal/boxy	Ref.			1.0		
Long feet	0.38	0.62		1.5	0.4	4.9
Long toe/low heels	1.26	0.63	0.2	3.5	1.1	12.5

LRS=Likelihood ratio test statistic

Discussion

The number of clinical events recorded in this cohort (28.8/1000 starts) is slightly higher than those reported by Williams et al. (2001). They reported frequencies of 24.7/1000 starts in steeplechasing and 19.45/1000 starts in hurdling. This difference may be due to changes in reporting methods between the two time periods but is most likely due to the selection of the six racecourses in this study, some of which have a large proportion of high prize money, competitive, championship races. Even within these six racecourses the frequencies of injuries rates varied. In contrast the frequency of tendon injuries reported in this study is slightly lower than that reported by Williams et al. (2000) of 9 and 8 per 1000 starts in steeplechasing and hurdling respectively.

In this study, increasing race distance and fast races were found to be significantly associated with both injury groups. An increase in race distance allows more chance of injury due to both an increase in exposure time and an increase in the number of fences or hurdles encountered in longer races. A previous study showed that the risk for falling in steeplechase racing increased with increasing distance of race (Pinchbeck et al. 2002a). Distance of race was also shown to be associated with lameness in Thoroughbreds racing on the flat in the USA (Rooney et al. 1982) and significantly associated with the risk of fatality of Thoroughbreds racing on the flat (Wood et al. 2000) and in hurdling (Wood et al. 2002).

Winning speed (furlongs/minute) was not significantly associated with the risk of injury in this study but horses starting in races that were fast, compared to the average for that race over that distance on that course, did have a significantly greater risk of suffering an injury or medical event. Speed of the race has also been shown to increase the risk of falling in hurdling (Pinchbeck et al. 2002c) and of fatality in hurdling (Wood et al. 2002) although in both studies there were complex interactions with distance and track surface. In the current study speed is likely to be confounded by the condition of the track surface (going).

Many previous studies have found that the track surface condition has an effect on the risk of injury (Mohammed et al. 1991; Bailey et al. 1998; Williams et al. 2000; Williams et al. 2001). Although surface condition was not significantly associated with the risk of injury in the final multivariable model in this study, the trend was similar to those previously reported (i.e. softer going was associated with a decrease in the risk of injury).

In the model including all injuries, the time since shoeing was associated with the risk of injury. Horses that were shod more than 1 week ago had an increased risk of suffering an injury (OR=3.0, 95% CI = 1.5, 5.8). Horses that were shod more than 4 weeks ago had an even greater risk of suffering an injury (OR=35.3, 95% CI=4.8, 260.8). However, only 0.2 % of respondents reported that the horse was shod more than 4 weeks ago so the categories were combined. Time since last shod may be a proxy measure of general care or of training intensity which may have had an effect on risk of injuries. However, when injuries excluding medical events were examined, the finding that horses with a combination of low heel and long toe conformation were more likely to suffer an injury (OR =3.5, 95% CI= 1.0, 12.5) suggests this may be a true effect of foot and shoe status on injuries. Prolonged periods between shoeing may be partly causal for long toes and low heels, however this is one of the most common malformations of the foot seen and the racing Thoroughbred is often deliberately trimmed and shod for this conformation because of the misconception by trainers that it increases the stride and speed of the horse (Stashak 1987). Previous studies have demonstrated that low hoof angles (resulting from long toe/low heels) predispose horses to musculoskeletal injury (Rooney 1984) and conformation, hoof size and shape, and horse shoe characteristics have all been found to be associated with musculoskeletal problems in Thoroughbreds racing on the flat (Kobluk et al. 1990; Kane et al. 1996; Kane et al. 1998). Kane et al. (1998) demonstrated that toe angle and an increase in the difference between the toe angle and heel angle were associated with suspensory apparatus failure and condylar fractures in 95 horses that died on Californian racetracks. In a cohort of 95 Thoroughbred racehorses in training Kobluk et al. (1990) found that horses with higher hoof angles were less likely to suffer musculoskeletal disease. These studies were confined to flat horses. In National Hunt horses racing over jumps in the UK, the incidence of tendon injuries is higher (McKee 1995; Pickersgill 2000; Williams et al. 2001) and Meershoek et al. (2001) showed that the relative loading of the SDFT was very high during landing after a jump. Superficial digital flexor tendon (SDFT) and suspensory ligament injuries are more common than injuries to the deep digital flexor tendon in racing Thoroughbreds (Gibson et al. 1995; Williams et al. 2001), and in this study 18/20 were due to SDFT injury. Long toe and low heel conformation may result in increased over extension of the fetlock and increased tension on the flexor support structures (Moyer and Raker 1980; Stashak 1987) and Thompson et al. (1993) demonstrated that toe angle affects the strain on the suspensory ligament branches.

The assessment of hoof conformation in this study was subjective only. The parade ring observations were all undertaken by the first author so observer bias should be minimal. However all observations were undertaken using a focal point sampling method (Martin and Bateson 1993) whilst horses were in the parade ring, and there was no opportunity to pick up limbs to allow closer examination of foot conformation. Consequently only obvious dorso-palmar abnormalities were recorded and these are likely to be an underestimation of the true level of abnormalities that would be identified by measuring foot balance. However, these preliminary results, based on a very small number of cases of injury, suggest that further investigation using more quantitative methods of assessment, such as those used by Kobluk et al (1990) and Kane et al (1998), would be warranted in investigating risk factors for musculoskeletal injuries in National Hunt race horses in the UK.

In this study age was significantly associated with injury in univariable analysis of hurdle racing only (Table 2). This is consistent with findings by Williams et al. (2001) where the risk of death per start was not significantly associated with age in steeplechasing but was in flat and hurdle racing. Increasing age has been shown to be associated with increased risk of musculoskeletal injury in flat racing both in the USA (Mohammed et al. 1991; Cohen et al. 2000) and in Australia (Bailey et al.1997). The difference between steeplechasing and hurdling and the effects of age may be due the fact that young horses are more at risk of falling (and therefore suffering from injuries associated with falling) in steeplechasing (Pinchbeck et al. 2002a). When the effect of age on the risk of tendon injuries only was evaluated on all UK racecourses the risk increased with increasing age for all race types (Williams et al. 2000).

Horses that had water withheld prior to racing were more likely to suffer an injury or medical event than those that were allowed access to water right up until racing. Details of the 27 medical events were not available in this study and small numbers would have precluded analysis of individual conditions. However it is feasible that mild dehydration could predispose to conditions such as heat exhaustion, tying up or collapse.

This study has also provided some insights into racing practices and routines in National Hunt racing in the UK. Some practices, for example, schooling frequency, varied quite widely between horses (and therefore trainers) whereas some, such as the withholding hay/haylage for a period before racing were a common finding amongst most horses. This is in agreement with the findings of a study examining feeding practices in racehorse stables in Australia where 90% of trainers changed feeding practices on race days and this usually involved no or a reduction in the hay ration (Southwood et al. 1993). Although no association with injury was found with time since last fed hay or hard feed, withholding food for prolonged periods before racing may be a contributing factor to the high incidence of gastric ulceration seen in the racing Thoroughbred population (Vatistas et al. 1999; Kong et al. 2002; Lorenzo-Figueras et al. 2002).

This cohort study was specifically designed to identify and quantify risk factors for injuries of all types and falling in National Hunt racing in the UK and consequently power calculations to identify risk factors for specific injuries were not performed prior to the design of the study. However, the study does highlight some areas for further research such as hoof balance and the risk of injury.

Risk factors for injuries are likely to vary between different types of injuries. For example the risks for cervical vertebral fracture due to a fall are likely to be very different to risk factors for fatal distal limb fracture. In this study the small sample sizes precluded the division of injuries into more than two categories, however when designing future studies to identify risk factors for injuries in racing this should be considered. It may be necessary to design studies specific to each injury such as that conducted by Parkin et al. 2002, as well as methods utilising multiple outcomes, such as multinomial logistic regression (Hosmer and Lemeshow 2000).

Acknowledgements

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Appendix to Manuscript 4

In this appendix a copy of the injury reporting form from the Jockey Club is shown. Descriptive statistics and results from univariable analysis of categorical and continuous variables are shown. Also presented are the results from the Hosmer-Lemeshow goodness of fit test used to assess the fits of the models.

Reporting form

Table 1 shows the reporting form for the accidents and injuries that all Jockey Club veterinary officers fill out at the end of each race meeting. These forms are then faxed to Weatherbys and entered onto a veterinary database.

Univariable analysis

Tables 2, 3 and 4 show the univariable relationship, derived from chi-square tests, between categorical variables from racing records, the questionnaire and the parade ring observations, and the risk of injury in hurdle or steeplechase racing. Table 5 shows the results from univariable logistic regression analyses of the continuous variables and their relationship with the risk of injury.

Table 1. Injury reporting form filled out by Jockey Club veterinary officers after each race meeting.

DATE:			COURSE:			VO:		NIL RETURN			—
RACE		HORSE:				TRAINER:					
TENDON INJURY								LF	RF	LH	RH
—	Strain (mild/moderate)			—SDFT	—DDFT	—SL	—CL	—	—	—	—
—	Strain/rupture (moderate/severe)			—SDFT	—DDFT	—SL	—CL	—	—	—	—
—	Breakdown (fetlock down)(severe)			—SDFT	—DDFT	—SL	—CL	—	—	—	—
—	Severed/partially severed			—SDFT	—DDFT	—SL	—CL	—	—	—	—
—	Dislocation/split			—Tendo-Achilis		—Other		—	—	—	—
—	Evidence of previous tendon injury was reported/seen. Indicate which limb/limbs							—	—	—	—
OTHER MUSCULOSKELETAL INJURY								LF	RF	LH	RH
—	Inflammation/sore		—Head	—Withers	—Cannon	—Back	—Sacroiliac	—	—	—	—
—	Bruise/haematoma		—Neck	—Scapula	—Shin	—Trunk	—Pelvis	—	—	—	—
—	Laceration/wound		—Chest	—Shoulder	—Tendons	—Quarters	—Hip	—	—	—	—
—	Penetration/puncture		—Ear	—Humerus	—Splint	—Ribs	—Femur	—	—	—	—
—	Muscle strain		—Eye	—Elbow	—Sesamoid	—Belly	—Stifle	—	—	—	—
—	Joint sprain		—Mouth	—Forearm	—Fetlock	—Coronet	—Thigh	—	—	—	—
—	Dislocation		—Teeth	—Radius	—Pastern	—Hoof	—Tibia	—	—	—	—
—	Fracture	—possible	—Jaw	—Knee	—Heel	—Foot	—Hock	—	—	—	—
LAMENESS								LF	RF	LH	RH
—	Lame associated with injury above			—Gr1 Visibly lame at trot		—Gr3 Visibly lame at walk		—	—	—	—
—	Lame undiagnosed			—Gr2 Markedly lame at trot		—Gr4 Non weight bearing		—	—	—	—
—	Poor mover/restricted action			—in paddock	—at trot	—to post	—in race	—	—	—	—
MEDICAL EVENT											
—	Respiratory		—RR raised	—Cough	—Epistaxis	—Whistler	—Soft palate	—SDF			
—	Cardiovascular		—HR raised	—Arrhythmia	—Murmur	— Fibrillation	—Vascular catastrophe				
—	Exhaustion		—Fatigue	—Heat	—Tied up	—Recumbency for		minutes			
—	Other medical		—Neurologic	—Digestive	—Skin	—Fluid/Electrolyte		—Other			
CIRCUMSTANCES AND OUTCOME OF INJURY OR EVENT											
—	Fall related (injury/event associated with a fall)				—at a fence/hurdle***		—on the flat***	***at location:			
—	Death	—Died	—Destroyed	—Gun	—Chemical	—Off track	—On track***:				
—	The injury/event occurred during race (default)				—In transit	—Before race	—After race				
—	Recovery and return to racing likely to be possible within 3 weeks (default)										
—	Short term incapacity (3 weeks to 3 months likely to be required for return to racing)										
—	Long term incapacity (more than 3 months likely to be required for return to racing)										
COMMENT			—Horse(default)		—Course	—Trainer	— Jockey	—Vacc. error			

Table 2: Descriptive statistics and chi square analyses of the categorical variables investigated in the cohort for their association with injury in hurdle and steeplechase racing on 6 UK racetracks

Variable	Controls % (n)	Cases % (n)	Odds Ratio	P-value
Racecourse				
Aintree	97(375)	3(12)	1.0	
Bangor	97(549)	3(19)	1.1	
Cartmel	98(158)	2(3)	0.6	
Cheltenham	97(635)	4(23)	1.1	
Haydock	98(369)	2(6)	0.5	
Huntingdon	97(710)	3(20)	0.9	0.5
Steeplechase				
No	98(1621)	2(35)	1.0	
Yes	96(1175)	4(48)	1.9	0.004
Novice				
No	97(1761)	3(48)	1.0	
Yes	97(1035)	3(35)	1.2	0.3
Handicap				
No	97(1070)	3(35)	1.0	
Yes	97(1726)	3(48)	0.9	0.5
Hunterchase				
No	97(2787)	3(83)	1.0	
Yes	100(9)	0(0)	0.0	-
Race class				
A	96(302)	4(11)	1.0	
B	97(403)	3(11)	0.8	
C	97(251)	3(7)	0.8	
D	96(761)	(48)	1.0	
E	98(552)	2(13)	0.7	
F	98(452)	2(11)	0.7	
G	97(66)	3(2)	0.8	
H	100(9)	0(0)	0.0	0.4
Condition of track surface (going)				
Good to firm	98(313)	2(7)	1.0	
Good	96(1042)	4(41)	1.8	
Good to soft	97(529)	3(16)	1.4	
Soft	98(667)	2(15)	1.0	
Heavy	98(245)	2(4)	0.7	0.1
Going changed on race day				
No	97(2149)	3(72)	1.0	
Yes	98(647)	2(11)	0.5	
Horse gender				
Female	97(373)	3(10)	1.0	
Male	97(2424)	3(73)	1.1	0.4
Speed compared to the average for that race				
Slow	98(1972)	2(44)	1.0	
Medium	98(106)	2(2)	0.9	
Fast	95(718)	5(37)	2.3	<0.001

Variable	Controls % (n)	Cases % (n)	Odds Ratio	P-value
Age of horse(years)				
4-5	98(670)	2(11)	1.0	
6-7	97(1004)	3(27)	1.6	
8	97(443)	3(15)	2.1	
9	96(316)	4(12)	2.3	
10-15	95(363)	5(18)	3.0	0.002
Weather				
Cloud	98(1512)	2(38)	1.0	
Sun	97(941)	3(34)	1.4	
Rain	97(343)	3(11)	1.3	0.3

Table 3: Descriptive statistics and chi square analyses of the categorical variables from the questionnaire investigated in the cohort for their association with injury in hurdle and steeplechase racing on 6 UK racetracks

Variable	Controls% (n)	Cases% (n)	Odds ratio	P-value
Time since shod				
Within 2 days	97(919)	3(26)	1.0	
Within 1 week	98(6220	2(12)	0.7	
1-4 weeks	96(244)	4(11)	1.6	
>4 weeks	50(2)	50(20	35.4	<0.001
Exercise Yesterday				
No	100(36)	0(0)	Inf	
Yes	97(1803)	3(57)	Inf	0.3
Walked yesterday				
No	97(1471)	3(44)	1.0	
Yes	97(357)	3(11)	1.0	0.9
Cantered Yesterday				
No	96(664)	4(26)	1.0	
Yes	98(1168)	2(29)	0.6	0.1
Turned out yesterday				
No	97(1689)	3(49)	1.0	
Yes	96(142)	4(6)	1.5	0.4
Schooled yesterday				
No	97(1701)	3(52)	1.0	
Yes	98(130)	2(3)	0.8	0.6
Other exercise yesterday				
No	97(1817)	3(54)	1.0	
Yes	93(14)	7(1)	2.4	0.4
Exercise today				
No	97(1181)	3(37)	1.0	
Yes	97(669)	3(19)	0.9	0.7
Walked today				
No	97(1291)	3(41)	1.0	
Yes	98(558)	2(14)	0.8	0.5
Cantered today				
No	97(1774)	3(53)	1.0	
Yes	97(75)	3(2)	0.9	0.9
Turned out today				
No	97(1824)	3(54)	1.0	
Yes	96(25)	4(1)	1.4	0.8

Variable	Controls% (n)	Cases% (n)	Odds ratio	P-value
Behaviour after travel				
Excited and sweating	99(109)	1(1)	1.0	
Bright and alert	98(226)	2(5)	2.4	
Calm	97(1133)	3(38)	3.6	
Slight sweating	97(377)	3(13)	3.8	0.6
Behaviour in box				
Calm	97(1268)	3(41)	1.0	
Bright and alert	97(495)	3(13)	0.8	
Box walking, weaving	96(22)	4(1)	1.4	
Sweating and excited	100(59)	0(0)	0.0	0.5
Water withdrawn				
No	99(266)	1(2)	1.0	
Yes	97(1583)	3(55)	4.6	0.007

Table 4: Descriptive statistics and chi square analyses of the categorical variables from parade ring observations investigated in the cohort for their association with injury in hurdle and steeplechase racing on 6 UK racetracks

Variable	% Controls (n)	% Cases (n)	Odds Ratio	P-value
No handlers				
One	97(2743)	3(81)	1	
Two	93(26)	7(2)	1.5	0.6
Sweating entry to parade ring				
No	97(2559)	3(79)	1.0	
Yes	98(190)	2(4)	0.7	0.6
Sweating parade ring				
No	97(2198)	3(66)	1.0	
Yes	97(248)	4(9)	1.2	0.2
Locomotion in parade ring				
Walking	97(2524)	3(78)	1.0	
Trotting or other	98(236)	2(5)	0.7	0.7
Behaviour entry to parade ring				
Normal	97(2613)	3(80)	1.0	
Abnormal	98(152)	2(3)	0.6	0.3
Behaviour parade ring				
Normal	97(2147)	3(68)	1.0	
Abnormal	97(303)	3(8)	0.8	0.4
Bandages fore limbs				
No	97(2593)	3(75)	1.0	
Yes	96(177)	4(7)	1.4	0.4
Bandages hind limbs				
No	97(2705)	3(83)	1.0	
Yes	100(66)	0(0)	0.0	0.2
Boots fore limbs				
No	97(886)	3(32)	1.0	
Yes	97(1885)	3(51)	0.8	0.2
Boots hind limbs				
No	97(2232)	3(69)	1.0	
Yes	97(538)	3(14)	0.8	0.6

Variable	% Controls (n)	% Cases (n)	Odds Ratio	P-value
Head gear				
None	97(2467)	3(70)	1.0	
Blinkers	96(213)	4(9)	1.5	
Visor	97(113)	3(4)	1.3	0.5
Shod behind				
Yes	97(2150)	3(56)	1.0	
No	97(32)	3(1)	1.2	0.9
Shoeing				
Normal	97(1793)	3(50)	1.0	
Abnormal	98(389)	2(7)	0.7	0.3
Foot conformation				
Normal	98(1994)	2(51)	1.0	
Long feet	98(136)	2(3)	0.9	
Long feet and low heels	95(52)	5(3)	2.3	
Boxy feet	100(47)	0(0)	0.0	0.3
Fired tendons				
No	97(2167)	3(56)	1.0	
Yes	94(15)	6(1)	2.6	0.3

Table 5: Univariable logistic regression analyses of the continuous variables investigated in the cohort study for their association with injury in hurdle and steeplechase racing on 6 UK racetracks.

	Univariable Logistic Regression	
Variable	Odds Ratio	p-value
Race Distance	1.1	0.009
Horse age	1.2	<0.001
Race speed (furlongs/minute)	0.9	0.7
Horses rating	1.0	0.1
Days since last ran	1.0	0.8
Weight Carried	1.03	0.02
Rainfall	1.0	0.8
Schooling frequency	0.9	0.2
Distance exercised yesterday	1.00	0.6
Journey time(hours)	1.05	0.5
Time form arrival to race	1.00	0.4
Last hard feed (hours)	1.06	0.03
Last access to hay	1.0	0.8

Assessing goodness of fit of the models.

The Hosmer-Lemeshow test statistic is a summary measure of goodness-of-fit. The estimated probabilities are grouped based on percentiles (usually 10). Estimates of the expected values in the cases are obtained by summing the estimated probabilities over all subjects in a group. For controls the estimated expected value is obtained by summing 1 minus the estimated probability. The Hosmer-Lemeshow goodness-of-fit statistic is obtained by calculating the Pearson chi-square statistics from the nx2 table of observed and expected frequencies. The distribution of the statistic is well approximated by the chi-square distribution with n-2 degrees of freedom. So a large p-value for the test indicates that there is no significant difference between the observed and expected frequencies (Hosmer and Lemeshow 2000).

Table 6: Observed and expected frequencies used for Hosmer–Lemeshow goodness of fit test for the multivariable model of all injuries.

Group	Cases		Controls	
	Observed	Expected	Observed	Expected
1	1	0.8	182	182.2
2	0	1.7	183	181.3
3	3	2.3	181	181.7
4	3	2.9	185	185.1
5	5	3.4	178	179.6
6	4	4.2	183	182.8
7	6	5.1	178	178.9
8	9	6.6	174	176.4
9	4	9.2	181	175.8
10	16	14.8	158	159.2

Hosmer-Lemeshow chi square=6.97, p=0.54

Table 7: Observed and expected frequencies used for Hosmer–Lemeshow goodness of fit test for multivariable model of all injuries excluding medical events. In this model only 8 deciles of risk were used because the number of distinct factor/covariate patterns was small.

