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**Epidemiology of health and performance
in New Zealand racehorses**

A thesis presented

In partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Veterinary Epidemiology

at Massey University, Palmerston North,

New Zealand

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2005

Abstract:

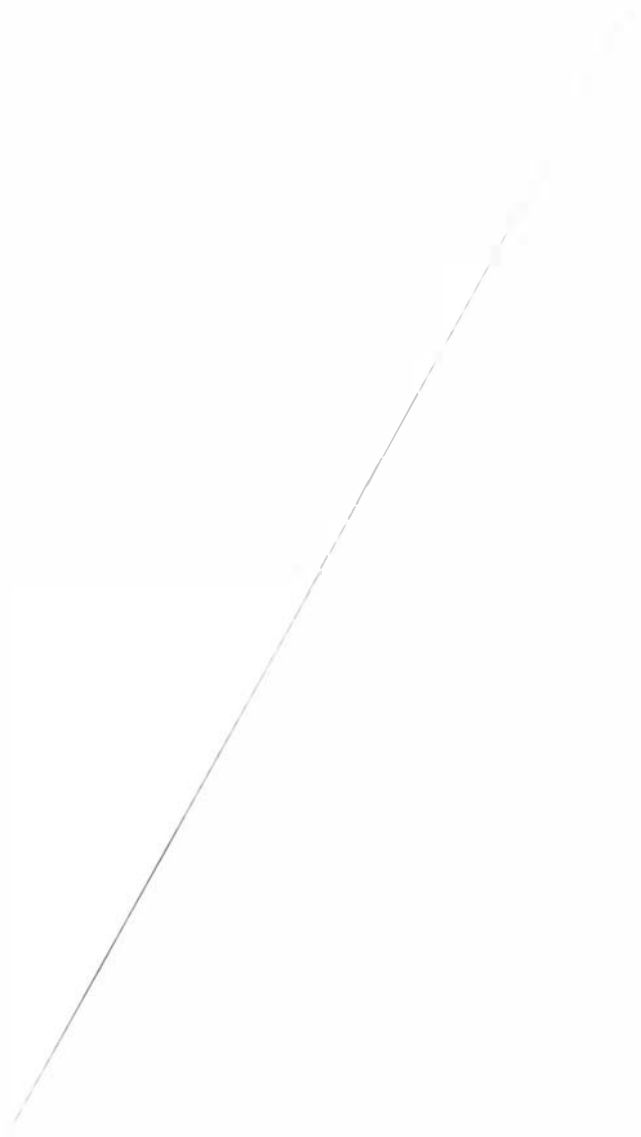
The aim of this research was to describe training and racing patterns, and causes of wastage in New Zealand Thoroughbred racehorses. Two separate studies were performed. The first involved analysis of data from before and after construction of a new training track at the Matamata Racing Club. Comparisons of measures of performance failed to detect any adverse impact that could be attributed to the new track.

The second involved a longitudinal study over a 34-month period, and that involved 1,571 horses. Duration of training preparations and spell periods were associated with horse age, and with the reason for ending a training preparation. Most horses began a training preparation doing slow work and then progressively advanced to a first start. Incidence rates were estimated for starts per 100 training-days, and other summary measures were estimated including training-days to first start, and between successive starts.

A total of 834 musculoskeletal injuries (MSI) were observed, resulting in either a spell period, retirement, or death of the horse. There were 165 respiratory disease events, and 58 conditions involving other body systems.

Multivariate statistical models were used to explore risk factors for different types of MSI. Older horses were at higher risk of lower limb MSI, and injury to either the superficial digital flexor tendon (SDFT) or suspensory apparatus (SA), while they were at lower risk of shin soreness and other conditions. Male horses had higher risk of tendon and ligament injury than females. Lower risk of injury was observed in Autumn and Winter months compared with December, and in the 1999-2000 year relative to 1997-1998. Measures of cumulative exercise intensity showed a complex relationship with risk of injury that varied with type of injury. The risk of SDFT and SA injury was higher for those preparations without starts, while that for shin soreness was increased after the first start. For lameness conditions other than shin soreness or injury to the SDFT, the hazard was increased after the first start in a preparation, but the magnitude of effect was dependent on the number of days from the beginning of a preparation to the first start.

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Acknowledgements

A large number of people contributed towards various stages of this project and I am grateful to them all for their support.

The New Zealand Equine Research Foundation provided funding and encouragement. New Zealand Thoroughbred Racing staff and regional racetrack management staff, provided assistance. A special thank you is due to Ms Dagmar Fikken who was employed as a technician to assist in the collection of data, and to Glenda who helped so much with the Matamata end of the project.

Thank you to the large number of veterinarians, trainers, and stable staff, who helped in so many ways to make this project possible, not the least of which was giving up their time on a regular basis to allow myself, Dagmar, or Glenda to ask questions and fill out forms.

A special thank you to my supervisors, Stuart Reid and Roger Morris, for their guidance and advice, and to colleagues from the Institute of Veterinary, Animal and Biomedical Sciences for their general support.

Finally to Kim, Emily and Caroline, and my extended family, your love and support has been wonderfully sustaining throughout this process.

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Chapter 1

Introduction

All horses taking part in athletic competition are at some risk of injury. Injuries incurred during training or racing have direct and indirect impacts. Direct impacts include time lost from training and racing, costs associated with treatment and recovery, as well as loss of future earning potential. Public perceptions of racing and animal welfare represent an important indirect cost that is difficult to quantify.

Implementation of effective measures to minimise occurrence and impact of conditions that interfere with training and racing, must be preceded by efforts to understand the complex relationships between factors that influence the occurrence and severity of such conditions.

This thesis reports the results of studies conducted to investigate the epidemiology of conditions affecting New Zealand racehorses, in particular musculoskeletal injuries incurred during training and racing. The thesis is presented as a literature review in Chapter 2, followed by a series of chapters each representing a paper submitted for publication to a peer reviewed journal.

Chapters 3 and 4 present results of descriptive and analytical studies respectively, attempting to determine whether the construction of a new training track at the Matamata Racing Club had any impact on indirect measures of racehorse performance.

Chapter 5 presents descriptive results of training and racing patterns in New Zealand Thoroughbreds, using data derived from 1,571 horses enrolled during a 34-month longitudinal study. Chapter 6 describes conditions that interfered with training and racing in New Zealand Thoroughbreds.

Chapter 7 presents results of multivariate logistic regression analyses using a nested case-control design, to investigate risk factors associated with lower-limb musculoskeletal injury in training and racing Thoroughbreds. Chapter 8 describes the use of Poisson regression to investigate risk factors for two specific classes of injury: superficial digital flexor tendonitis, and injuries affecting components of the suspensory apparatus.

Chapter 9 presents results from a competing risks survival analysis to assess factors associated with time-to-event data, where the event of interest was the first occurrence of one of three subcategories of lower-limb musculoskeletal injury (shin soreness, superficial digital flexor tendonitis, and lameness other than shin soreness or superficial digital flexor tendonitis).

The thesis concludes with a general discussion (Chapter 10). References cited in the literature review and general discussion are listed at the end of the thesis, while those cited in chapters 3 to