Group	Cases		Controls	
	Observed	Expected	Observed	Expected
1	3	2.9	417	417.1
2	2	1.9	260	260.1
3	2	3.7	391	389.3
4	6	2.6	242	245.4
5	2	3.0	235	234.0
6	4	5.0	257	256.0
7	6	7.1	221	219.9
8	11	9.8	180	181.2

Hosmer-Lemeshow chi square=6.24, p=0.4

Manuscript 5

Whip use and race progress are risk factors for falling in hurdle and steeplechase racing

Pinchbeck, G.L. Clegg, P.D., Proudman, C.J., Morgan, K.L., French. N.P.

Department of Veterinary Clinical Science and Animal Husbandry, University of Liverpool, Leahurst, Neston, CH64 7TE, UK.

Corresponding Author. G.L.Pinchbeck

Key words: Horse falls; steeplechase; hurdle; video; whip use; race progress

Abstract

A retrospective, matched, nested case-control study using video recordings of races was conducted on six UK racecourses to identify and quantify within race risk factors associated with horse falls in hurdle and steeplechase racing in the UK. Cases and controls were matched on both the race type and the jump number of the fall. Conditional logistic regression analyses was used to examine the univariable and multivariable relationship between predictor variables and the risk of falling. The risk of falling was significantly associated with whip use and race progress. Horses which were being whipped and progressing through the race were at greater than 7 times the risk of falling compared to horses which were not being whipped and which had no change in position or were going backwards through the field.

Introduction

Accidents during racing, such as falling at a fence or colliding with another horse threaten the lives of horses and contribute to horse and jockey injury (Allen 1992). The horse fatality rates during jump racing are higher than those on the flat (Bailey et al. 1998; Bourke et al. 1995) and in the UK, equine fatality rates of 0.1 per 100 starts for flat racing, 0.52 per 100 starts for hurdling and 0.71 per 100 starts for steeplechasing have been reported (Wood et al. 2000)

In two descriptive studies of fatalities on in National Hunt racing between 50% (McKee 1995) and 60% (Bourke 1995) of all fatalities in jump racing were associated with falls. In an earlier study by Vaughan and Mason (1975) 55% of reported racecourse fatalities were associated with a fall, and 22% of these injuries were vertebral fractures. Furthermore 90% of these were associated with a fall at a fence. The majority of these horses died instantly or were quadriplegic immediately after falling and injuries such as these are likely to have a very negative impact on the public's perception of animal welfare in horse racing.

A workshop of the Horserace Betting Levy Board in 1996 identified the need to quantify risk factors for racing injuries in the UK (Mellor and Newton 1997). Subsequent to this there have been various studies in the UK conducted on racecourse fatalities and injuries (Parkin et al. 2002; Williams et al. 2001; Verheyen et al. 2001; Wood et al. 2000). Although readily available, there has been limited use made of video analysis to describe the circumstances surrounding racing accidents (Ueda et al. 1993) or to try and identify within race risk factors (Parkin et al. 2002; Cohen et al. 1997) and there have not been any studies that have addressed falling in jump racing in the UK. In a retrospective study of death on UK racecourses Wood et al. (2001a) showed that much of the variation in the risk of death in hurdling was at the level of the start. As many jump-racing deaths are associated with falls video analysis was used to try and identify and quantify start level risk factors.

This study uses video recordings of races to report descriptive data and risk factors for horse falls on 6 UK racetracks.

Materials and Methods

Study Design

A nested, matched case-control study was conducted with cases and controls being selected from a previous cohort study of falling in hurdle and steeplechase racing on 6 UK racetracks from 1st February 2000 to 30th November 2002 (manuscript 3). One hundred and nineteen cases were selected during this cohort study and power calculations estimated that 2 controls selected per case would give an estimated power of 85% to detect odds ratios of two or more with an exposure of 50% in the controls. A nested, matched study was selected due to time constraints of the observers and the desire to match on race type and jump number.

Identification and selection of cases and controls.

Cases were defined as any horse in any start on the six UK racecourses that suffered a fall at a steeplechase fence or hurdle on any of these racecourses during the study period. Cases were identified by author attendance at the racecourses and were verified against an independent data source and subsequently during video observation. Horses that unseated the rider or were brought down by another horse were not included in the case definition. Two controls per case were randomly selected using random number generation (Epi-Info 6.04) from all horses in the same race that reached the jump number that the case occurred at. In two races only one other horse reached the same point in the race as the case horse so these two cases had only one matched control.

After the cases and controls had been identified a spreadsheet was created identifying the cases and controls by number and racing colours only. This enabled the observer to be blinded with respect to which was a case or control horse up to the point of the fall.

Data Collection

Videos on all races containing cases and controls were obtained from Racetech Ltd. At least 3 views were available on all races and some races had up to 5 views. Four television screens and videos were set up with synchronised freeze frame which enabled slow motion viewing of up to four views simultaneously, enabling all horses to be followed at every point in the race. One observer followed all cases and controls and recorded information relating to the horse's position, jumping mistakes and jockeys use of the whip throughout the race up to the point of the fall. The categorical variables recorded are shown in Table 1. Observational data on the cases were also recorded. These data were recorded directly onto a data sheet designed for use with a data entry scanner (Fujitsu fi-4110CU image scanner) and software (Teleform elite v 7.0, Cardiff Software Inc.). Ten percent (33 data sheets) of these data sheets were randomly selected using random number generation in Epi Info

(Epi Info 6 Version 6.04 CDC Georgia) for double-checking of the data entry manually by the author. The error rate was 0.1% (1 error in 968 entries).

Data on fatalities and injuries on the racecourses were obtained from the Jockey Club.

Statistical Analysis

Due to the presence of potentially correlated, independent variables, simple correlation analysis was performed prior to analysis to avoid multicollinearity (Dohoo et al. 1997). The dependent variable for all the analyses was the case horse that fell and the control horses that successfully jumped the fence. To take account of the matching, conditional logistic regression methods using maximum likelihood estimation were used for both univariable and multivariable analyses. A comparative univariable odds ratio was calculated for exposures with only two categories using the Mantel-Haenszel method to check for agreement. Continuous variables were considered first as linear in their relationship with the outcome and then as categorical variables. New variables relating to changes in position throughout the race were created. Interaction terms between the matching variables (race type and jump number of fall) and explanatory variables were tested to see if there was any significant difference between race type and jump number and the risk of a particular variable. Interaction terms were subsequently tested between all biologically plausible terms with a particular hypothesis that interactions between whip use and changes in position may exist. Variables with a p-value<0.25 were considered for inclusion in a multivariable model. The critical probability throughout was 0.05. The stability of the model was assessed by examining the delta-betas (Pregibon 1981). All analyses were performed in EGRET (Egret Application 2.0, Cytel Software Corporation)

Results

Descriptive statistics

One hundred and nineteen cases were available for analysis. Of these 9 cases were excluded due to inability to visualise the case and control horses properly in any of the views. Of the remaining 110 cases 31 were in hurdle races, 73 in steeplechase races and 6 were over the National steeplechase racecourse.

Of the 110 cases satisfactory observation of what occurred at the actual fall was obtained in 106 cases. None of the falls were due to an obvious problem, such as limb fracture or cardiovascular problem, before take off at the fence. In 91.5% (97/106) of the cases the fall was due to the horse hitting the fence or hurdle. Of these 6% (6/97) of horses appeared to hit the guardrail on the take off side of the fence first. In 10% (10/97) of falls the horse took off too early and extended its front legs into the fence or hurdle and 8% (8/97) took off too late and hit the fence before they could take off. Out of 31 hurdle cases 29% (9/31) of horses appeared to canter into the hurdle flight with no attempt to jump the obstacle and 60% (5/9) of these occurred when there was a large field of horses in close proximity to each other. The remaining cases that hit the fence or hurdle either caught the fore limbs only (11%); the hind limbs only (9%) or hit the fence with fore and hind limbs (46%). Horses that caught the hind limbs were quite often somersaulted (landing on dorsal aspect of neck or back) over the fence. Four horses jumping an open ditch attempted to put in an extra stride with the forelegs in the ditch of the fence. All 4 of these then hit the fence hard and one suffered a fractured shoulder and had to be euthanased. In 8% (8/97) the reason for not being able to clear the fence seemed to be due to extreme fatigue.

Only 8% (9/106) of horses cleared the fence and then fell on landing. Two of these appeared to be due to interference from another horse on landing and the remaining horses seemed to lose their forelimb footing on landing. After the falls 65% (69/106) horses ran on rider less, 10% (11/110) were non-fatally injured and 7% (8/110) were fatally injured.

Univariable and multivariable logistic regression

The results of univariable analysis of categorical variables are shown in Table 1. Interaction terms between the jump number of the fall, the race type and other variables were not significant so the complete data were analysed together. The final multivariable model is shown in Table 2. Examination of the delta betas showed this model to be stable and removal of matched sets containing the observations with the largest delta betas had little effect on the size of the odds ratio.

Table 1: Descriptive statistics and univariable conditional logistic regression analyses of categorical variables investigated during video analysis for association with falling in hurdle and steeplechase racing on 6 UK racetracks February 2000 -November 2001

Variable		%Controls (n)	%Cases (n)	Conditional unadjusted odds ratio	P-Value
Position start					
	Front third	76(81)	24(26)	1.0	
	Middle third	63(88)	37(51)	1.8	
	Back third	60(45)	40(31)	1.9	0.04
Position start					
	Inside	70(84)	30(36)	1.0	
	Middle	66(74)	34(38)	1.2	
	Outside	63(56)	37(33)	1.3	0.5
Position first fence					
	Front third	75(77)	25(26)	1.0	
	Middle third	67(99)	33(49)	1.5	
	Back third	54(38)	46(32)	2.3	0.02
Position first fence					
	Inside	67(64)	33(31)	1.0	
	Middle	65(49)	35(49)	1.3	
	Outside	68(57)	32(27)	1.0	0.9
Position 2 fences previous		68(69)	31(32)		
	Front third			1.0	
	Middle third	63(80)	37(47)	1.2	
	Back third	68(41)	32(19)	1.0	0.7
Position 2 fences previous		58(44)	42(32)		
	Inside			1.0	
	Middle	68(122)	32(58)	0.6	
	Outside	71(50)	29(20)	0.6	0.2
Position 1 fence previous					
	Front third	67(59)	33(29)	1.0	
	Middle third	64(80)	36(45)	1.2	
	Back third	69(48)	31(22)	1.04	0.8
Position 1 fence previous					
	Inside	65(44)	35(24)	1.0	
	Middle	65(94)	35(51)	1.1	0
	Outside	70(49)	30(21)	0.8	0.8
Position at fence					
	Front third	67(70)	33(34)	1.0	
	Middle third	64(86)	36(49)	1.2	
	Back third	70(48)	30(21)	1.0	0.9
Position at fence					
	Inside	66(44)	34(23)	1.0	
	Middle	67(101)	33(50)	0.9	0.98
	Outside	67(62)	33(30)	0.9	0.9
Horse immediately beside					
	No	69(180)	31(83)	1.0	
	Yes	58(38)	42(27)	1.8	0.09
Horse immediately in front					
	No	69(200)	31(91)	1.0	
	Yes	49(18)	51(19)	3.5	0.006

Variable		%Controls (n)	%Cases (n)	Conditional unadjusted odds ratio	P-Value
Previously brushed fence					
	None	68(107)	32(51)	1.0	
	Once	66(57)	34(30)	1.1	
	Twice	62(29)	38(18)	1.4	
	Three times	74(14)	26(5)	0.6	
	Four times	70(7)	30(3)	0.9	
	Five times	57(4)	43(3)	1.7	0.8
Previous mistakes					
	None	66(165)	34(86)	1.0	
	One	70(44)	30(19)	0.8	
	Two	64(7)	36(4)	1.1	
	Three	67(2)	33(1)	0.9	0.9
Previous jumping direction					
	Straight	65(179)	35(95)	1.0	
	Left	60(9)	40(6)	1.2	
	Right	93(14)	7(1)	0.1	0.1
Whip use 2 fence previous					
	None	68(207)	32(103)	1.0	
	One	58(7)	42(5)	1.4	
	Two	67(4)	33(2)	1.0	0.9
Whip use 1 fence previous					
	None	66(183)	34(95)	1.0	
	One	79(23)	21(6)	0.5	
	Two	57(12)	43(9)	1.4	0.2
Whip use at fence					
	None	69(188)	31(84)	1.0	
	One	57(17)	43(13)	2.2	
	Two	50(9)	50(9)	3.7	
	Three	50(4)	50(4)	3.6	0.05
Position change from1st fence					
	None	71(66)	29(28)	1.0	
	Forward	59(80)	41(56)	2.3	
	Back	73(72)	27(26)	1.2	0.02

Table 2. Final multivariable conditional logistic regression model of risk factors assessed from video analysis associated with horse falls on 6 UK racecourses.

Variable	Coefficient	Std. Error	P value	Adjusted odds ratio (95% CI)
Horse in front				
No	Ref.			1.00
Yes	1.08	0.50	0.03	2.94 (1.1, 7.9)
Horse beside				
No	Ref.			1.00
Yes	0.59	0.40	0.14	1.81 (0.8, 3.9)
Whip use at fence				
No	Ref			1.00
Yes	0.85	0.60	0.16	2.35 (0.7, 7.6)
Position change from 1st fence				
None/backwards	Ref.			1.00
Forwards	0.90	0.35	<0.01	2.45 (1.2, 4.8)
Position change from 2 fences previous				
None	Ref.			1.00
Forward	-0.97	0.43	0.02	0.38 (0.2, 0.9)
Backwards	-0.001	0.42	0.99	0.99 (0.4, 2.3)
Interaction term*				
Position change forward x whip yes	2.13	0.92	0.02	8.41 (1.4, 51.3)
Interaction term**				
Position change backwards x whip yes	-0.64	0.88	0.46	0.53 (0.1, 2.9)

*i.e. the odds ratio for a horse that was had progressed forwards from 2 fences previously and was being whipped was estimated to be 0.38x2.35x8.41=7.5

** i.e. the odds ratio for a horse that was had gone backwards from 2 fences previously and was being whipped was estimated to be 0.99x2.35x0.53=1.23

Horse immediately in front and horse beside

A case or control was defined as having a horse in front at take off at the fence if another horse was directly in front and this horse had not landed before the case or control horse took off at the jump. This variable was significant in the final multivariable model with increased odds of falling of 2.9 (95% CI =1.1, 7.9). Although there was no significant interaction between jump number and horse in front, if only the first five fences were analysed the odds of falling increased (OR= 13.3, 95% CI =1.7, 106.4).

A case or control was defined as having a horse beside if at the time of the take off at the fence the horse were directly next to each other such that there was no visible space between them. Although this variable was not significant in the final model (OR=0.14, 95% CI=0.8, 4.0) it did significantly improve the fit of the model (likelihood ratio chi-square $P<0.05$).

Use of the whip

The use of the whip by the jockey was measured leading up to 2 fences previous and one fence previous to the fall and leading up the fall fence. Any use plus the number of strikes the horse received was recorded. To reduce the degrees of freedom in the final multivariable model use of the whip leading up to the fall fence was assessed with a binary yes/no outcome and an interaction term between whip use and change in position from 2 fences previously was significant. Figure 1 shows the relationship between the odds ratios for change in position and whip use and the outcome of falling. In univariable analysis and in a multivariable model adjusted for position change from two fences previously and horse in front there appeared to be a dose response relationship with 2 and 3 strikes of the whip associated with an even greater odds of falling (figure 2).

Change in position from 2 fences previously to fall fence

Neither the position at the fence nor the positions at one and two fences previously were significant in univariable analysis. However the change in position from 2 fences previously to the fall fence had a significant interaction with whip use as shown in Figure 1. Horses which were being whipped and going forward were most at risk followed by horses being whipped and not changing position. Horses not being whipped and those going backwards in the field were at the lowest risk.

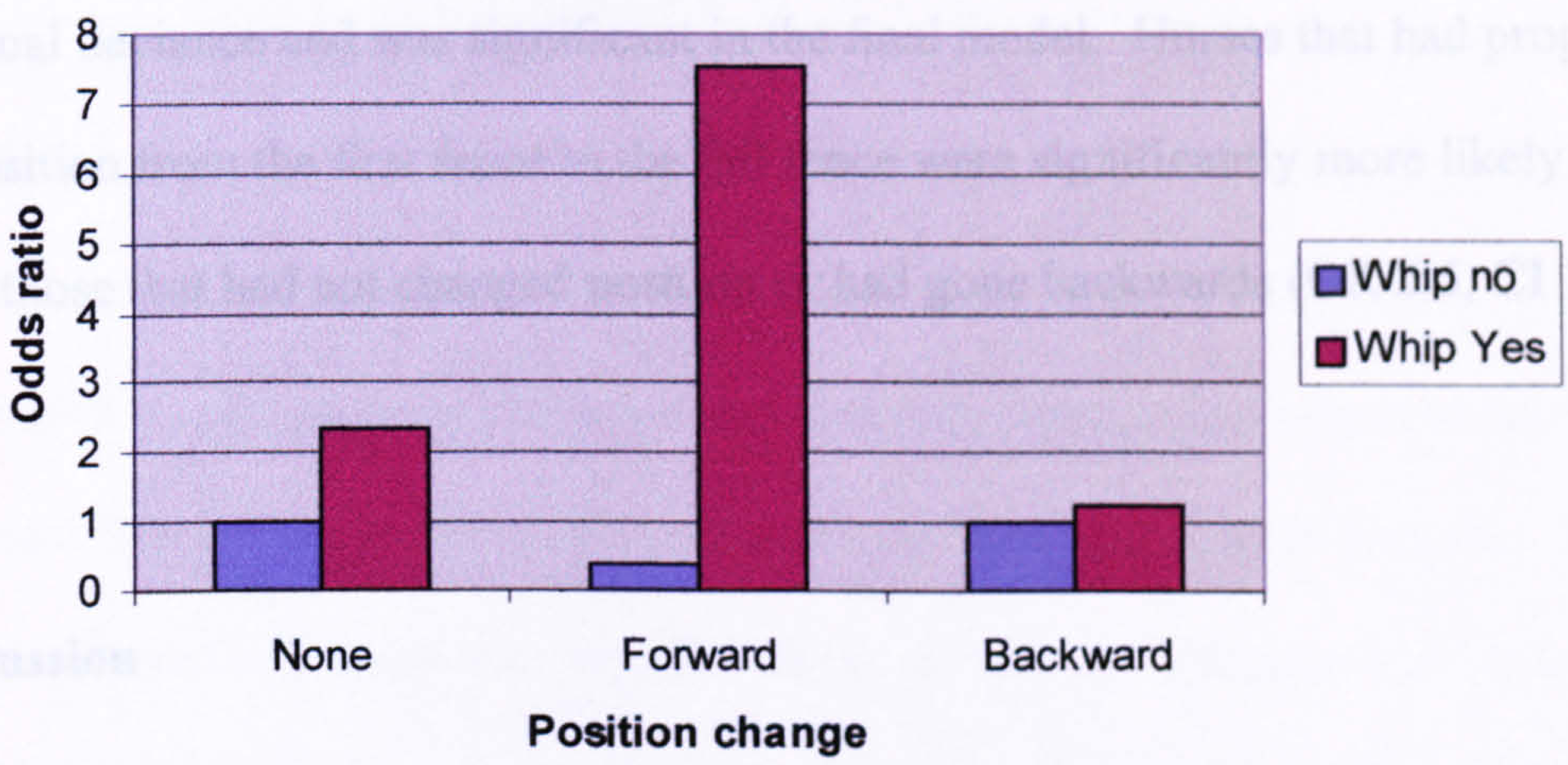

Figure 1. The relationship between the risk of falling and whip use and change in position from 2 fences previous adjusted for other variables in the multivariable model (table 2) in hurdle and steeplechase races on 6 UK racecourses.

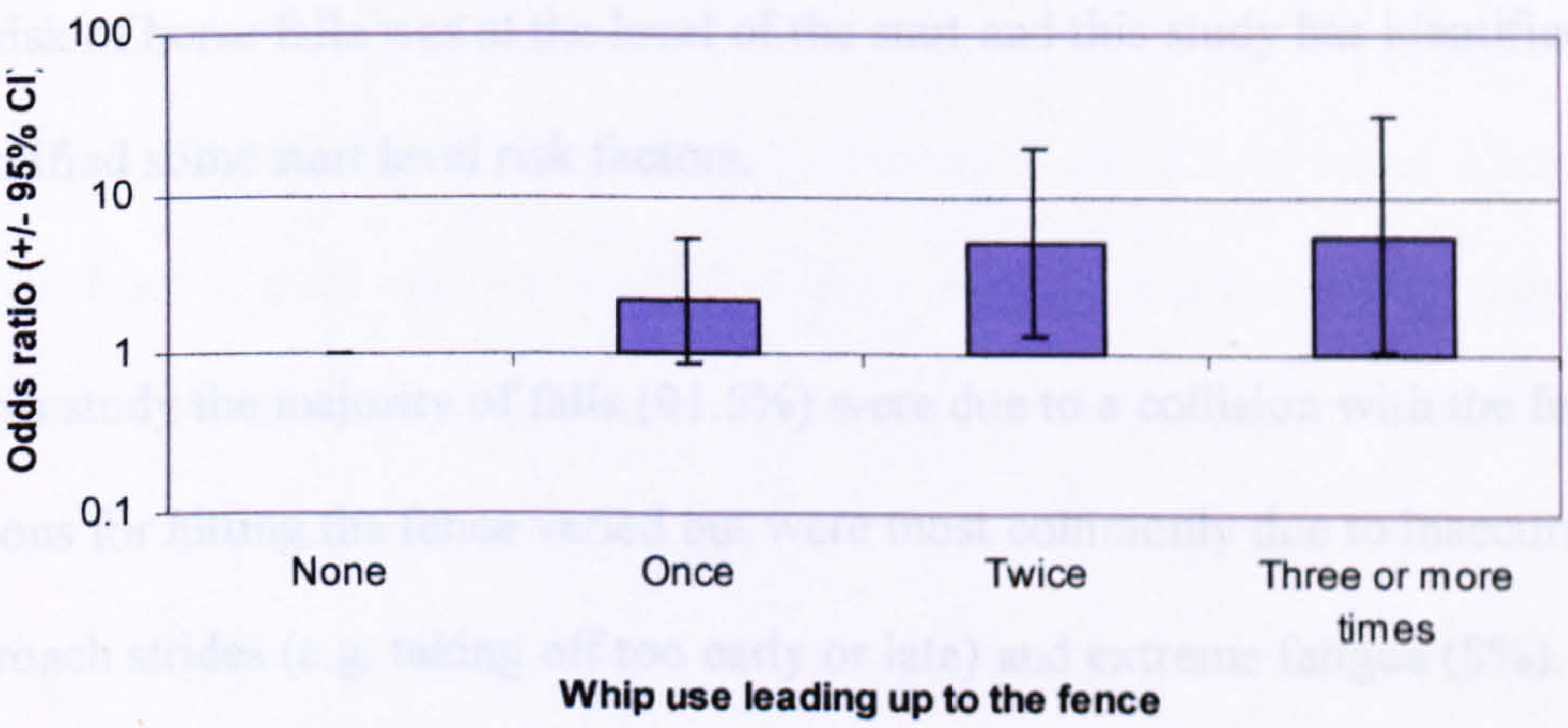

Figure 2. The relationship between the risk of falling and whip use adjusted for the position of the horse 2 fences previous and a horse in front in hurdle and steeplechase races on 6 UK racecourses.

Change in position from the first fence.

Although the position at the first fence was significant in univariable analysis, the change in position from the first fence to the fall fence explained more of the residual deviance and was significant in the final model. Horses that had progressed in position from the first fence to the fall fence were significantly more likely to fall than those that had not changed position or had gone backwards (OR 2.5, CI 1.2, 4.8).

Discussion

This study has provided information regarding the circumstances surrounding horse falls on 6 UK National hunt racecourses. In two retrospective studies of horse falls in hurdling and steeplechasing (Pinchbeck et al. 2002a & b) most of the variation in the risk of horse falls was at the level of the start and this study has identified and quantified some start level risk factors.

In this study the majority of falls (91.5%) were due to a collision with the fence. The reasons for hitting the fence varied but were most commonly due to inaccurate approach strides (e.g. taking off too early or late) and extreme fatigue (8%). Only horses that were obviously very fatigued were classed as fatigued (possible observation inaccuracies may have occurred if we had tried to assess mild fatigue) so this may be an underestimation. Previous studies have observed that the risk of falling increases at later hurdles and fences in the race (Pinchbeck et al. 2002c) and that the risk of distal limb fracture increases in the later part of races in National Hunt racing (Parkin et al. 2002). Rooney (1982) showed that race length was a factor in causing fatigue and lameness although this was flat racing only. In an earlier study by Vaughan and Mason (1975) that described some of the aspects of fatal falls on UK racecourses between 1970-1973, the authors observed that 9 of 29 horses that suffered vertebral fractures were near the end of the race when the accident happened.

Four horses jumping open ditches in this study appeared to misjudge the take off. The one fatal case at an open ditch in this study had a diagnosis of shoulder fracture that was based on clinical examination on the racecourse. Vaughan and Mason (1975) also described one case of scapula fracture and two cases of humeral fracture where a horse misjudged an open ditch and hit the fence. The author observed that 13 horses somersaulted after hitting the fence with their hind or forelimbs. The nature of the fall may be important with respect to injuries and all of the 3 cases of vertebral fracture in this study were somersaulted at the time of the fall. Vaughan and Mason (1975) also observed that 13/14 cases of cervical vertebral fracture occurred due to a fall at a fence and that all of these were subjected to trauma about the head or neck. Other than fatigue the reasons for the inaccurate approaches and hitting the fence are unclear. It may be due to rider error, poor visibility of the fence, due to other horses or it may be that some horses are inherently poor jumpers. Barrey and Galloux (1997) showed that in an accelerometry study of eight horses all ridden by instructor grade riders there was a significant horse effect on most of the parameters. A study by Powers and Harrison (2000) on the techniques used by untrained horses during loose jumping showed that horses in a "poor" jumping group, that consistently hit or knocked the fence, had a significantly increased approach horizontal velocity compared to a "good jumping group". The authors hypothesised that this higher speed may affect the horse's judgement of approach speed and distance from the fence. This study also showed that the angles of the carpi at take off were smaller in the "good" jumpers and it may be that some horses are better at tucking their forelimbs up during the jump. It is interesting to note that horses that previously brushed fences during the race or those that made mistakes did not seem to be at significantly greater risk of falling in this study and the numbers of mistakes and fence contact made by both cases and controls was high (table 1).

Previous analysis of accidents in horse racing utilising video recordings have been limited to racing accidents in Japan and flat racing accidents in the USA (Ueda et. al.1993, Cohen et al.1997) and to the study of fatal distal limb fractures in the UK (Parkin et al. 2002)

In this study having a horse directly in front at the point of take off increased the risk of falling (OR 2.9, 95% CI 1.1, 7.9) and 2 of the horses that fell after clearing a fence did so because of physical interaction with the horse in front. There may be some cross over in the classification of horse falls and being brought down by another horse. However, these two cases were left in the analysis as there was no error by the horses in front. Two other falling horses appeared to collide with another horse at their side at the point of take off although having a horse beside was not significantly associated with falling in the final multivariable model. Physical interaction during the race was associated with the risk of overall and catastrophic injuries in a matched study of 216 cases of musculoskeletal injury in flat racing on 4 US racecourses (Cohen et al. 1997). In the study by Ueda et al. (1993) accidents resulting from a collision with another horse were excluded from the analysis and figures detailing these were not published.

Univariable analysis showed that horses positioned in the middle or at the back of the field at the start or at the first fence were associated with a greater risk of falling than those in the front third of the field. This is similar to findings by Peloso et al. (1994) in a study on musculoskeletal racing injuries. However this study was in flat racing only and the aetiology of musculoskeletal injuries on the flat and injuries due to falling in jump racing are likely to be very different. In the final multivariable analysis the position at the start was confounded by the change in position from the first fence to the fall fence and horse in front and horse beside and these variables were retained in the model. Horses that had progressed in the race were at more risk of falling. The position of the horse at the time of the fall relatively to others in the field was not significantly associated with the risk of falling.

Whip use leading up to the fall fence was associated with falling in this study and there appeared to be a relationship between the number of times a horse was whipped and falling. Horses going forward and being whipped were at the most risk of falling. This may be because these horse are very extended and do not reduce their velocity in approach strides sufficiently before take off and therefore have a weak acceleration impulse by the fore and hind limbs at take off (Barrey and Galloux 1997). Horses with no change in position from 2 fences previous were also more at risk if the whip was used. Another possible explanation is that whip use imbalances the horse on the approach to the jump. Very few jockeys used the whip at the actual point of take off at the fence. In the study by Cohen et al. (1997) a protective effect of use of the whip was found for musculoskeletal injuries. However this study only recorded whip use from 12 seconds before the injury and, as the authors suggest, it is possible that the jockey had already recognised a problem and was reluctant to use the whip. In the study in Japan (Ueda et al. 1993) it was suggested that whip use was associated with racing accidents excluding those associated with a fence but this study did not use control horses. In a study by Parkin et al. 2002 horses receiving encouragement in the final 10 seconds before time of fracture were at greater risk of suffering a fatal distal limb fracture.

Because this study was conducted over a 2 year period control horses were eligible to become case horses and because the cases and controls were matched on jump number, in two races case horses were controls for a fall that occurred earlier in the race. However the result of this would have been to bias the odds ratios towards one because the control population would have been made more similar to the case population.

In conclusion this study has described some of the circumstances surrounding horse falls in National Hunt racing and has identified whip use and race progress as significant risk factors for these falls.

Acknowledgements

We gratefully acknowledge Mr Tim Parkin for instruction on the use of the TV and video equipment and Racetech for supplying the videos. Thanks also go to Dr R Christley and Mr J Hotchkiss of University of Glasgow for help with data entry.

Appendix to Manuscript 5

In this appendix a further description of all the fatal falls from the video study is presented along with the results from univariable analysis of the continuous variables.

The method used for assessing the fit of the model is also described. A plot of the standardised delta beta for whip use is shown where two observations had large delta betas. A multivariable model with these matched sets removed is also shown.

Finally results from a study investigating the association between sectional speeds (derived from the videos), number of runners and the risk of falling are presented.

Injuries sustained

The type of fall may be related to the subsequent injury sustained. In this study there were only eight fatalities so we were unable to perform any statistical analyses. Table 1 shows the causes of fatality and describes what happened at the fall.

Continuous variables

Table 2 shows the conditional unadjusted odds ratio and p-values for all continuous variables investigated in the study. Position refers to the position of the horse compared to other horses and the changes in position variables refer to the numerical change (positive or negative) in position between two points.

Table 1. Cause of fatality and description of the fall in the 8 fatal cases.

Injury	Race type	Description of fall
Shoulder fracture*	Steeplechase	Took off too early and extended front limbs into fence.
Shoulder injury*	Steeplechase	Very tired, failed to rise at take off and hit fence hard.
Shoulder fracture*	Steeplechase	Misjudged take off and put fore limbs in ditch and hit fence hard at shoulder level.
Cervical fracture	Steeplechase	Took off too early, didn't gain height, extended front limbs into fence and was somersaulted over fence
Cervical fracture	Hurdle	Caught front limbs on hurdle and somersaulted.
Cervical fracture	National Steeplechase	Ploughed through the fence and was somersaulted
Third metacarpal fracture	Steeplechase	Took off too early and extended front limbs into fence
Fetlock dislocation	Steeplechase	Hit fence and fell awkwardly on landing. Immediately lame, ran on and then completely dislocated fetlock

* No post-mortem report available

Table 2. Continuous variables investigated during video analysis for association with falling in hurdle and steeplechase racing on 6 UK racecourses (February 2000-November 2001)

Variables	Odds ratio (per unit change in variable)	P-value
Position start	1.02	0.3
Position first	1.04	0.2
Position 2 fences previous	1.01	0.8
Position 1 fence previous	0.9	0.9
Position at fence	0.97	0.4
Change in position from 1st to fall fence	1.05	0.1
Change in position 2 previous to fall fence	1.04	0.39
Change in position 1 previous to fall fence	1.03	0.53

Assessing the fit of the model

Standardised delta - betas were assessed for all variables in the final multivariable model. The multivariable models were then repeated with the matched sets containing the observations with the largest delta betas removed. Any changes in coefficients and standard errors were then noted. Figure 1 shows an example of the standardised delta beta for whip use. Observation 250 and 328 had the largest delta betas. Table 3 shows the multivariable model repeated with these matched sets excluded from the analysis.

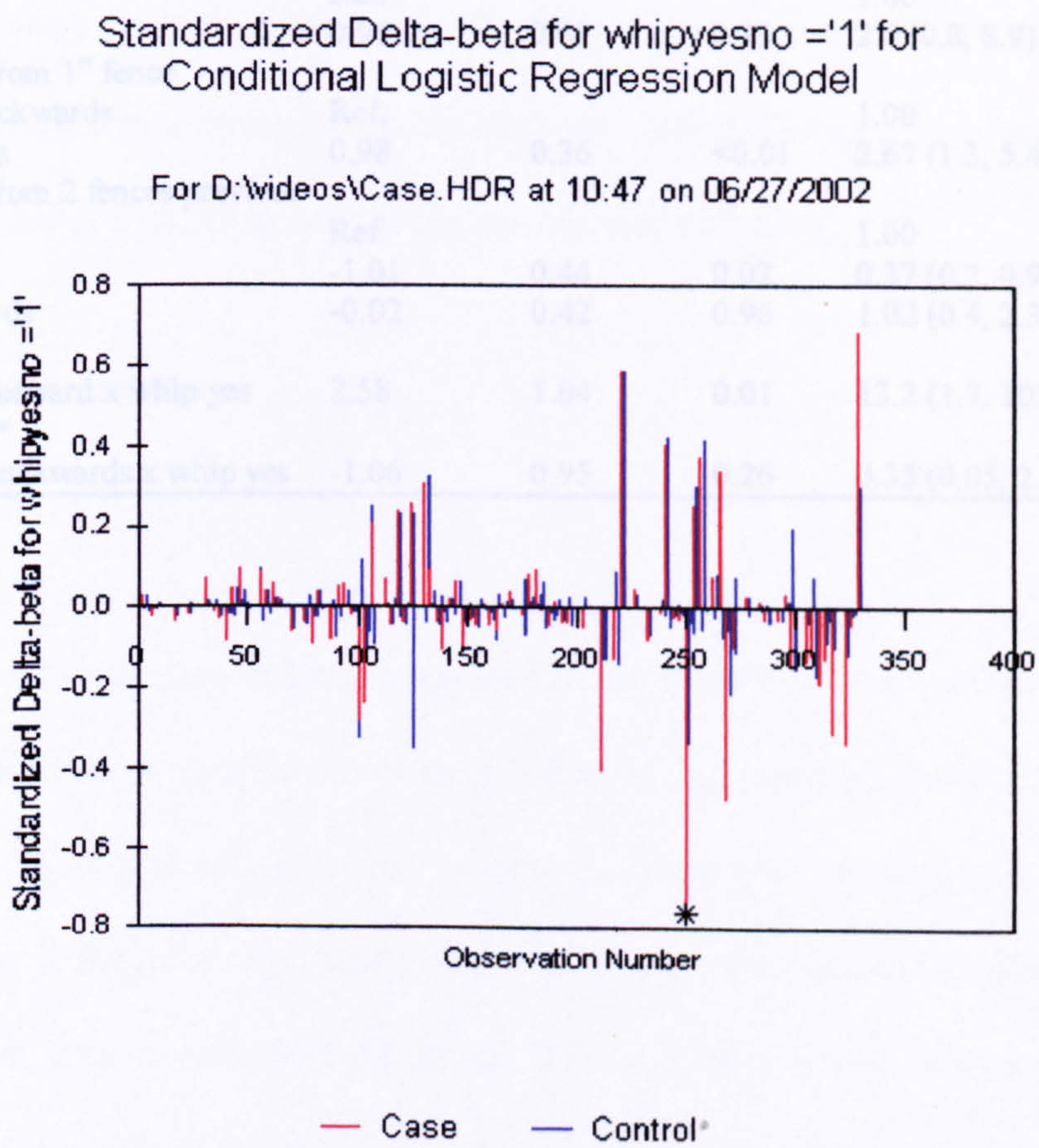

Figure 1: Standardised delta-beta for whip use. *=Observation 250

Table 3: Multivariable model with observation set 72 (observation 250) and set 57 (observation 328) removed from analysis.

Variable	Coefficient	Std. Error	P value	Adjusted odds ratio (95% CI)
Horse in front				
No	Ref.			1.00
Yes	1.06	0.50	0.04	2.9 (1.07, 7.8)
Horse beside				
No	Ref.			1.00
Yes	0.59	0.41	0.15	1.80 (0.8, 4.0)
Whip use at fence				
No	Ref.			1.00
Yes	0.96	0.63	0.13	2.6 (0.8, 8.9)
Position change from 1st fence				
None/backwards	Ref.			1.00
Forwards	0.98	0.36	<0.01	2.67 (1.3, 5.4)
Position change from 2 fences previous				
None	Ref.			1.00
Forward	-1.01	0.44	0.02	0.37 (0.2, 0.9)
Backwards	-0.02	0.42	0.96	1.02 (0.4, 2.3)
Interaction term*				
Position change forward x whip yes	2.58	1.04	0.01	13.2 (1.7, 103.2.3)
Interaction term**				
Position change backwards x whip yes	-1.06	0.95	0.26	0.35 (0.05, 2.2)

Investigation of the association between sectional speeds, number of runners and the risk of falling in steeplechasing.

Overall winning speed of the race and the number of starters in the race have been shown to be significantly associated with falling and fatality in previous studies (Pinchbeck et al. 2002c; Wood et al. 2002). However, sectional speeds are not currently published in jump racing in the UK. The aim of this study was to use video analysis to examine the relationship between sectional speeds between each jump, the number of runners at each jump and the risk of falling

Material and methods

Data Collection

Racetech videos of the steeplechase races used in the study described in manuscript 5 were used for the analysis. The races were followed and sectional times from the start to the first fence and between each subsequent fence were recorded using slow motion viewing of the race. The time point at each fence was defined as when the leading group of horses took off at the fence. The number of horses remaining in the race at each fence and the number of fallers at each fence was also recorded. Exact distances between each fence were available from visits made during the case-control study described in manuscript 7. From these variables the sectional speeds between each fence and the proportion of horses that fell at each fence were calculated.

Statistical Analysis

The individual observations were grouped at each jump so the data were grouped by number of runners (number of horses) at each jump representing the total number of observations with a given covariate pattern. The outcome was the proportion of fallers within the group. Logistic regression methods using maximum likelihood estimation were used for both univariable and multivariable analyses. Continuous variables were considered first as linear in their relationship and then polynomial terms were considered. Interaction terms were tested between all biologically plausible sets of terms.

Extra binomial variation was allowed for between races by including race as a random effect and between jump numbers within the race by including jump number as a fixed effect within the model.

A restricted data set of first fences only was also analysed to examine the relationship between number of runners, speed and distance to the first fence and falling.

Results

There were 56 steeplechase races available for analysis. Table one shows descriptive statistics of the variables.

Table 1: Descriptive statistics of the continuous variables used to examine the relationship between sectional speeds and the risk of falling in steeplechase racing.

Variable	Mean	Minimum	Maximum
Distance between fences (yards)	261	81	939
Speed (furlongs per minute) between fences	3.6	1.6	7.8
Proportion fallers at each fence	0.012	0.0	0.5
Number runners	9	1	40

There was no significant association between the sectional speeds from fence to fence and the risk of falling (Table 2). The number of the jump was associated with the risk of falling.

Table 3 shows the results of the restricted data set of first fences only. The results show that number of runners was significantly associated with first fence fallers with an odds ratio of 1.2 for every increase in number of runners by 1 horse. However this result was influenced by races over the Grand National course as if these were omitted number of runners was no longer significant (β=0.04, P=0.8)

Table 2: Multivariable model of sectional speed between fences and the relationship with the risk of falling. The outcome was the proportion of horses that fell per group (number of runners) at each fence.

Variable	Coefficient (β)	St. Error	P-value
Random effect			
Race	0.27	0.21	
Fixed effects			
Speed (furlongs per min)	0.03	0.25	0.9
Jump number	0.05	0.02	0.01

Table 3: Multivariable model of the relationship between the risk of falling at the first fence and distance to the first fence, speed and number of runners. The outcome was a binary variable of fallers at the fence or no fallers

Variable	Coefficient	St. Error	P-value
Distance to start	-0.01	0.01	0.5
Number of runners	0.21	0.10	0.04
Speed (furlongs per minute)	0.41	0.93	0.66

Discussion

We were particularly interested in sectional speeds as there have been no previous published reports of the relationship between sectional speeds in jump racing and the risk of falling or injury. In flat racing winning speed has been investigated as a risk factor for musculoskeletal injury but no association was reported (Cohen et al. 1999). In contrast previous studies in hurdle racing have shown that overall winning speed was significantly associated with the risk of falling (Pinchbeck et al. 2002c) and of fatality (Wood et al. 2002). Sectional speeds are likely to be more variable in jump racing compared to flat racing because of their longer distances, the presence of obstacles and the tactics involved. Results from this study suggest that on the six racecourses investigated sectional speeds were not important in the risk of falling in steeplechase racing. Unfortunately data for sectional speeds in hurdle racing were not available as the distance between the hurdle flights changes regularly between race days. Jump number in the race was associated with the risk of falling with jumps later in the race associated with an increased risk. This is consistent with results from a case-control study on the risk of falling in steeplechase racing (manuscript 7). That study did not find any association with winning speed and the risk of falling.

Although logistic regression models were used to analyse this data another approach would be to use survival analysis with time-dependent covariates. This method would also allow for the censoring of horses that occur throughout the race due to falling, being pulled up or refusing.

Manuscript 6

A case-control study to investigate risk factors for horse falls in hurdle racing in the UK.

Pinchbeck, G.L. Clegg, P.D., Proudman, C.J., Morgan, K.L., French. N.P.

Department of Veterinary Clinical Science and Animal Husbandry, University of Liverpool, Leahurst, Neston, CH64 7TE, UK.

Corresponding Author. G.L. Pinchbeck

Key words: Hurdle racing; horse falls; case-control study

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Abstract

A case-control study was conducted on 12 UK racecourses from 1st March 2000 to 31st August 2001 to identify and quantify risk factors associated with horse falls in hurdle racing. A unique definition of cases and controls was used to allow variables relating to the horse, the jockey, the race and racecourse and the jump to be considered within a single study. Cases were defined as a jumping effort at a hurdle flight that resulted in a fall. Controls were defined as a successful jumping effort over a hurdle at any of the 12 racecourses within 14 days either before or after the case fall. Conditional logistic regression was used to examine the univariable and multivariable relationships between predictor variables and the risk of falling. The risk of falling was significantly associated with the jump number in the race and the distance and speed of the race. The horses previous racing experience and history were also significantly associated with the risk of falling and horses participating in their first ever hurdle race were at almost 5 times the risk of falling compared to those that had hurdled before.

Introduction

Horse fatalities and injuries are of great concern to the Thoroughbred racing industry in terms of their impact on animal welfare, the economics of racing and because of the negative impact that such injuries, occurring on the racecourse, have on the public perception of racing.

Fatalities occur in all types of racing but the fatality rate is higher in hurdling than for flat racing. In the UK, fatality rates of 0.1 per 100 starts in flat racing and 0.52 per 100 starts in hurdle racing have been reported between 1990 and 1999 (Wood et al. 2000). Around 43% of all fatalities in racing occur in hurdle racing despite these races accounting for only 25% of all starts in the UK (Wood et al. 2000). A study by Bailey et al. (1998), conducted at 4 Australian racetracks, found incidence rates for fatal musculoskeletal injury of 0.06% for flat racing and 0.63% for hurdling. Furthermore, this study identified firmer tracks, older horses and one particular racecourse as significant risk factors, although these were not specific for hurdle racing. Although musculoskeletal injuries are the commonest cause of racecourse fatality (Williams et al. 2001), most previous studies have failed to differentiate between different causes of death. In two descriptive studies of fatalities on UK racecourses between 55% (Vaughan and Mason 1975) and 50% (McKee 1995) of all fatalities in jump racing were associated with falls. In a previous study examining all starts in hurdle racing during 1999, the falling rate was 2.1 per 100 starts and 35% of all fatalities were associated with a fall (Pinchbeck et al. 2002b).

Hurdle racing takes place on 42 racecourses in the UK and all hurdle flights are uniformly made and placed according to Jockey Club regulations. The hurdles should be not less than 105 centimetres in height from top to bottom. When placed the top bar should be between 90-95 centimetres above the ground with an overlay of the top bar in the direction of racing of 45 centimetres beyond the bottom bar. However there will be differences at each flight in regard to gradients, placement in the race and, in this study, padding.

The main objectives of this study were to use a case-control study design to identify risk factors associated with falling during hurdle racing at horse, race, jump and jockey levels.

Materials and methods

Study design

A concurrent case-control study was conducted on 12 UK racecourses from 1st March 2000 to 31st August 2001. The racecourses were selected partly due to their membership of the Racecourse Holdings Trust Ltd (Aintree, Cheltenham, Haydock, Huntingdon, Kempton, Market Rasen, Sandown, Warwick) and partly to give variation in the type of racecourses with respect to prize money offered and topography of the course (Bangor-on-Dee, Carlisle, Cartmel, Stratford). Based on estimates of the incidence of falling from the Jockey Club, of 2 falls per race day, at least 100 cases were expected over this study period. With 2 controls per case this would give an estimated 80% power to detect odds ratios of 2 or more with an exposure of 50% in the controls and odds ratios of 2.5 or more with an exposure of 20% in controls with 95 per cent confidence. The controls were matched on time.

Identification and selection of cases and controls

Cases were defined as a jumping effort at a hurdle flight that resulted in a fall, identified from racing records (Racing Post online-www.racingpost.co.uk). Cases were verified against an independent data source (Raceform Ltd) and 49% of the cases were verified by author attendance at the racecourse during races. Jumping efforts in which the rider was unseated or in which the horse was brought down by another horse were not included in the case definition. Controls were defined as a successful jumping effort over a hurdle at any of the 12 racecourses within 14 days either before or after the case fall. In this way the controls were matched on time. To enable selection of controls a record of jumping efforts in every hurdle race on the 12 courses was kept during the study period. The number of jumping efforts available as controls 14 days before and after the case was then counted and 2 controls were selected for each case using random number generation (Epi-Info 6.04, CDC, USA). This unique definition of cases and controls, used first in a study identifying risks for horse falls in 3-day eventing (Singer et al. 2003), allowed variables relating to the horse, the jockey, the race and racecourse and the jump to be considered within a single study.

Variables on jockeys, horses and races were collected from Raceform Ltd. and Racing Post online and variables about the course and jumps were collected by 2 visits to each racecourse and by consultation with the Jockey Club racecourse inspectors. The variables available for analysis are shown in Table 1. Variables relating to the horses' previous racing exposure and performance were measured throughout their career, whereas those relating to the jockey's previous racing exposure related to the previous 12 months only. The padding of hurdle flights was a new recommendation from the Jockey Club in 2000 and different racecourses installed padded hurdles at different times throughout the study period, with 2 racecourses selectively padding only some of the hurdle flights on their course. Traditionally, distances on racecourses are measured in furlongs and this unit of measurement was used in this paper. One furlong is equal to 198 metres.

Table 1: Description of variables available for analysis in a case-control study of falling in hurdle racing on 12 UK racecourses.

Variable	Description
Racecourse	ID for each of the 12 racecourses
Track direction	Left or right
Going	Condition of track surface - Good to firm, good, soft, good to soft, soft, heavy
Speed	Winning time divided by distance
Distance	Distance of race in furlongs
Race classification	Handicap, novice, maiden, selling, juvenile
Race class	Official class A-H
Field size	Number of horses starting the race
Prize money	Prize money available in race
Number of jumps	Total number of hurdle flights in the race
Jump number	Jump number in the race of case or control
Gradient	Gradient at flight –flat, uphill or downhill.
Padded	Hurdle flight padded, yes or no.
Number fallers	Total number fallers in the race
Race number	Number of hurdle race that day
Horse gender	Male or female
Horse age	Age at time of start
Horse aged when raced	Age of horse at first ever start
Horse age hurdled	Age of horse at first hurdled start
Country of breeding	Country of birth place, UK, Ireland, USA, Europe, Australia.
First race type	First race type under rules – Flat, national hunt flat, hurdle, chase
Previous number races	Total number starts under rules
Previous flat races	Total number flat starts
Previous hurdle races	Total number hurdle starts
Previous chase races	Total number chase starts
Previous number wins	Total wins in any race type
Previous number falls	Total previous falls in hurdling or steeplechasing
Days since last ran	Number of days since previous start
Race frequency 3 months	Number starts of any type race in last 3 months
Race frequency 12 months	Number starts any type race in last 12 months
Official rating	Official BHB rating at time of race
Weight carried	Weight carried by horse in pounds
Head gear	Headgear worn during race – none, blinkers, visor
Tongue tie	Tongue tie worn in race – yes, no
Jockey gender	Male female
Jockey allowance	Professional or claiming 7, 3 or 5lbs
Previous races jockey	Number hurdle races ridden in the last 12 months
Previous races 1 month	Number hurdle races ridden in the last month
Previous race this course	Number previous hurdle races ridden on that hurdle course
Previous falls per 10 races	Number previous falls by jockey per 10 hurdle races started in last 12 months
Previous wins jockey	Number previous hurdle winners ridden in last 12 months

Statistical analysis

The dependent variable for all the analyses was the outcome of the jumping effort with cases defined as falls and controls as successful jumping events. To take account of the matching, conditional logistic regression methods using maximum likelihood estimation were used for both univariable and multivariable analyses. Continuous variables were considered first as linear in their relationship with the outcome and then categorised into 4 or 5 categories representing the four quartiles or five quintiles of that variable. If the categorical relationship between the variable and the outcome suggested a non-linear relationship then polynomial terms were considered. Interaction terms were tested between all biologically plausible terms with a particular hypothesis that interactions between speed, distance and jump number may exist. Due to the large number of potentially correlated, independent variables available for analysis, and to avoid multicollinearity, simple correlation analysis was performed (Dohoo et al. 1997). If correlated variables were found (Pearson correlation coefficient > 0.8) only the variable which explained most of the residual deviance was included in the final model. Variables with a p-value<0.3 and those considered *a priori* to be of particular biological importance were considered for inclusion in a multivariable model. The inclusion of too many predictor variables may lead to over parameterisation resulting in over fitting and shrinkage (Martin 1997), so the most parsimonious model was selected by using continuous terms when a log-linear fit was appropriate and by collapsing variables into categories based on initial model results. After development of the final multivariable model racecourse was forced into the model to assess any changes in coefficients. The critical probability throughout was 0.05.

The fit and stability of the model was assessed by calculating the sensitivity and specificity at varying predicted value cut off points and by examining the delta-betas

(Pregibon 1981). All analyses were performed in EGRET (Egret Application 2.0, Cytel Software Corporation)

Results

One hundred and twenty seven cases were identified over the study period and the 254 control jumping efforts were selected from a total of 56723 successful jumping events. The results indicated a frequency of falls of 1 per 447 jumping efforts. The fatality rate amongst the fallers was 7%. Table 2 shows the causes of fatality, although not all cases received post mortem confirmation of the cause of death. The final multivariable model is shown in Table 3.

Table 2: Cause of fatality or reason for euthanasia in the 9 fatal cases of falling identified during the study.

Cause of fatality	Number of cases
Vertebral fracture	4
Radial fracture	2
Pelvic fracture	1
Shoulder fracture*	1
Vascular catastrophe*	1

* No Post Mortem performed

TABLE 3: Final multivariable conditional logistic regression model of risk factors associated with horse falls in hurdle racing on 12 UK racecourses from 1st March 2000 to 31st August 2001. The table shows coefficients, standard errors and p-values for all variables and odds ratios and 95% confidence intervals (CI) of odds ratios for categorical variables.

Variable	Coefficient	Std. Error	Wald test p-value	Odds ratio	Lower 95% CI	Upper 95% CI
Continuous						
Previous number wins	-0.30	0.09	< 0.001			
Number races last 3 months	0.20	0.10	0.046			
Number Previous hurdle races	0.06	0.02	0.007			
Falls per 10 hurdle races run	0.35	0.17	0.047			
Prize money (per £1000 increase)	0.07	0.03	0.009			
Jump number of fall	0.34	0.06	< 0.001			
Categorical						
First fence						
-No	Ref.			1.00		
-Yes	1.15	0.55	0.036	3.16	1.08	9.25
First hurdle race						
-No	Ref.			1.00		
-Yes	1.52	0.49	0.002	4.56	1.73	12.02
Race number that day						
-First	Ref.			1.00		
-Second	0.66	0.37	0.074	1.92	0.94	3.94
-Third	1.25	0.38	<0.001	3.50	1.68	7.32
Hurdle padded						
-No	Ref.			1.00		
-Yes	-0.70	0.45	0.115	0.49	0.21	1.19
Novice race						
-No	Ref.			1.00		
-Yes	-1.45	0.40	< 0.001	0.23	0.11	0.51
Distance						
<17.5 furlongs	Ref.			1.00		
≥17.5 furlongs	0.65	0.58	0.267	1.91	0.61	5.96
Speed						
≤3.9 furlongs/minute	Ref.			1.00		
>3.9 furlongs/minute	2.18	0.67	0.001	8.88	2.40	32.85
Interaction term						
Distance ≥17.5furlongs and speed > 3.9 furlongs/minute	-2.39	0.72	< 0.001	*0.09	0.02	0.38

Deviance 177.4. Likelihood ratio test 100.8 ($p<0.001$). Degrees Freedom = 15

*i.e. the odds ratio for a race that was ≥ 17.5 furlongs and >3.9 furlongs per minute was estimated to be 1.91x 8.88 x 0.09 = 1.5.

Race and fence variables

Compared with the first flight, there was an initial decline in the risk of falling followed by a steady increase between jump numbers 3 and 10 (figure 1). In the final model this was best described by two terms, a binary term representing the first flight (odds ratio for first flight 3.2) and a continuous term for subsequent flights.

There was an interaction between distance, speed and falling. After allowing for other confounding variables (including going) it was evident that in short races (<17.5 furlongs) faster speeds were associated with an increased risk of falling (figure 2) whereas the opposite was evident for longer races. Compared to the slowest, shortest races (<17.5furlongs and < 3.9 furlongs/minute) the risk of falling was greatest for fast short races (OR=8.9, 95% CI=2.4, 32.8). This was modelled in the final multivariable model by fitting two categories of distance (16-17 furlongs and greater than 17 furlongs) and two categories of speed (3.2-3.9 furlongs per minute and greater than 3.9 furlongs per minute) plus an interaction term between these two. After allowing for speed and distance, going was not significantly associated with falling and was not an important confounder.

Padded fences were not significantly (p=0.1) associated with falling. The apparent two-fold reduction in risk had confidence intervals that included the null value (OR=0.5, 95% CI=0.2, 1.2). This variable was included in the final model both as an important confounder and to demonstrate the size and direction of the relationship with falling.

The hurdle race number on that day was also significantly associated with the risk of falling with the third hurdle race being 3.5 times more likely to be associated with a fall compared to the first race. The prize money of the race was also significantly associated with the risk of falling (odds ratio for every 1000 pounds increase 1.05).

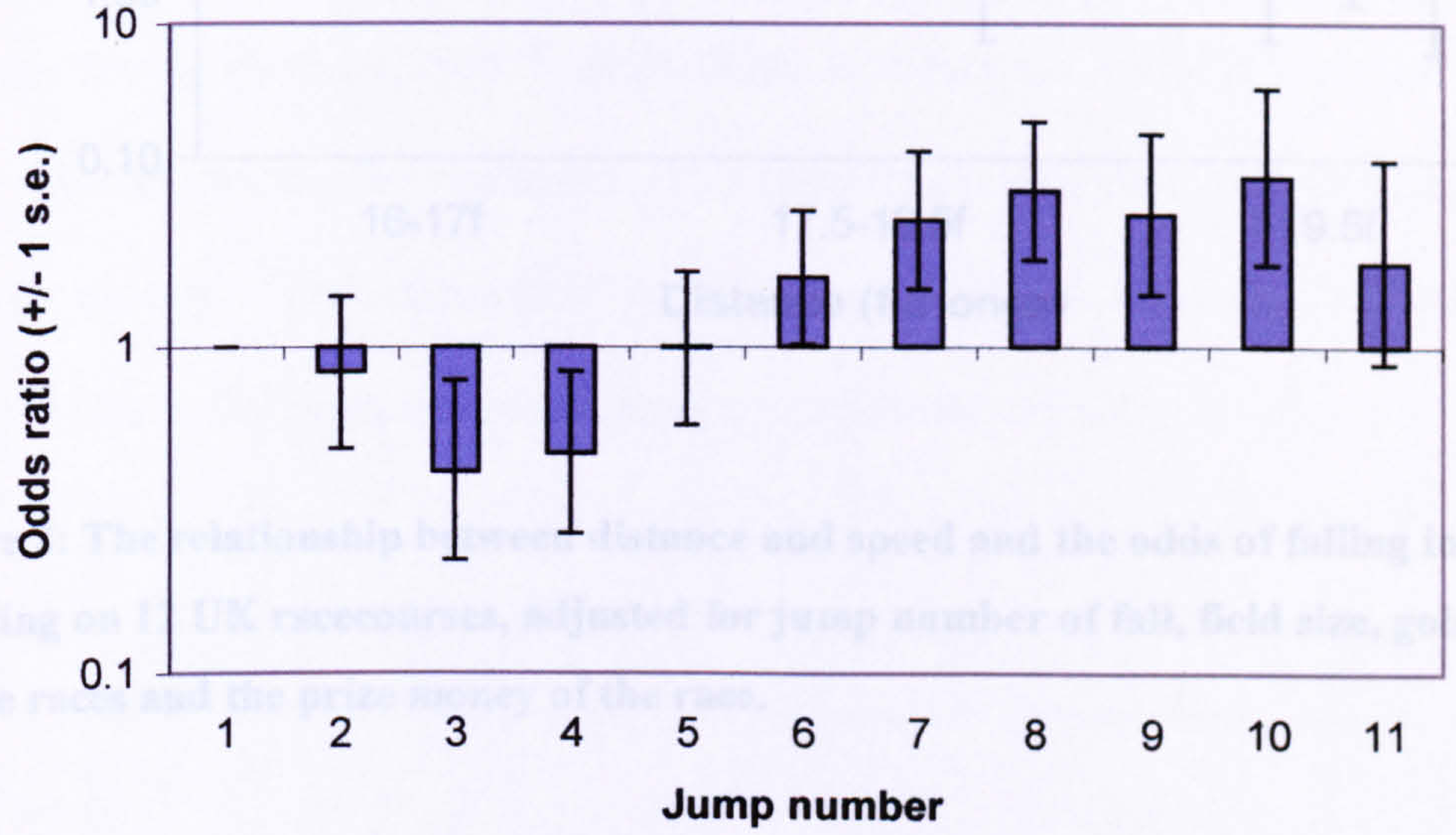

Figure 1: The univariable odds of falling at each jump number compared to the first jump in hurdling on 12 UK racecourses.

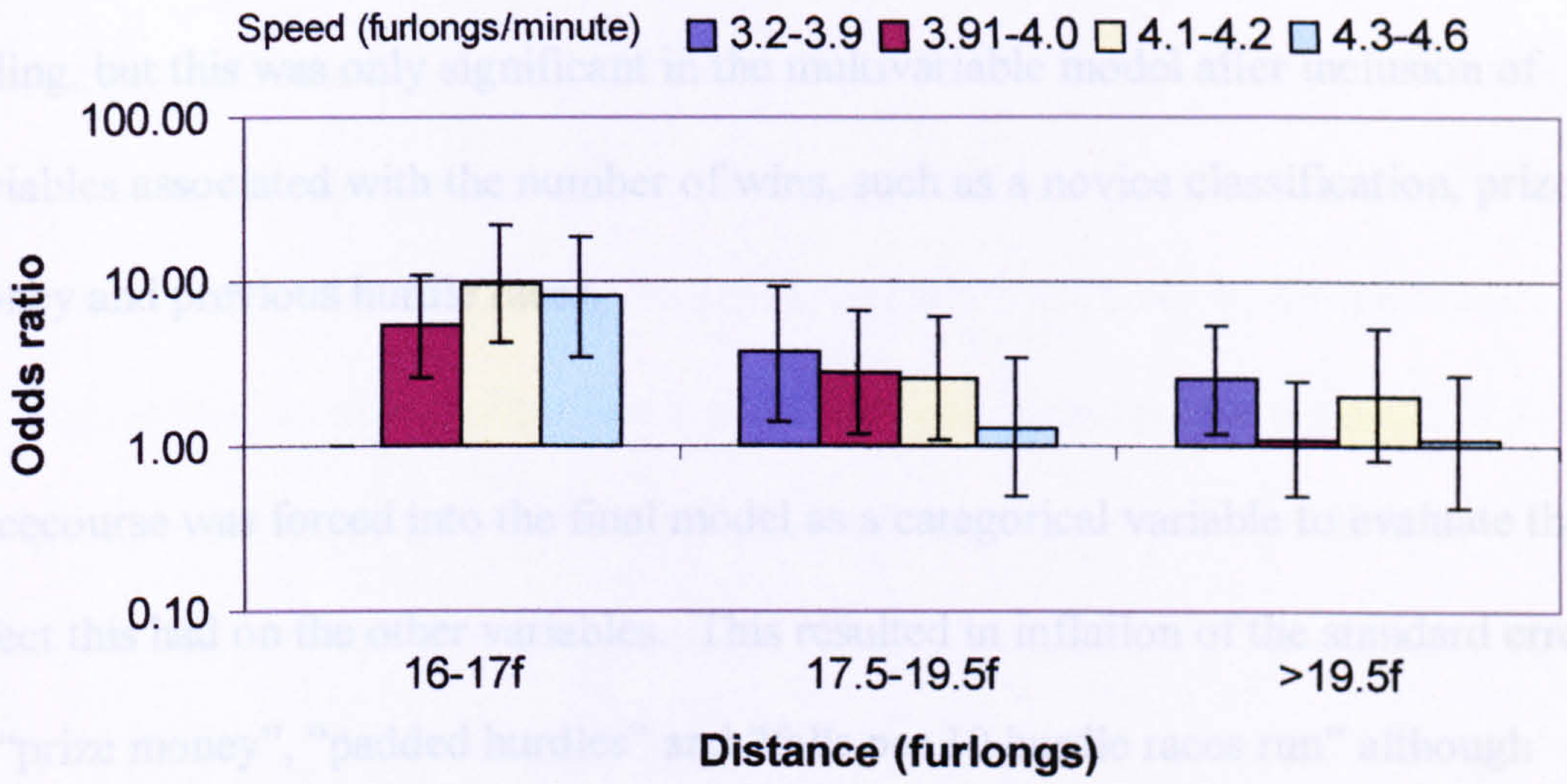

Figure 2: The relationship between distance and speed and the odds of falling in hurdling on 12 UK racecourses, adjusted for jump number of fall, field size, going, novice races and the prize money of the race.

Horse level variables

Horses that had never hurdled before were at an almost five-fold increased risk of falling compared to all other horses. However, after allowing for the first race, there was a small but significant increase in the risk the greater the number of hurdle races in the horse's career. This is shown graphically in Figure 3 after allowing for confounding by other variables. In the final model this was best described by two terms, a continuous linear term for previous number of hurdle races and a binary variable to describe if this was the horse's first ever hurdle race. The greater the number of starts the horse had in any type of race in the previous 3 months, the greater the risk of falling. The number of previous falls a horse had was also associated with an increased risk of falling, with an estimated odds ratio of 1.4 for every extra fall per 10 hurdle races started. An increase in the number of previous wins a horse had in any type of racing was associated with a decrease in the risk of falling, but this was only significant in the multivariable model after inclusion of variables associated with the number of wins, such as a novice classification, prize money and previous hurdle races.

Racecourse was forced into the final model as a categorical variable to evaluate the effect this had on the other variables. This resulted in inflation of the standard errors of "prize money", "padded hurdles" and "falls per 10 hurdle races run" although there was little change in the coefficients of any of the variables.

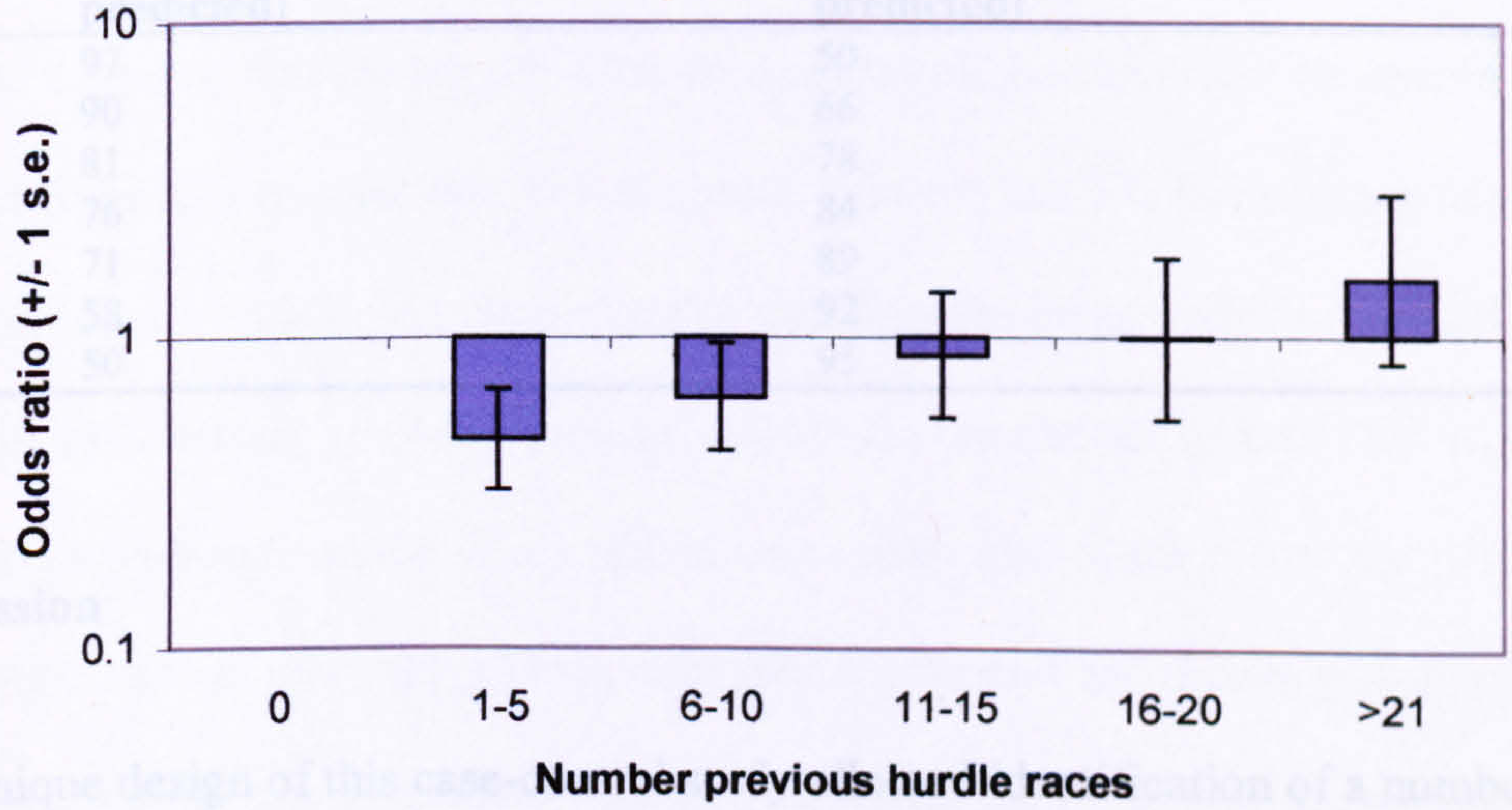

Figure 3: Relationship between the number previous hurdle races the horse has started in and the risk of falling in hurdling on 12 UK racecourses, adjusted for number previous wins, number of runs in last 3 months and falls per hurdle races run.

Assessing the fit of the final model.

Examination of the delta betas (approximation of the amount an estimated regression coefficient would change if a given observation were omitted from the regression fit), showed the model to be stable and removal of matched sets containing data observations with the largest delta betas had very little effect on the size of the odds ratio or the significance of individual variables. The fit and predictive ability of the model was assessed by calculating the sensitivity and specificity of the model predicted values at various cut off points (Table 4). For example at a cut off of 0.3 (i.e. if the predicted probability is above 0.3 the horse is predicted to fall) the sensitivity was 81% and the specificity was 78%.

Table 4: Sensitivity (fallers) and specificity (non-fallers) of the multivariable conditional logistic regression model, shown in Table 3, at various cut-off points.

Cut-off	Sensitivity (% of fallers predicted)	Specificity (% of non-fallers predicted)
0.1	97	50
0.2	90	66
0.3	81	78
0.4	76	84
0.5	71	89
0.6	58	92
0.7	50	95

Discussion

The unique design of this case-control study allowed identification of a number of variables associated with the risk of horse falls in hurdling on 12 racecourses in the UK. It will help to identify high-risk horses and indicate areas for possible intervention studies, which may reduce the incidence of horse falls. The death rate amongst the fallers of 7% was similar to that from a study examining horse falls on all UK hurdle courses during 1999 of 7.1% (Pinchbeck et al. 2002b).

The greater risk of falling at the first flight compared to flights 2-4 may be due to lack of concentration at the beginning of the race, greater speeds in this early part of the race or close proximity of other horses in the field leading up to the first flight. The increase in falling at later flights may be due to fatigue, sectional speeds or a "racing for the finish line" effect as extended horses find it more difficult to jump. The number of hurdle flights in a race is now governed by the Jockey Club, which states that there must be at least 8 flights in the first two miles of the course, with an additional flight for every additional quarter of a mile.

The finding that faster speed races were associated with a significantly increased risk only over shorter distance races (17 furlongs or less) was surprising. Although it may be expected that the longer distance races would be run at slower speeds, 45% of starts over 20 furlongs were run at speeds greater than 4.0 furlongs per minute in this case-control study. It is important to note that the measurement of speed used (and the only readily available measurement) was the overall speed of the winner of the race, which may not be a true reflection of the speed of the fall or the successful jumping events in this study. This initial model of speed and distance allowed for the going (condition of the track surface as defined by the clerk of the course on the day of racing) because of the potential confounding effect that going may have on speed. Going may also interact with speed, although a 3-way interaction term between distance (as a continuous variable), speed (as a continuous variable) and going was not significant. Wood et al. (2001a) found that winning speed, going and distance were all significantly associated with the risk of fatality in hurdling and there was also evidence of a significant interaction between firmness of going and racing speed. Although going was not significantly associated with the risk of falling in our final multivariable model, we observed a univariable trend of softer and heavy going associated with a decrease in the risk of falling. This was similar to that found in previous studies on falling in hurdle racing (Pinchbeck et al. 2002b), fatalities (Wood et al. 2001b) and injuries (Bailey et al. 1998, Williams et al. 2001).

The observation that the third hurdle race on the track on that day was associated with an increased risk of falling may be due to numerous factors that warrant further investigation. Third hurdle races are often the last of the race day and will be run on ground damaged by previous races. Alternatively, light conditions at that stage of the day may not be optimal due to either blinding from sunset or lack of light in the winter months. Furthermore horses generally travel to the racecourse in groups and horses running in the last race may have been at the racecourse all day, usually without food (manuscript 4).

The padding of hurdles was introduced gradually on racecourses during the period of study. This was a Jockey Club and racecourse initiative which took place during the study period, specifically to try and reduce injury rates, and particularly degloving injuries, in hurdling. Courses undertook padding of hurdles at different times in the study period and some courses had only some of the hurdles on their courses padded for part of the study. As this intervention was not randomly allocated to racecourses throughout the study period the results should be interpreted with caution. The hurdles were padded along the top rail and along the vertical standards with rubber padding that was painted bright orange. The relationship between padding and falling was assessed in this study by including the variable in models along with other potential confounding variables. Although the final adjusted relationship between padding and falling was not significant, the size and direction of the relationship warrants further investigation. The estimated odds ratio was 0.5, suggesting a two-fold reduction in risk associated with padding, but this had wide confidence intervals (95% CI 0.2, 1.2). There have been no published reports to date on whether padding has decreased the injury rates during hurdling.

The previous racing experience of the horse was associated with falling; the number of previous hurdle races, the number of previous wins and the racing frequency were all related to the risk of falling. Horses starting in their first ever hurdle race were almost 5 times more likely to fall and this was consistent with previous findings (Pinchbeck et al. 2002b). However, after allowing for the 'first race' effect an increase in the number of hurdle races after the first hurdle was associated with a small but significant increase in the risk of falling. This may reflect a difference in the population of horses that stay hurdling and do not progress to chasing or it may be that horses regularly competing in hurdle races do not receive as much schooling over fences or hurdles during training. It was possible that informed censoring occurred (horses were withdrawn from racing because of a fall) and although it was not possible to measure censoring this could have given rise to inflated or deflated odds ratios for some horse-level variables.

An increase in the number of races of any type in the previous 3 months was also associated with an increased risk of falling and this may be due to an "over racing" effect or fatigue effect. The number of previous wins a horse had in any type of racing was associated with a decreased risk of falling and this is probably a reflection of the horse's racing ability. Horses that had fallen more in their previous hurdle races were at greater risk of falling again. This is consistent with findings from previous studies looking at areas of clustering within levels of racing hierarchy on the outcome of falling, which showed that most higher level clustering, both in hurdling and steeplechasing, was at the level of the horse (Pinchbeck et al. 2002a and b).

The official British Horse Racing Board (BHB) rating was considered in this study and in univariable and multivariable analysis higher rated horses were at slightly increased risk of falling. However the official rating was correlated with the number of previous hurdle races, the number of wins and novice races and so was not included in the final multivariable model. Also the official BHB rating is to some degree a subjective measurement and horses from overseas may not be appropriately rated. In a previous study on falling in hurdle racing on all tracks in the UK in 1999, no association was found between the risk of falling and the rating of the horse (Pinchbeck et al. 2002b). In this study there may an overrepresentation of highly rated horses competing in high prize money races, such as those at Cheltenham, Aintree and Sandown. An increase in prize money of the race was associated with an increased risk of falling and this may be due to the competitive nature of these races. However, prize money was confounded by racecourse and was no longer significant when racecourse was forced into the model.

This case-control study forms part of a project to investigate and quantify risk factors associated with horse falls in hurdle racing. To our knowledge this is the first investigation of its kind. These results provide support to the theory of an increased risk of injury associated with a horses first hurdle race and the introduction of schooling races, or a change to schooling practices, are possible interventions. The study also identified some areas that warrant further investigation such as the increased risk associated with the first flight, the increased risk at faster speeds in short races and the increased risk associated with the last hurdle race of the day.

Acknowledgements

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Appendix to Manuscript 6

Univariable analysis

Tables 1 to 4 show descriptive statistics and the univariable relationship between horse, race and jockey level categorical and continuous variables and the risk of falling in hurdle racing, using conditional logistic regression models.

Table 1. Descriptive statistics and univariable conditional logistic regression analyses of race level variables and their relationship with the risk of falling from a case-control study in hurdle racing on 12 UK racecourses.

Variable	Description	Controls (n)=254	Cases (n)=127	Conditional unadjusted Odds Ratio	P-value
Categorical variables					
Racetrack	Aintree	7	7	Ref.	
	Bangor	33	16	0.33	0.2
	Carlisle	12	5	0.27	0.2
	Cartmel	12	4	0.18	0.1
	Cheltenham (New)	11	7	0.53	0.5
	Cheltenham (Old)	8	10	1.18	0.9
	Haydock	22	7	0.22	0.06
	Huntingdon	28	16	0.43	0.3
	Kempton	9	1	0.07	0.04
	Market Rasen	39	21	0.41	0.3
	Sandown	6	1	0.11	0.1
	Stratford	43	22	0.40	0.3
	Warwick	24	10	0.29	0.2
Track Direction					
	Left	159	84	Ref.	
	Right	95	43	0.84	0.5
Novice	No	122	76	Ref.	
	Yes	132	51	0.6	0.03
Handicap	No	140	58	Ref.	
	Yes	114	69	1.45	0.08
Selling	No	226	123	Ref.	
	Yes	28	4	0.23	0.01
Race class	A	19	10	Ref.	
	B	12	14	2.80	0.1
	C	13	7	1.12	0.9
	D	70	30	0.72	0.5
	E	73	29	0.62	0.4
	F	35	31	1.27	0.7
	G	32	6	0.27	0.05

Variable	Description	Controls (n)=254	Cases (n)=127	Conditional unadjusted Odds Ratio	P-value
Going	Good to Firm	60	33	Ref.	
	Good	78	43	0.93	0.8
	Good to Soft	42	19	0.56	0.2
	Soft	58	29	0.42	0.1
	Heavy	16	5	0.26	0.07
Race pace (Raceform)	Extra	8	5	Ref.	
	Very Fast	10	6	1.10	0.9
	Fast	18	8	0.95	0.9
	Medium	27	19	1.18	0.8
	Slow	42	21	0.83	0.8
	Very Slow	122	51	0.61	0.5
Distance	16-17f	80	56	Ref.	
	17.5-19.5f	46	24	0.75	0.4
	20 -21.5	67	23	0.48	0.02
	22-27	61	24	0.57	0.06
Other fallers	No	206	94	Ref.	
	Yes	48	33	1.48	0.1
Hurdles padded					
	No	162	87	Ref.	
	Yes	92	40	0.6	0.09
Gradient	Flat	220	105	Ref.	
	Uphill	18	13	1.53	0.3
	Downhill	16	9	1.2	0.7
Continuous variables					
Field size	Number Starters			1.03	0.3
Prize Money	Pounds			1	0.3
Race Distance	Furlongs			0.95	0.2
Race speed	Furlongs per min			1.92	0.2
Number hurdles	Total number of flights in race			0.89	0.08
Jump no of case/control	Jump number of fall or successful jumping event			1.20	<0.001

Table 2. Descriptive statistics and univariable conditional logistic regression analyses of horse level variables and their relationship with the risk of falling from a case-control study in hurdle racing on 12 UK racecourses.

Variable	Description	Controls (n)=254	Case (n)=127	Conditional unadjusted Odds ratio	P-Value
Categorical variables					
Gender	Male	192	105	Ref.	
	Female	62	22	0.64	0.1
Country Bred	GB	110	61	Ref.	
	Ireland	117	49	0.74	0.2
	USA	6	8	2.22	0.2
	NZ/AUS	8	2	0.46	0.3
	Other/Europe	13	7	0.92	0.9
Headgear	None	232	115	Ref.	
	Blinker	14	9	1.3	0.6
	Visor	8	3	0.73	0.7

Variable	Description	Controls (n)=254	Case (n)=127	Conditional unadjusted Odds ratio	P-Value
Tongue tie	No	234	118	Ref.	
	Yes	20	9	0.9	0.8
Official BHB rating	Unrated	99	42	Ref.	
	1-76	39	11	0.64	0.3
	77-97	59	38	1.42	0.2
	98-176	57	36	1.56	0.1
First race type	Flat	98	60	Ref.	
	Nat Hunt Flat	114	48	0.69	0.1
	Hurdle	41	19	0.76	0.4
Previous falls	No	219	95	Ref.	
	Yes	35	32	2.43	0.004
Previous hurdle races	0	33	21	Ref.	
	1-2	58	15	0.40	0.3
	3-5	49	29	0.89	0.8
	6-10	56	25	0.67	0.3
	11-57	58	37	0.96	0.9
No. Previous wins	0	124	54	Ref.	
	1-5	98	63	1.43	0.1
	>5	32	10	0.67	0.4
Continuous variables					
Age	Years			0.97	0.6
Age first raced	Years			0.92	0.2
Age first Hurdled	Years			0.92	0.3
Previous races	No. races in career			1.00	0.7
Previous races course	No. races this course			0.96	0.6
Previous Flat	No. flat races			0.99	0.7
Previous Hurdle	No. hurdle races			1.01	0.3
Previous Chase	No. chase races			0.96	0.5
Previous Falls	No. falls			1.41	0.06
Previous Pull ups	No. pull ups			1.01	0.9
Previous Wins				0.97	0.5
Last Ran	Days since last run			0.99	0.2
Racefreq. 3 months	No. races previous 3 months			1.14	0.07
Race freq. 12 months	No. races previous 12 months			1.06	0.05
Time off 365 days	Yes			0.737	0.2
Weight carried	In pounds			0.9881	0.3
Falls per 10 hurdle races				1.38	0.02

Table 3. Descriptive statistics and univariable conditional logistic regression analyses of jockey level variables and their relationship with the risk of falling from a case-control study in hurdle racing on 12 UK racecourses.

Variable		Controls (n)=254	Cases (n)=127	Conditional unadjusted Odds ratio	P-value
Categorical variables					
Jockey Gender	Male	250	126	Ref.	
	Female	4	1	0.50	0.5
Jockey Allowance	0lbs	174	88	Ref.	
	3lbs	32	16	0.97	
	5lbs	20	6	0.56	
	7lbs	28	17	1.19	0.6
Continuous variables					
Previous races	No. races last 12 months			1.00	0.3
Races last month	No. races last month			0.99	0.7
Races course	No races on course last 12 months			0.99	0.5
Previous Wins	Wins last 12 months			1.00	0.3
Previous Falls	Falls last 12 months			1.03	0.2
Previous UR	No Unseats in last 12 months			0.98	0.7
Falls per race	No. falls per race last 12 months			15.74	0.3
Wins per race	No. wins per race last 12 months			4.12	0.4

Table 4. Descriptive statistics and univariable conditional logistic regression analyses of the jump number and the relationship with the risk of falling from a case-control study in hurdle racing on 12 UK racecourses.

Jump number	Controls (n)	Cases (n)	Conditional unadjusted Odds Ratio	p-value
1	26	9	Ref.	
2	31	10	0.82	0.7
3	33	5	0.40	0.2
4	34	7	0.47	0.2
5	25	9	0.96	0.9
6	26	16	1.60	0.3
7	27	21	2.46	0.06
8	25	24	3.15	0.01
9	11	11	2.50	0.1
10	9	10	3.99	0.03
11	5	1	0.42	0.5
12	1	2	5.13	0.2
13	1	1	3.40	0.4

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A concurrent case-control study to investigate risk factors for horse falls in steeplechase racing in the UK.

Pinchbeck, G.L. Clegg, P.D., Proudman, C.J., Morgan, K.L., French. N.P.

Department of Veterinary Clinical Science and Animal Husbandry, University of Liverpool, Leahurst, Neston, CH64 7TE, UK.

Corresponding Author. G.L.Pinchbeck

Key words: Steeplechase racing; horse falls; water jumps; case-control study; conditional logistic regression

Abstract

A concurrent case-control study was conducted on 12 UK racecourses from 1st March 2000 to 31st August 2001 to identify and quantify risk factors associated with horse falls in steeplechase racing. Cases were defined as a jumping effort at a steeplechase fence that resulted in a fall and controls were defined as a successful jumping effort over any steeplechase fence at any of the 12 racecourses within 14 days either before or after the case fall. Information on the horse, the jockey and the race were collected and all fences on all courses were surveyed.

Conditional logistic regression was used to examine the relationships between predictor variables and the risk of falling. The results indicated an frequency of falls of 1 per 254 jumping efforts. The risk of falling decreased with an increase in the number of previous races the horse had on the particular racecourse. The number of fences, distance from the previous fence and the previous fence type were also associated with falling. If the previous fence was a water jump the risk of falling increased. Fences that were sited on flat or slightly uphill gradients (up to approximately 1 in 25) were at decreased risk of horses falling compared to downhill fences and higher take off boards were associated with an increased risk of falling.

Introduction

Horseracing is a high-risk sport for both horse and jockey. Equine fatalities occur in all types of racing, both in the UK and overseas (Vaughan and Mason 1975, Ueda et al. 1993; Bourke 1995; Mckee 1995; Estberg et al. 1998) but the fatality rate is higher in steeplechase racing than in hurdle and flat racing (Wood et al 2000; Bailey et al 1998). Fatality rates of 0.71 per 100 starts have been reported in UK steeplechasing between 1990 and 1999 with 31% of all racing fatalities occurring in steeplechasing (Wood et al. 2000). Previous descriptive studies reported that 50% (Mckee 1995) to 60% (Bourke 1995) of fatalities in jump racing were associated with a fall. In a previous study by the author examining all starts in steeplechase racing in 1999, the falling risk was 6.0/100 starts and 3.7% of fallers died (Pinchbeck et al 2002a). Of all deaths recorded on racecourses, 42% were associated with a fall. Horse falls often occur in full public view and fatal injuries in particular are likely to have a negative impact on the public's perception of racing welfare and evoke strong reaction from groups concerned with animal welfare.

The injury rate among jockeys is also high and point-to-pointing and jump racing are ranked first and second on the list of dangerous sports for injuries (Pritchard 2001). Common injuries include clavicle (Middleton et al. 1995) and other fractures, as well as head and neck injuries (including concussion) (Waller et al. 2002). Some injuries can be life threatening (Fletcher et al. 1995) and many injuries are serious enough to result in prolonged periods of convalescence.

At present steeplechase racing takes place on 42 racecourses in the UK with some courses having more than one steeplechase track. Placement of the fences is governed by the Jockey Club general instructions. In a steeplechase race there should be at least 12 fences in the first 2 miles and at least six fences in each succeeding mile. One of the fences may be a water jump and there should be at least 1 open ditch for each mile. The majority of fences are constructed on course and consequently there is some variation in fence design. However there are also Jockey Club regulations regarding fence construction. Plain fences must be a minimum of 4 ft 6 inches high and constructed with all birch or birch with spruce, broom or other material at the bottom of the fence. The fences should be built on a base of 6ft deep, measured from the take off board to the back of the fence (Figure 1). Water jumps should be a minimum of 3 ft high with water 9 ft wide and an overall width of 11.5 to 12 ft. Open ditches must be a minimum of 4 ft 6 inches high and the take off board should be between 1ft 6 inches and 2ft in height. Most courses replace individual fences once every 2 to 3 years.

The objectives of this study were to identify and quantify risk factors associated with horse falls in steeplechases racing at horse, racecourse, race and jump levels using a case-control study to . This study forms part of a larger project aimed at identifying risk factors for horse falls and injury in National Hunt racing with a view to designing intervention strategies to reduce the incidence of horse falls and therefore horse and jockey injury.

Materials and methods

Study design

A concurrent case-control study was conducted on 12 UK steeplechase racecourses from 1st March 2000 to 31st August 2001 using a similar study design to that reported by Pinchbeck et al. (2002c) in hurdle racing. The racecourses were selected partly due to their membership of the Racecourse Holdings Trust Ltd (Aintree, Cheltenham, Haydock, Huntingdon, Kempton, Market Rasen, Sandown, Warwick) and partly to give variation in the type of racecourses with respect to prize money offered, topography of the course and fence design (Bangor-on-Dee, Carlisle, Cartmel, Stratford). Based on estimates of the incidence of falling in steeplechase races from the Jockey Club, at least 200 cases were expected over this study period. With 1 control per case this would give power of at least 80% to detect odds ratios of 2 or more with 95 per cent confidence for exposures of greater than 15% in the controls.

Identification and selection of cases and controls

All jumping efforts at a steeplechase fence that resulted in a horse fall at any of the 12 racecourses during the study period were selected as cases. Jumping efforts by horses in hunter chase races were included, however races over the Grand National course at Aintree were excluded due to the different design of fences on this course. Cases were identified from racing records (Racing Post online-www.racingpost.co.uk) and were verified against an independent data source (Raceform Ltd) and by author attendance at the racecourse during 49% of the races.

Jumping efforts in which the rider was unseated or in which the horse was brought down by another horse were not included in the case definition. Controls were defined as a successful jumping effort over a steeplechase fence at any of the 12 racecourses within 14 days either before or after the case fall. In this way the controls were matched on time. To enable selection of controls a record of jumping efforts in every steeplechase race on the 12 courses was kept during the study period. The number of jumping efforts available as controls 14 days before and after the case were then counted and 1 control was selected for each case using random number generation (Epi-Info 6.04, CDC, USA).

Data collection

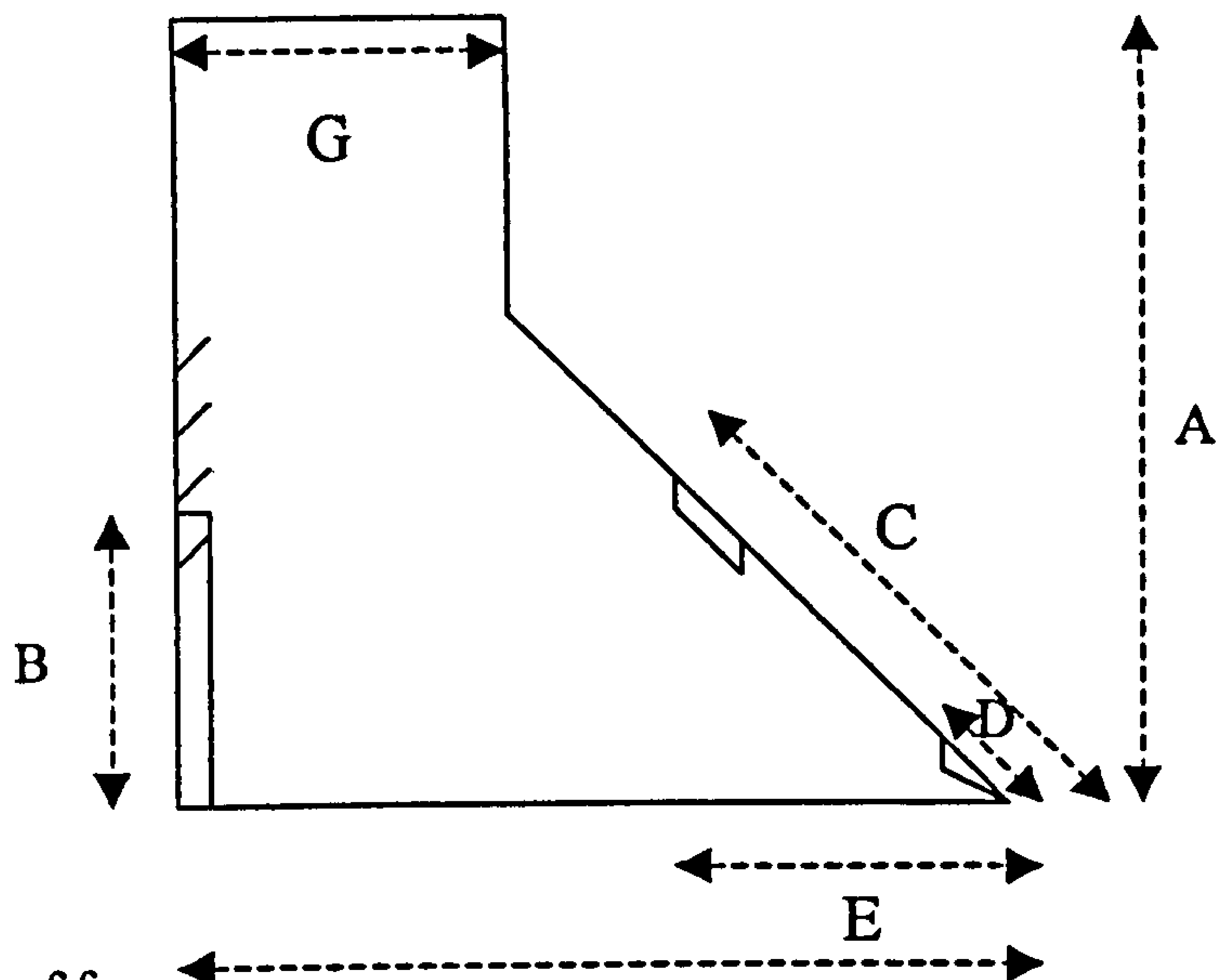
Variables on jockeys, horses and races were collected from Raceform Ltd. and Racing Post online and where possible checked for agreement between the two data sources. The variables available for analysis are shown in Table 1. Information regarding the course and jumps were collected by consultation with the Jockey Club racecourse inspectors and by visits to each racecourse. All courses and fences were surveyed. This included precise measurements of the distances between fences using a distance wheel and taking detailed measurements of every fence. For example, variables recorded on a plain steeplechase fence are shown in Figure 1. Additional measurements were made on open ditch and water fences. Gradients on the approach and landing 10 metres before and after every fence were measured using levelling techniques using a staff and a level (Nikon Automatic Level AC-2, Nikon, Inc. Instrument Group, Melville, USA). All course and fence level variables recorded are shown in Table 2. Traditionally, distances on racecourses are measured in furlongs and this unit of measurement was used in this paper. One furlong is equal to 198 metres and there are 8 furlongs per mile.

Table 1: Description of race, horse and jockey variables available for analysis in a case-control study of falling in steeplechase racing on 12 UK racecourses.

Variable	Description
Racecourse	ID for each of the 12 racecourses
Track direction	Left or right
Going	Good to firm, good, soft, good to soft, soft, heavy
Speed	Winning time divided by distance
Distance	Distance of race in furlongs
Race classification	Handicap, novice, maiden, selling, juvenile
Race class	Official class A-H
Field size	Number of horses starting the race
Prize money	Prize money available in race
Number of jumps	Total number of fences in the race
Jump number	Jump number in the race of case or control
Number fallers	Total number fallers in the race
Race number	Number of steeplechase race that day
Racing previous day	Racing on the course the previous day
Horse gender	Male or female
Horse age	Age at time of start
Horse aged when raced	Age of horse at first ever start
Horse age steeplechased	Age of horse at first steeplechase start
Country of breeding	Country of birth place, UK, Ireland, USA, Europe, Australia.
First race type	First race type under rules – Flat, National Hunt flat, hurdle, chase
Previous number races	Total number starts under rules
Previous flat races	Total number flat starts
Previous hurdle races	Total number hurdle starts
Previous chase races	Total number chase starts
Previous number wins	Total wins in steeplechase racing.
Previous number falls	Total previous falls in hurdling or steeplechasing
Days since last ran	Number of days since previous start
Race frequency 3 months	Number starts of any type race in last 3 months
Race frequency 12 months	Number starts any type race in last 12 months
Official rating	Official BHB rating at time of race
Weight carried	Weight carried by horse in pounds
Head gear	Headgear worn during race – none, blinkers, visor
Tongue tie	Tongue tie worn in race – yes, no
Jockey allowance	Professional or claiming 7, 5 or 3 lbs

Table 2: Description of fence and course variables measured in a case-control study of falling in steeplechase racing on 12 UK racecourses.

Variable	Description
All fences	
Fence type	Plain, open ditch, water.
Previous fence type	Plain, open ditch, water.
Distance to previous fence	Racing distance in yards to previous fence
Distance to next fence	Racing distance in yards to next fence
Construction date	Year of construction of fence. 1999, 2000, 2001.
Camber	Camber from outside to inside of fence
Gradient on approach	Gradient from 10 metres in front of fence
Gradient on landing	Gradient to 5 metres after fence
Height at front	Height of fence at front
Height at back	Height of solid base of fence measured at the back
Breadth of fence	Breadth of fence across the course
Total width	Total width measured at the base of the fence
Width of birch	Width of birch at top of fence
Overall angle	Angle of fence (using tangent of height /width)
Angle approach	Angle of approach
Barrier length	Length of barrier
Plain fences	
Guard rail present, fixed, tied	Guard rail, present. If present is it fixed or tied
Guard rail padded	Padding around the guard rail
Height guard rail	Height of guard rail from ground
Height take off board	Height of board from ground
Width to guard rail	With to guard rail
Open ditches	
Height take off board	Height of board from ground
Ditch width	Width of ditch
Drop in ditch	No=at ground level. Yes=drop present
Water jumps	
Width and depth of water	Width of water section of fence
Construction of water base	Edges of water- matting grass, sloping, straight.



A = Height of fence
B = Height of solid base at back of fence
C = Height of guard rail (if present)
D = Height of take off board
E = Width to guard rail
F = Total width of fence
G = Width of birch

Figure 1. Diagrammatic representation of the fence measurements taken on all plain fences on the 12 UK racecourses in the study.

Statistical analysis

The dependent variable for all the analyses was the outcome of the jumping effort with cases defined as falls and controls as successful jumping events. To take account of the matching, conditional logistic regression methods using maximum likelihood estimation were used for both univariable and multivariable analyses. Continuous variables were considered first as linear in their relationship with the outcome and then categorised into 4 or 5 categories representing the four quartiles or five quintiles of that variable. If the categorical relationship between the variable and the outcome suggested a non-linear relationship then either categorical or continuous polynomial terms were considered. Interaction terms were tested between all biologically plausible sets of terms. Due to the large number of potentially correlated independent variables available on the horses' previous racing career, simple correlation analysis was performed (Dohoo et al. 1997). If highly correlated variables were found (Pearson correlation coefficient > 0.8) only the variable which explained most of the residual deviance was included in the final model. Variables with a p-value<0.3 and those considered *a priori* to be of particular biological importance were considered for inclusion in a multivariable model. The final multivariable model was built using backward elimination procedures where variables remained in the model if they significantly improved the fit of the model (assessed by the change in deviance). The critical probability throughout was 0.05. The fit and stability the model was assessed by examining the delta-betas (Pregibon 1981).

Analysis of fatal falls

The dependent variable for this analysis was the outcome of the fall with fatal falls defined as cases and non-fatal falls defined as controls. Univariable screening of all variables was performed using chi-squared test for categorical variables and univariable logistic regression model for continuous variables.

All analyses were performed in EGRET (Egret Application 2.0, Cytel Software Corporation) and Minitab (Minitab 13.1).

Results

Two hundred and eighty four cases were identified over the study period from a total of 72,227 successful jumping events. The results indicate an incidence of falls of 1 per 254 jumping efforts. The fatality rate amongst the fallers was 6.3% and table 3 shows the causes of fatality reported by the Jockey Club veterinary surgeons.

Table 3: Cause of fatality or reason for euthanasia in the 18 fatal cases of falling identified during the study.

Cause of fatality	Number of cases
Vertebral fracture	4
Shoulder fracture	6
Radial fracture	2
Pelvic fracture	1
Third metacarpal fracture	2
Humerus fracture	1
Fetlock dislocation	1
Carpal fracture	1

Horse level variables

Many of the variables associated with the horse's previous experience were significantly associated with falling in univariable analysis. For example horse age in years (OR=0.6 for every five year increase, 95% CI=0.8, 0.9) and previous number of chase races (OR= 0.6 for every increase of ten races, 95% CI =0.9, 1.0). However in the final multivariable model (table 4) the number of previous races a horse had on that particular chase course provided the best fit (i.e. resulted in the largest change in deviance) and after the inclusion of this variable neither age nor previous number of chase races were significant. The greater the number of times a horse had previously run on that steeplechase course the lower the risk of falling on the same course (OR=0.6 for every extra run, 95% CI =0.4, 0.7). Figure 2 shows the categorical relationship between previous number of races on the course and the risk of falling after allowing for other variables.

Course and fence level variables

Compared to the first fence, there was an initial decline in the risk of falling followed by a steady increase in risk at later fences (Figure 3). In the final model first fence falls were included as a separate category in the variable "previous fence type" and there was a significant interaction with the distance to the previous fence or to the start. After allowing for this interaction the first fence had a slightly increased risk compared to other plain fences and there was a very slight increase in risk as the distance to the start increased (Figure 4). After allowing for the jump number of the case or control an increase in the total number of jumps in the race was associated with a decrease in the risk of falling.

The previous fence type was significantly associated with the risk of falling. If the previous fence was a water jump there was an increased risk of falling at the following jump. This effect was modified by the distance from the previous fence to the case or control fence. This is illustrated in figure 4. Increasing distance from a previous plain fence was associated with increasing risk whereas increasing distance from a water jump or open ditch jump was associated with decreasing risk. In the final multivariable model distance was centered, by subtracting the mean from all values, to give estimates around the mean distance of 266.7 yards rather than 0 yards

The height of the take off board was associated with the risk of falling with an odds ratio of 3.7 for every increase in 10 inches in height of the take off board. Open ditches had the highest take off boards and after allowing for the height of the board, fence type was no longer significant in the final model. Prior to the addition of take off board height, open ditches increased the risk of horses falling (OR=1.9, 95% CI

1.0, 3.5). There was no significant difference between plain fences and water jumps (OR= 0.8, 95 % CI 0.2, 3.1).

The approach gradient was also associated with the risk of falling. Compared to flat or slight positive (up hill) gradients, negative (downhill) gradients were associated with 2-fold increase in risk of falling. Steeper uphill gradients of greater than 1 in 26 tended to be associated with an increase in risk however this finding was not significant possibly due to the small number of fences sited on gradients of this magnitude.

Plain fences only

Analysis of variables unique to each fence type was also performed. There were 114 matched sets of plain fences available for analysis and logistic regression analysis showed that for plain fences that had a guard rail, the presence of padding around the guard rail was associated with a decreased risk (OR= 0.4, 95% CI 0.2, 0.8). After allowing for the confounding effect of racecourse the OR for padded guardrail decreased (OR = 0.2, 95% CI 0.04, 0.6).

Analysis of fatal falls

Analysis of all falls with a case outcome of fatality with controls as non-fatal falls was performed. Jump number of the fall showed a similar pattern to that seen in the model of falling (i.e. there was an increase in risk at later flights). No other significant associations were identified, however this analysis was based on only 18 cases so the power of the study was low.

Table 4: Final multivariable conditional logistic regression model of risk factors associated with horse falls in steeplechase racing on 12 UK racecourses from 1st March 2000 to 31st August 2001. The table shows coefficients, standard errors and P-values for all variables and odds ratios and 95% confidence intervals (CI) of odds ratios for categorical variables.

Variable	Coefficient	Std. Error	LRS P-value	Odds Ratio	Lower 95% CI	Upper 95% CI
Continuous						
Previous races on course	-0.60	0.14	< 0.001			
Total number of jumps	-0.12	0.04	0.003			
Jump number of case/control	0.18	0.03	< 0.001			
Height take off board	0.13	0.05	0.003			
Distance to previous fence/start (cent)	0.003	0.001	< 0.001			
Categorical						
Fence type			0.42			
Plain	Ref.			1.00		
Open ditch	-0.70	0.57		0.50	0.16	1.53
Water	-0.25	0.70		0.78	0.20	3.09
Previous fence type			<0.001			
Plain	Ref.			1.00		
Open ditch	-0.66	0.30		0.52	0.28	0.93
Water	1.68	0.87		5.36	0.97	29.63
First fence	1.12	0.66		3.07	0.84	11.23
Approach gradient from 10 metres			0.07			
Flat/slight uphill (0.001to 0.38)	Ref.			1.00		
Downhill (-0.22 to 0.00)	0.71	0.34		2.03	1.05	3.94
Steep uphill (0.39 to 0.63)	0.66	0.50		1.92	0.73	5.09
Interaction term previous fence type and distance to previous fence (cent)			0.004			
Plain * distance to previous fence	Ref.			1.00		
Open ditch*distance to previous fence	-0.003	0.002		0.99	0.99	1.00
Water* distance to previous fence	-0.013	0.004		0.99	0.98	0.99
First*distance to start	-0.002	0.005		1.00	0.98	1.01

LRS-likelihood ratio test statistic
Cent - centered variable

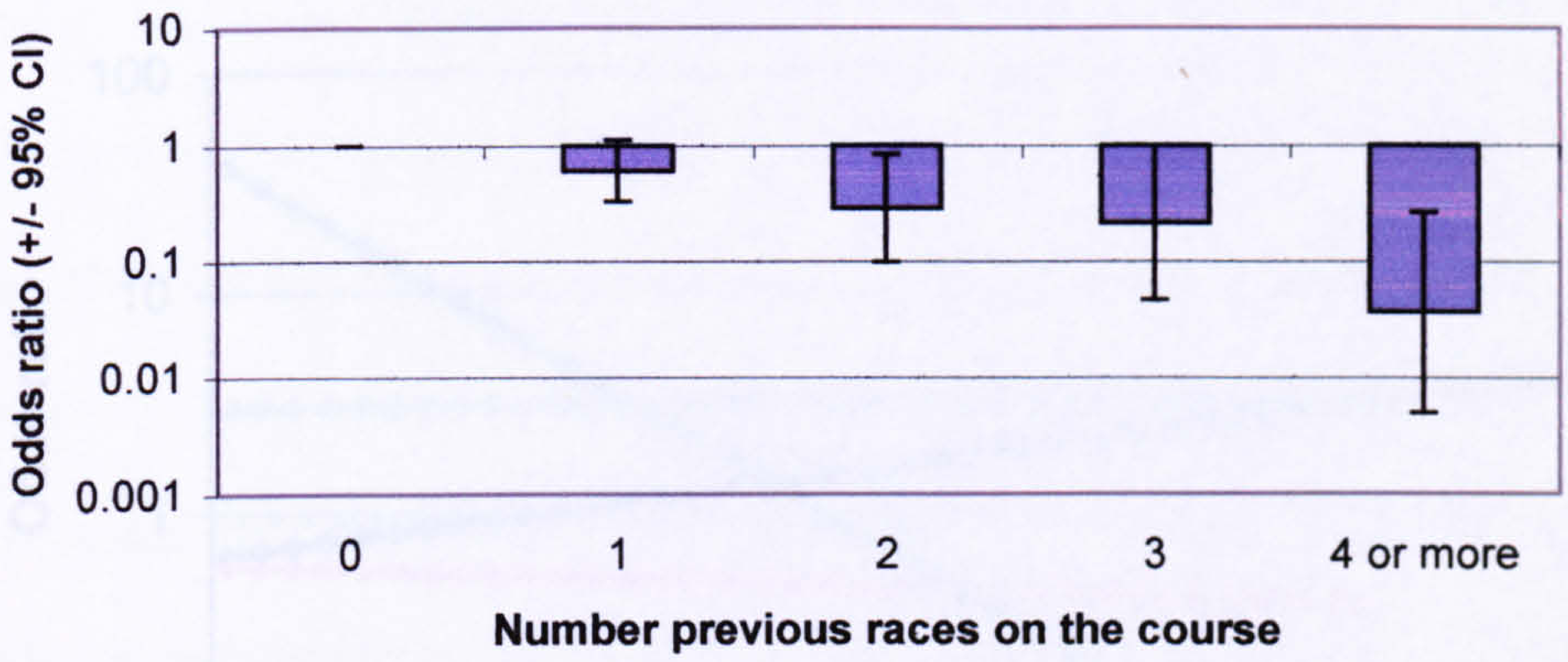


Figure 2. The relationship between the number previous races the horse has started in on the steeplechase course and the risk of falling in steeplechasing on 12 UK racecourses. This is modelled in a multivariable model including all variables in table 4.

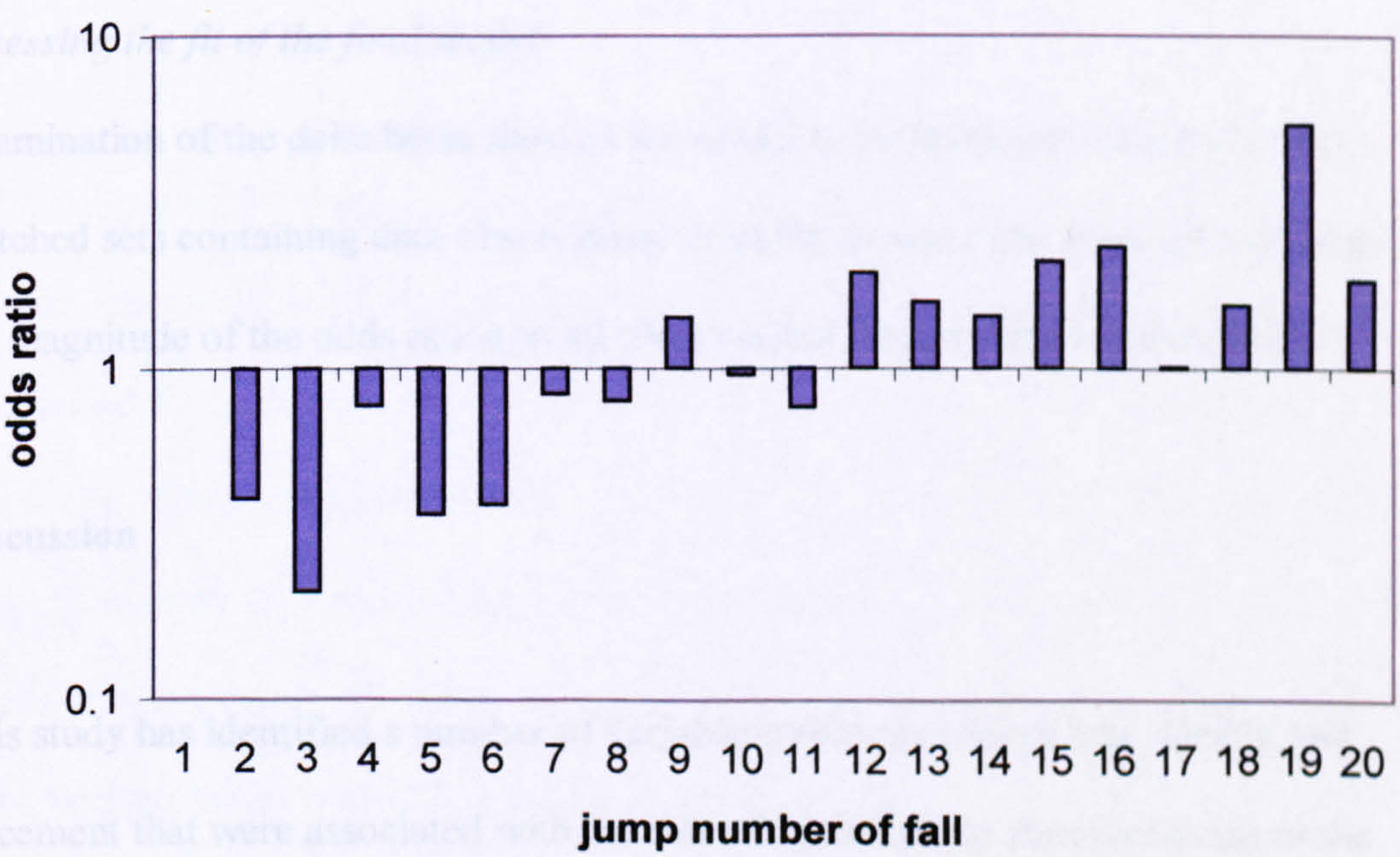


Figure 3. Univariable relationship between jump number of the fall and the risk of falling.

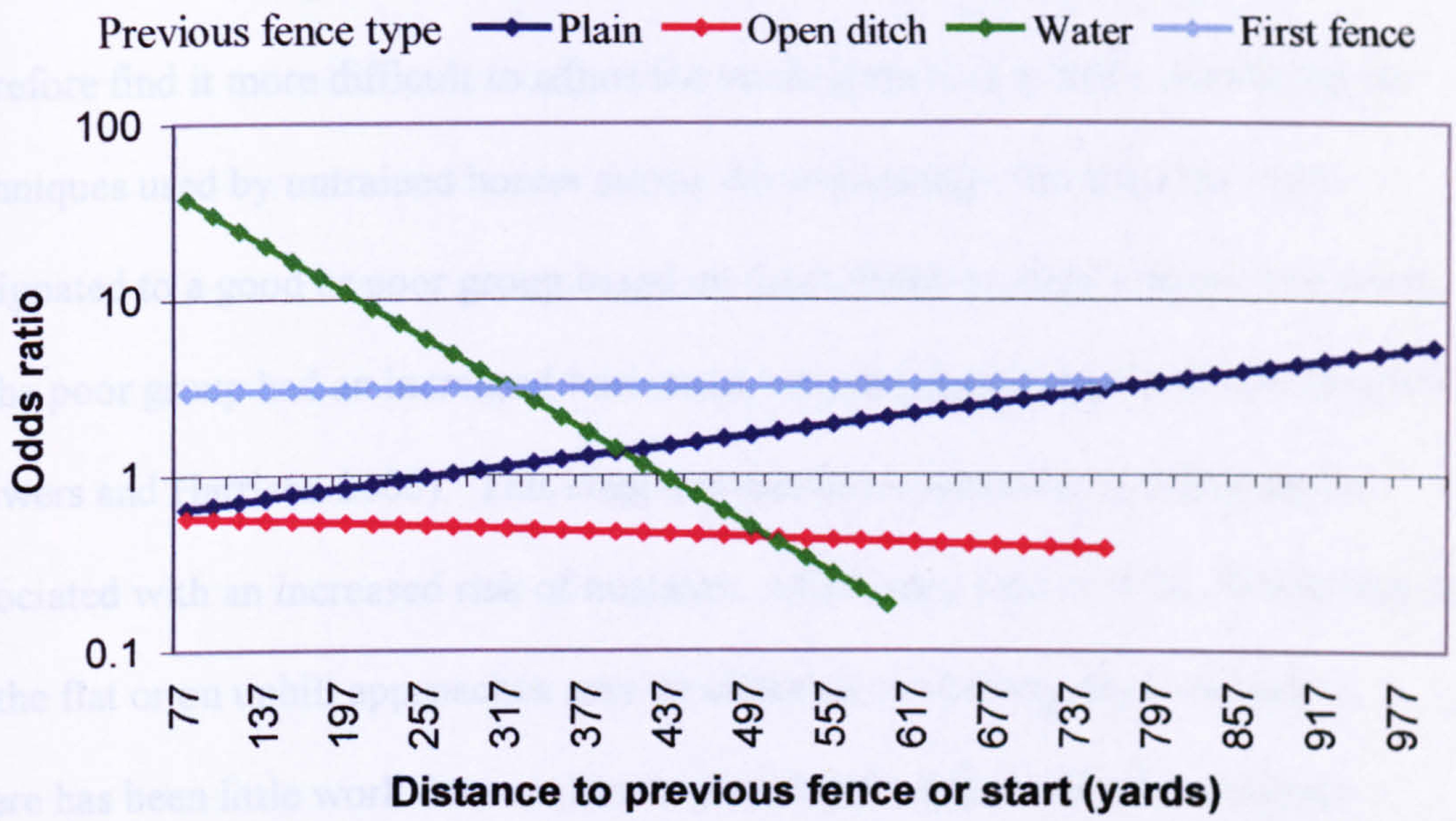


Figure 4. Relationship between distance to the previous fence or start and the type of previous fence and the risk of falling in steeplechase racing on 12 UK racecourses. The plots for open ditches and the first fence end at 740 and for water jumps at 570 yards, as these were the maximum observed distances on any of the 12 courses.

Assessing the fit of the final model

Examination of the delta betas showed the model to be stable and removal of the matched sets containing data observations with the largest delta betas all increased the magnitude of the odds ratios so all observations were retained in the model.

Discussion

This study has identified a number of variables relating to fence type, design and placement that were associated with the risk of horse falls in steeplechasing in the UK. Fences that were sited on flat or slightly uphill gradients (up to approximately 1 in 25) were at decreased risk of horses falling compared to downhill fences. This may be due to slight uphill approaches slowing the horse down or assisting in take off. Horses travelling downhill may travel faster and be more extended and therefore find it more difficult to adjust the stride length. In a study examining the techniques used by untrained horses during loose jumping where horses were designated to a good or poor group based on their ability to clear a fence, the horses in the poor group had an increased horizontal velocity during approach and take off (Powers and Harrison 2000). This suggests that faster approach speeds may be associated with an increased risk of mistakes, which may lead to falls. Siting fences on the flat or on uphill approaches may be effective in slowing the horse down. There has been little work done on horses jumping during steeplechase racing, however a study examining horse falls in the sport of horse trials also found that downhill jumps were associated with greater risk. In that study up-hill sited jumps were also at significantly increased risk compared to flat-sited jumps (Singer et al. 2003). However gradients of approaches to fences in horse trials can be much greater than those that exist in steeplechase racing.

Before allowing for height of the take off board, open ditches were associated with a 2-fold increased risk of falling. However, height of the take off board was confounded by fence type. Open ditches had higher take off boards in accordance with Jockey Club regulations which state "that the take off board on open ditches must be between 1ft 6 and 2ft in height". There are no regulations for take off boards on plain fences. When plain fences only were considered, increasing height of the take off board was still associated with increased risk of falling with a similar odds ratio, however the confidence intervals did cross one (OR= 1.12, 95% CI 0.99, 1.26). This suggests that reducing the height of the take off board may be beneficial for open ditch fences. The combination of a high take off board with a ditch may lead to reluctance of the horse to jump or misjudging of the fence by the horse. Video analyses of falls at open ditches (manuscript 7) identified that falls often occurred when horses landed with the forelimbs in the ditch. Vaughan and Mason (1975) also described one case of scapula fracture and two cases of humeral fracture where a horse misjudged an open ditch and hit the fence. In the study by Singer et al. (2003) on horse falls in horse trials, fences with a ditch in front were the only types of obstacle associated with an increased risk of falling.

The type of fence jumped previously was associated with the risk of falling and water jumps were at the greatest risk. This may be due to the horse misjudging the subsequent plain or open ditch fence after jumping a much lower and wider water jump fence. The closer the water jump was to the subsequent fence, the greater the risk of falling. This was in contrast to the effect of distance from the previous fence when the previous fence was a plain fence. This may be due to the fact that when there is a very long distance between fences, for example around bends, a plain fence is usually the first fence sited afterwards. Horses may speed up and extend when racing over longer distances and subsequently find it harder to jump. In univariable analysis fences after the bend (which on the 12 courses in the study were all plain fences) were at increased risk of horses falling (OR=2.2, 95% CI 1.4, 3.4). However as expected this variable and distance to previous fence were correlated so only distance to previous fence was used in the final model.

The increase in risk of falling at flights later in the race is consistent with previous studies on horse falls in hurdling (Pinchbeck et al. 2002c) and in horse falls in horse trials (Singer et al. 2003). Previous studies have also shown that longer distance races are associated with increased risk of falling in steeplechase racing (Pinchbeck et al. 2002a) and the risk of fatality in steeplechase races (Wood et al. 2002) and these findings are likely to be due to the increase in number of fences over longer distance races. After allowing for the jump number of the fall an increase in the total number of jumps was associated with a decrease in risk. This means, for example, the risk of falling at fence 11 in a race with only 12 fences would be greater than falling at fence 11 in a race with 20 fences. This increase in falling at later flights may be due to fatigue in some cases or due to a "racing for the finish line effect" where horses are being encouraged to gallop fast by the jockey.

The padding of guardrails was introduced gradually on racecourses during the period of study. This was a Jockey Club and racecourse initiative specifically to try and reduce injury rates in steeplechasing, and from 1st July 2003 is mandatory. Courses undertook padding of guardrails at different times in the study period and some courses had only some fences with padded guardrails. As this intervention was not randomly allocated to racecourse throughout the study period the results need to be interpreted with caution. However even after allowing for racecourse the finding was still significant. Guardrails are padded with rubber that is painted bright orange and it may be this contrast of the rail rather than the padding that reduced the risk of falls. In a study examining which fences were most problematical for horses taking part in jumping events, obstacles that had two contrasting colours were jumped without fault more often compared to those of one colour (Stachurska 2002). Factors relating to a horses' previous racing and, particularly, steeplechasing career were significantly associated with falling and this is consistent with previous studies on falling (Pinchbeck et al. 2002a) and fatalities (Wood et al. 2002). Many previous studies examining musculoskeletal injuries in racehorses have found that increasing age increases the risk (Mohammed et al. 1991; Bailey et al. 1998; Williams et al 2001) which is in contrast to studies on falling in steeplechasing. It seems that previous experience of jumping fences under race conditions appears to be an important factor in the risk of horse falls and fatalities in steeplechasing. In the current study the horses' previous number of races on the particular course explained most of the variation and this has not been reported previously. This suggests that if schooling races were to be introduced, as has been suggested at an industry meeting (Wood et al. 2001b) then efforts should be made to have a variety of fence designs and course topography on the schooling courses.

The lack of significant findings associated with fatal falls and with open ditch and water jumps should be interpreted in light of the small numbers of cases and therefore the low statistical power to detect associations. Further studies with these particular outcomes would be warranted.

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Appendix to Manuscript 7

In this appendix a discussion of data quality and results from univariable conditional logistic regression analyses of all categorical and continuous variables are presented. Also in the appendix is a study utilising survival analysis to investigate whether cases (horses that fell) had an increased time to return to racing compared to control horses.

Data quality

Cross checking of data from Racing post online, Raceform Ltd and from author attendance at races did not find any misclassification of cases or controls. No discrepancies were found between Racing post online and Raceform Ltd on data for the horses past racing career and performance. Two discrepancies on the description of the going were found and after contacting the racecourse directly the errors were found to be in Raceform Ltd.

Univariable analysis

Tables 1 and 2 show descriptive statistics and the univariable relationship between horse, race and jockey level categorical and continuous variables and the risk of falling in steeplechase racing, using conditional logistic regression models.

Table 1: Descriptive statistics and univariable conditional logistic regression analyses of horse, race and jockey level categorical variables and their relationship with the risk of falling from the case-control study in steeplechase racing on 12 UK racecourses.

Variable	% Controls (n)=284	% Cases (n)=284	Conditional unadjusted OR	LRS P-value
Trainer gender				
Male	51(233)	49(221)	1.0	
Female	45(51)	55(63)	1.3	0.2
Racetrack				
Aintree	39(19)	61(30)	1.0	
Bangor	56(22)	44(17)	0.5	
Carlisle	53(9)	47(8)	0.4	
Cartmel	33(8)	67(16)	2.5	
Cheltenham (new course)	54(32)	46(27)	0.4	
Cheltenham (old course)	53(9)	47(8)	0.1	
Haydock	69(20)	31(9)	0.2	
Huntingdon	59(34)	41(24)	0.4	
Kempton	50(15)	50(15)	0.5	
Market Rasen	49(45)	51(47)	0.7	
Sandown	60(24)	40(16)	0.3	
Stratford	39(35)	61(54)	1.1	
Warwick	48(12)	52(13)	0.6	0.01
Track direction				
Left	47(157)	53(174)	1.0	
Right	54(127)	46(110)	0.8	0.1
Racing previous day				
No	50(240)	50(237)	1.0	
Yes	48(44)	52(47)	1.1	0.7
Novice				
No	54(174)	46(146)	1.0	
Yes	44(110)	56(138)	1.5	0.02
Handicap				
No	49(154)	51(159)	1.0	
Yes	51(130)	49(125)	0.9	0.7
Maiden				
No	50(280)	50(277)	1.0	
Yes	36(4)	64(7)	1.8	0.4
Hunterchase				
No	49(211)	51(221)	1.0	
Yes	54(73)	46(63)	0.8	0.3
Race class				
A	50(17)	50(17)	1.0	
B	54(36)	46(31)	0.9	
C	50(28)	50(28)	1.1	
D	46(68)	54(79)	1.2	
E	39(32)	61(512)	1.6	
G	64(38)	36(21)	0.5	
H	53(65)	47(57)	0.9	0.1

Variable	% Controls (n)=284	% Cases (n)=284	Conditional unadjusted OR	LRS P-value
Track surface (going)				
Good to firm	49(67)	51(69)	1.0	
Good	48(75)	52(82)	1.1	
Good to soft	53(59)	47(52)	0.8	
Soft	46(51)	54(61)	1.0	
Heavy	62(32)	38(20)	0.5	0.3
Other fallers in race				
No	51(154)	49(147)	1.0	
Yes	49(130)	51(137)	1.1	0.6
Horse gender				
Male	49(253)	51(260)	1.0	
Female	56(31)	44(24)	0.8	0.3
Country bred				
UK	44(100)	56(128)	1.0	
Ireland	54(140)	46(117)	0.7	
USA	55(11)	45(9)	0.7	
New Zealand/Australia	29(2)	71(5)	3.2	
Other	55(31)	45(25)	0.7	0.1
Headgear				
None	50(249)	50(247)	1.0	
Blinkers	50(26)	50(26)	1.0	
Visor	45(9)	55(11)	1.3	0.9
Tongue tie				
No	59(263)	50(265)	1.0	
Yes	53(21)	47(19)	0.9	0.7
First race type				
Flat	52(64)	48(58)	1.0	
National Hunt flat	49(117)	51(122)	1.1	
Hurdle	50(57)	50(57)	1.1	
Steeplechase	49(46)	51(47)	1.1	0.9
No	43(33)	57(44)	1.0	
Yes	51(251)	49(240)	0.7	0.2
Time off racing >365 days				
No	47(151)	53(172)	1.0	
Yes	54(133)	46(112)	0.8	0.09
Jockey status				
Professional	49(156)	51(164)	1.0	
Conditional claiming 7lbs	54(55)	46(47)	0.8	
Conditional claiming 5lbs	50(25)	50(25)	1.0	
Conditional claiming 3lbs	52(37)	48(34)	0.9	
Amateur	44(11)	56(14)	1.2	
Race number that day				
1	52(103)	47(93)	1.0	
2	46(84)	54(98)	1.2	
3	50(67)	50(68)	1.1	
4	53(19)	47(17)	1.0	
5	75(6)	25(2)	0.4	
6	45(5)	55(6)	1.2	0.8

LRS-Likelihood ratio test statistic

Table 2: Descriptive statistics and univariable conditional logistic regression analyses of horse and race level continuous variables and their relationship with the risk of falling from the case-control study in steeplechase racing on 12 UK racecourses.

	Univariable conditional Logistic Regression		Controls				Cases			
Variable	**OR**	**p-value**	**Mean**	**St Dev.**	**Min**	**Max**	**Mean**	**St Dev.**	**Min**	**Max**
Distance	0.97	0.3	22.4	3.7	16.0	33.0	22.2	3.4	16.0	33.0
Prize Money	1.00	0.83	9784	16383	1098	162400	100081	16507	1098	162400
Speed (furl/min)	0.88	0.74	3.8	0.3	2.4	4.3	3.8	0.3	2.1	4.3
Horse age	0.89	0.03	7.9	1.8	5.0	14	8.3	1.7	5.0	13
Horse rating	0.9	0.3	66.1	538	0.0	177.0	61.9	54.9	0.0	168.0
Age first raced	1.05	0.3	4.5	1.7	2.0	10.0	4.7	1.7	2.0	10.0
Age first steeplechased	0.9	0.4	6.6	1.4	4.0	11.0	6.5	1.3	4.0	11.0
No. previous races	0.9	0.2	19.2	13.7	0.0	70.0	17.7	14.1	0.0	81.0
No. previous races course	0.6	<0.001	0.8	1.7	0.0	17.0	0.4	0.8	0.0	6.0
No. previous flat races	1.01	0.34	3.6	5.5	0.0	40.0	4.1	7.9	0.0	44.0
No. previous hurdle races	0.98	0.2	8.0	7.7	0.0	43.0	7.2	6.9	0.0	40.0
No. previous chase races	0.97	0.04	7.7	7.7	0.0	39.0	6.4	6.8	0.0	39.0
Previous falls/starts	4.2	0.4	0.04	0.03	0.0	0.5	0.06	0.05	0.0	0.5
Previous wins steeplechase	0.9	0.06	1.7	2.1	0.0	14.0	1.3	1.7	0.0	8.0
Days since last ran	1.00	0.9	114.0	218.0	1.0	1480	113.0	230.7	1.0	1515
Race frequency 3 months	0.9	0.3	1.8	1.6	0.0	7.0	1.7	1.4	0.0	5.0
Race frequency 12 months	0.9	0.9	4.8	3.6	0.0	23.0	4.7	3.4	0.0	17.0
Weight carried	1.8	0.05	155.2	9.4	133	177	155.6	8.5	133	176

Tables 3 and 4 show descriptive statistics and the univariable relationship between fence level categorical and continuous variables and the risk of falling in steeplechase racing, using conditional logistic regression models.

Table 3: Descriptive statistics and univariable conditional logistic regression analyses of fence level categorical variables and their relationship with the risk of falling from the case-control study in steeplechase racing on 12 UK racecourses

Variable	% Controls (n)=284	% Cases (n)=284	Odds Ratio	LRS P-value
Fence type				
Plain	50(221)	50(224)	1.0	
Open ditch	46(48)	54(56)	1.2	
Water	79(15)	21(4)	0.3	0.05
Previous fence type				
Plain	48(196)	52(215)	1.0	
Open ditch	65(66)	35(36)	0.5	
Water	28(5)	72(13)	2.2	0.005
Fence type 2 previous				
Plain	50(193)	50(196)	1.0	
Open ditch	50(68)	50(67)	1.09	
Water	52(20)	47(18)	0.8	0.9
Construction date				
1998	58(32)	42(23)	1.0	
1999	55(93)	45(76)	0.9	
2000	47(111)	53(124)	1.2	0.5
Missing	44(48)	56(61)		
Guard rail				
Absent	47(9)	53(10)	1.0	
Present	50(212)	50(214)	1.2	0.7
Guard rail fixed or tied				
Fixed	54(165)	46(141)	1.0	
Tied	39(47)	61(73)	1.8	0.02
Guard rail padded				
No	46(90)	54(104)	1.0	
Yes	57(56)	43(42)	0.4	0.01
Drop in ditch				
No (level with ground)	(43)	(42)	(No convergence)	
Yes	(5)	(14)		-
Gradient on approach (20 metres)				
Positive(uphill)	51(246)	49(240)	1.0	
Negative(downhill)	46(38)	54(44)	1.2	0.5
Gradient landing (5 metres)				
Positive (uphill)	52(124)	48(115)	1.0	
Negative(downhill)	49(160)	51(169)	1.1	0.4
Camber				
Flat	49(19)	52(20)	1.0	
Positive	49(189)	51(199)	1.0	
Negative	54(76)	46(65)	0.8	0.6
Gradient on approach (10 metres)				
Flat/slight uphill (0.001to 0.38)	53(236)	47(212)	1.0	
Downhill (-0.22 to 0.00)	39(131)	61(49)	1.8	
Steep uphill (0.39 to 0.63)	42(17)	58(23)	1.6	0.04

LRS-Likelihood ratio test statistic

Table 4: Descriptive statistics and univariable conditional logistic regression analyses of fence level continuous variables and their relationship with the risk of falling from the case-control study in steeplechase racing on 12 UK racecourses

	Univariable conditional Logistic Regression		Controls				Cases			
Variable	**OR**	**p-value**	**Mean**	**St Dev.**	**Min**	**Max**	**Mean**	**St Dev.**	**Min**	**Max**
Number jumps	0.96	0.2	16.9	3.4	10.0	27.0	16.5	4.0	10.0	27.0
Jump number fall	1.1	<0.01	8.4	5.1	1.0	22.0	10.7	5.4	1.0	27.0
Gradient approach from 10 metres (x10)	0.4	0.1	0.13	0.13	-0.2	0.63	0.11	0.16	-0.2	0.63
Width of birch	0.95	0.1	25.5	5.5	15	45	25.4	5.3	15.0	45.0
Ditch width	0.8	0.3	46.2	11.7	20.0	74.0	42.7	13.9	18.00	68.0
Angle	0.9	0.3	33.5	3.9	22.0	39.0	33.3	4.1	24.0	39.0
Total width	0.9	0.6	82.3	18.7	35.0	140.0	82.2	16.8	35.0	161.0
Width to Guard rail	1.01	0.74	26.5	3.9	18.0	37.0	27.3	3.5	18.0	39.0
Height guard rail	0.9	0.2	24.0	3.2	13.0	32.0	23.6	3.9	13.0	32.0
Dist. between ground & guard rail	0.99	0.7	34.8	3.8	27.0	46.0	34.7	3.8	21.0	45.0
Height at back	1.01	0.5	23.0	3.2	15.0	30.0	22.8	3.3	10.0	30.0
Height front	1.03	0.3	52.0	4.6	33.0	65.0	52.8	3.1	33.0	65.0
Height ground rail	1.05	0.04	10.9	4.6	5.0	27.0	11.9	5.0	5.0	27.0
Angle app	1.01	0.7	2.5	2.9	0.0	12.0	3.3	3.7	0.0	14.0
Camber	0.01	0.4	0.005	0.02	-0.05	0.15	0.004	0.02	-0.05	0.15
Length barrier	0.9	0.1								
Distance to start	1.001	0.9	173.0	112.7	102.0	637.0	168.5	91.5	10.2.0	687.0
Distance to previous fence	1.001	0.09	263.3	159.0	77.0	973.0	294.4	191.3	89.0	1045.0
Distance to next fence	0.99	0.003	273.3	174.6	77.0	973.0	263.8	197.3	77.0	1045.0

Survival analyses to investigate the time taken to return to racing after a horse fall.

This study was performed to investigate if a horse fall led to an increase in the time taken to return to racing. The time until the horses' next race was recorded for all cases and their matched controls. Cases that suffered a fatal fall and their controls were excluded. The horses were followed for 14 months after the recruitment of the last case so horses that had not yet returned to racing contributed days up until that date. Kaplan Meier survival curves were plotted for cases and controls (figure 1). The mean time to the next race was 157 days for controls and 191 days for cases. Cox proportional hazard models showed that cases did have an increased time to return to racing (β= -0.14) however this difference was not significant (p=0.15).

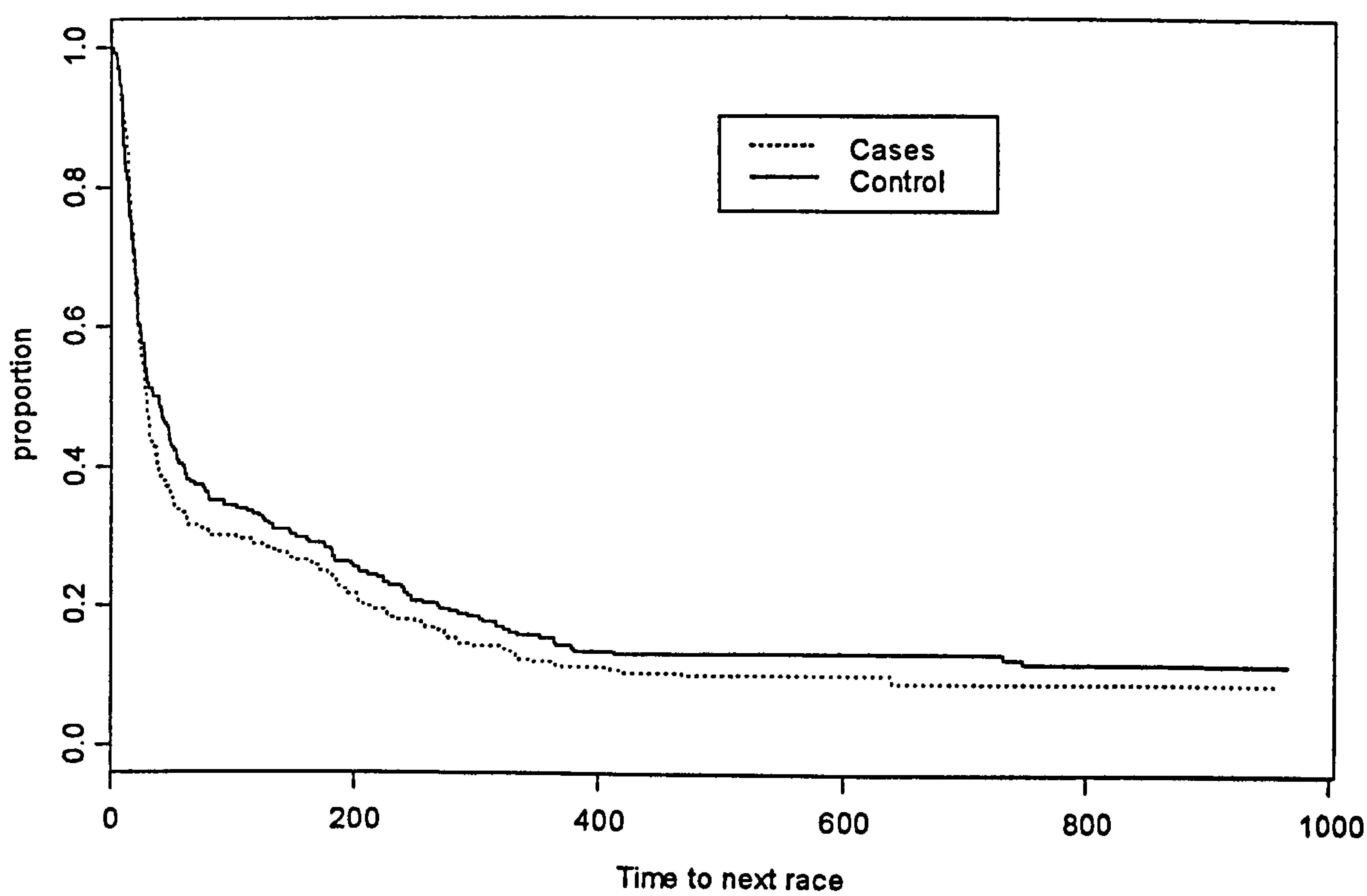

Figure 1: Kaplan-Meier plot of time until next race for case horses that fell and control horses.

Concluding Discussion

Work in this thesis has quantified the role that horse falls have in the fatality and injury rates of horses in National Hunt racing in the UK and has identified risk factors for falling over different types of obstacle. The retrospective and cohort studies indicated that the falling rate was higher in steeplechasing (6.0 per 100 starts) than hurdling (2.1 per 100 starts) with 3.7% and 7.1% of falls respectively leading to fatality. In the retrospective studies, 35% of hurdle fatalities and 42% of steeplechase fatalities were associated with falls, whilst in the cohort study the figure was slightly higher, which may be a reflection of the racecourses selected for inclusion in this study. These estimates were slightly lower than those quoted previously of between 50% (Mckee 1995) to 55% (Vaughan and Mason 1975). It is possible that the number of fatalities associated with falls has decreased in recent years. However, yearly figures would be necessary to confirm this trend. With such a high percentage of fatalities still attributable to falls, further investigation of risk factors for falling was warranted.

Examination of the sources of variation in the risk of falling showed that there was very little contribution to the variation in the risk of falling by trainer or jockey during 1999. There was also very little contribution by racecourse, although the "worst" racecourse was significantly different to the "best" racecourse in steeplechasing. Most of the level-2 variation was at the level of the horse and the race. Some of the horse variation was explained by age and previous experience, however the results suggest that some horses are more prone to falling than others. There was a proportion of variation that was attributable independently to sire and further examination of breeding lines, particularly National Hunt sires versus flat sire, may be more revealing

Several risk factors were identified as having a significant association with the risk of falling in more than one study within the thesis. These include variables relating to the horses previous racing experience, race distances and number of jumps and climatic factors.

Horses having their first ever race in either hurdling or steeplechasing were found to be at increased risk of falling in the retrospective studies and case-control studies. The increase in risk for first time racers varied from 1.3 for steeplechasers that had never raced before in the retrospective study, to a 5-fold increase in risk for first time hurdle racers in the case-control study. Studies of fatalities on all UK racecourses from 1990-1999 also found an increase in risk of fatality for horses having their first ever race of that type (Wood et al. 2002), so the results in this thesis support those findings. Younger horses were also found to be at increased risk of falling in steeplechase races in both the retrospective study and the cohort study. Introduction of compulsory schooling races on racecourses, prior to a horses first competitive race, or improved schooling of horses over jumps at home are possible interventions that may have a beneficial effect. However, if changes are made in schooling practices in the training yard careful monitoring of the falls and injuries that occur during training should be undertaken. An increase in the number of races in the previous 12 months and an increase in number of races on a particular course were associated with a decrease in the risk of falling. Together these findings support the argument that providing horses with recent experience of jumping fences or hurdles under proper race conditions should decrease the risk of falling and therefore injuries.

Increasing distance of the race in steeplechasing was found to be associated with an increase in the risk of falling and injury in both the retrospective and the cohort study. Studies of fatalities on all UK racecourses from 1990-1999 also found that increasing distance of race was associated with increasing risk in steeplechasing (Wood et al. 2002). In both the hurdle and steeplechase case-control studies, falls were more likely to occur at fences later in the race (with the exception of the first fence).

The association between jump number and the risk of falling was consistent in hurdling and steeplechasing; compared with the first jump, there was an initial decline in risk of falling, followed by a steady increase from the third fence onwards. Fences near to the finish of the race were associated with an increased risk of falling. This first fence effect was also seen in a study of Grand National races at Aintree over the last ten years (data not presented in this thesis).

Analysis of a restricted data set investigating the association between speed, distance and number of runners and the risk of falling at the first fence suggested only the number of runners was associated with the risk of falling, perhaps due to crowding. However, this was a small data set and was restricted to steeplechasing. Further investigation of the first fence effect is warranted, but recommendations which could be made now would be to site fences so that the field of horses could spread out on the approach and take off at the fence. The proximity of other horses was also associated with the risk of falling in the video study.

At present the distances of races and the number of fences required within a race is governed by the Jockey Club. Shortening races (or banning very long races) is probably not feasible as "staying" chase and hurdle races are an integral part of National Hunt racing. However, it may be possible to reduce the number of jumps the horse is required to make in these races and to have the last jump at a greater distance from the finish line.

Other modifications that could be made to course design in steeplechasing include the abolition of water jumps. Water jumps were not associated with an increased risk of falling compared to plain fences in this study, which is in contrast to the beliefs of some trainers and jockeys in the industry. However, when the previous fence was a water jump, there was increase risk of falling at the subsequent fence. It would be interesting to expand the steeplechase case-control study to all UK racecourses to see if this effect is consistent. Many trainers and jockeys dislike water jumps (personal communications) so removal of these jumps would probably be viewed as a positive move by many in the industry. Siting all jumps on flat, or slightly uphill approaches, would also be an intervention that could be tested on the majority of racecourses (with the exception of those sited in very hilly areas).

Padding of hurdles and the guard rails of steeplechase fence had already begun to be introduced during this study and will be mandatory from 2003. Although this was introduced to try to decrease the risk of limb injuries, it seems to also be associated with a decrease in the risk of falling.

Weather dependent variables were also found to be significantly associated with the risk of falling in many of the studies in the thesis. Softer going was associated with a decrease risk in falling in hurdling in the retrospective and case-control studies and has been shown to be associated with decreased risk of injury in a number of other studies (Bailey et al.1998; Wood et al. 2000; Williams et al. 2001). In steeplechasing, the retrospective study found that soft going was associated with an increased risk of falling. In the cohort study, good-to-soft going was associated with a decreased risk when compared to good going, although this was after allowing for the effects of rainfall, which increased the risk of falling. In the steeplechase case-control study the effect of going was not significantly associated with the risk of falling. However, previous studies have shown that softer going is associated with a decreased risk of injuries in steeplechasing (Wood et al 2000; Williams et al 2001) and it seems likely that falls on softer ground may be associated with a lower injury rate than falls on firmer ground.

Condition of the track surface or going is currently defined by subjective assessment by the clerk of each racecourse and consequently is not standardised across racecourses. Development of methods to record accurately the condition of the track surface and moisture content, that are applicable across all racecourses, are required before exact recommendations can be made. However evidence suggests that efforts should be made to race on good-to-soft or soft ground and development of facilities to water racecourses, to achieve this without causing damage to the surface of the racetrack should be sought.

Details on the light conditions and weather at the time of the race were only available in the cohort study. This showed that sunny weather was associated with an increased risk of falling. Although this is not directly modifiable, more efforts to miss out fences where visibility may be inhibited by the direction of the sun may be justified. At present this is only common practice at sunset when the sun is considered blinding by jockeys.

Increasing journey time was associated with an increased risk of falling and one way to decrease journey times would be to insist that horses travelling long distances stay overnight at the racecourse. However, this may have high financial implications both for the racecourses, who would have to provide more stabling accommodation, and for trainers (and, subsequently, owners) due to possible salary increase for carers of the horses. There may also be implications for the transmission of infectious disease between horses if they are stabled together at the racecourses for longer periods.

The cohort study also quantified racing practices such as withholding feed and water prior to racing which the majority of trainers practised. There was some evidence that withholding water increased the risk of injury although further work is needed to identify if this association is with a particular type of injury or medical event or if withholding water is a marker for another factor. There was also some evidence that pre-race behaviour was associated with falling. Further work to investigate the effects of journey times, withholding food and water, and behaviour, on the physiology of racing horses is indicated.

In the cohort study, there was evidence that time since shoeing, and hoof conformation, were associated the risk of injury, particularly tendon injury. Further studies with larger sample sizes, quantitative evaluation of hoof conformation, and specific injury outcomes are warranted.

Whip use was found to be associated with a large increase in risk of falling in horses that were progressing through the race. Banning of the whip would be a controversial decision, although it may be seen as a positive move, particularly by groups concerned with animal welfare. Another possible solution is that the whip can only be used after the last fence has been jumped. An intervention study, with whip free races, may be needed to provide further evidence to support these findings.

The sources of data used in the studies of this thesis are considered, by those in the industry, to be accurate. Cross checking between data sources and by the author during attendance at races in the cohort study did not reveal any misclassification of cases and controls. One major error in Raceform Ltd., which became evident during the retrospective data analysis, was the inclusion of horses that were withdrawn under starters orders. In Raceform Ltd. these horses appeared to have completed the race and this should be checked in any future studies. The only other errors found were in Raceform Ltd. and related to the going on the day of racing.

A number of different study designs and analytical methods were utilised in this thesis. The retrospective cohort studies enabled estimation of the incidence risk of falling and of fatalities due to falling. Data on all starts on all UK racecourses were used so the results were not bias with regard to racecourse or horse selection. There was a hierarchical structure to these data including more than 1 start by many horses and clustering at the level of trainer, jockey, sire, dam and racecourse. These areas of clustering have rarely been evaluated in previous studies on racing injuries and fatalities (Wood et al. 2001). We used multilevel models to address this hierarchical structure and this had two purposes. Firstly, to evaluate whether the effects of independent variables varied as a result of this clustering (Green et al. 1998), and secondly to investigate the contribution of these various levels of racing hierarchy to the risk of falling (Dohoo 2001). Although procedures for estimating parameters in multilevel models with a binary outcome are not well established the use of a variety of approaches, using different software, to derive the estimates allowed us to have confidences in our results (Dohoo 2001).

The main limitation from using this retrospective data set was that only information on a limited number of variables was available for analysis. However, the large number of cases and starts gave high power to detect small odds ratios for those available.

The cohort study on falling and injuries enabled confirmation of falling risks and further evaluation of injuries due to falling. Questionnaire administration before racing commenced should have eliminated non-differential bias in answers to the questionnaires. However the cohort was expensive and timely to conduct, and a relatively small number of cases of falling and injury were selected leading to low power in analysis of some of the variables.

In both the retrospective and prospective cohort studies, variables were examined for the relationship with the risk of falling using a number of techniques. Generalised additive models (Hastie and Tibshirani 1990) were used to explore what types of variable transformations might be appropriate for the continuous explanatory variables and the outcome. These proved useful in informing the polynomial terms to use in subsequent logistic regression models and enabled the retention of continuous terms in the models rather than categorisation of variables and the resultant loss of power. The relationship between categorical variables and the risk of falling was explored using chi-squared analysis and then logistic regression models (including multilevel logistic regression models) to allow for the effects of other variables and confounding.

The case-control studies were relatively quick and of low cost to conduct and information on a large number of variables and a large number of cases were collected. The data came from Racing Post online, Raceform Ltd and from course visits during the data collection period so there was little potential for differential recall bias which is a common problem in case-control studies. The case-control studies provided exposure odds ratios, however as falling is rare these were used as estimations of relative risks. As the case-control studies were matched, conditional logistic regression analyses were used. The fitting of GAM models is more complex in matched case-control studies and was not possible with the software used in this study. Use of multilevel models would also have been a more complex in these matched studies and would have involved the use of cross-classification matrices. Another limitation of matched case-control studies is the loss of case numbers through the loss of concordant pairs during conditional logistic regression analyses.

Both the prospective cohort and the case-control studies were conducted on selected racecourses and therefore the results cannot necessarily be extrapolated to all racecourses in the UK.

To conclude, this thesis demonstrates that epidemiology can be a useful tool in identifying risk factors for injury in high-risk sports and for providing evidence based solutions to make sport safer. A similar study design is currently being used to investigate risk factors for falls in the sport of Eventing (Singer et al. 2003). The studies within the thesis have confirmed that horse falls contribute significantly to the horse fatality rate in National Hunt racing. They have provided very strong evidence of the effect of many risk factors, which, when considered in the light of results from other studies, indicate that interventions may be warranted. Table 1 shows some of the variables associated with an increased risk of falling and some of the possible intervention studies that could be implemented after consultation with the industry. In addition to the possible intervention studies highlighted in table 1, further studies to identify risk factors for particular types of common injuries, such as tendon injuries, are indicated including a more quantitative assessment of the contribution of foot conformation to the risk of injury. The thesis has also identified areas where further investigation is needed, particularly in the areas of equine behaviour and the physiological responses to travel and race day routine.

Table 1. Some of the variables identified as being significantly associated with an increased risk of falling in hurdling and steeplechasing from the studies within this thesis and potential intervention studies that may have a beneficial effect. The variables are grouped into horse, race, fence and jockey levels.

Level	Manu-script	Variable associated with increased risk	Possible interventions/ future studies
Horse			
	2 & 6	First hurdle race	i) Introduction of compulsory schooling races for horses before their first race. ii) Improved schooling of horses by trainers at home over a variety of fence types.
	1	First steeplechase race	
	1 & 3	Young age	
	7	Fewer races over a particular steeplechase course	
	1 & 6	Increased no. of previous falls	
	1 & 2	Number of races in previous 12 months	Regular schooling or schooling races for horses that haven't raced for long periods.
	2	Older age at first hurdle start	Introduction to schooling/schooling races at young age.
	3	Increased journey time	Horses travelling long distances stay overnight
	3	Excitable behaviour in parade ring	Needs further investigation
Race			
	1, 3 & 6	Longer distance races	Less jumps in long distance races and jumps further from finish
	6 & 7	Later fences/hurdle flights	
	6 & 7	First fence/hurdle flight	Needs further investigation (distance to fence and crowding of field). Jockey education
	1, 2 & 3	Good going	Water course to achieve good-soft/softer going
	3	Sunny weather	Remove/change position of obstacles where visibility is compromised
	6	Fast speeds in short hurdle races	Advise jockeys, course topography to decrease speeds
	1	Increase in number of runners	Limit field sizes
	6	Race number in day	Needs further investigation (light, ground conditions, horse effect)
Fence			
	7	Previous fence is a water jump	Abolition of water jumps
	7	Downhill sited jumps	Move to flat/slightly uphill ground
	6	Non-padded hurdles	Padding introduced–continue to monitor
	7	Non-padded guard rails	Padding introduced–continue to monitor
	7	Higher take off board	Reduce height of take off boards
Jockey			
	5	Whip use at fence	Whip free races or limit whip use until after last fence
	5	Close proximity to other horses	Advise to jockeys on positioning
	2	Conditional jockeys (claiming weight)	Improved instruction on jumping techniques

References

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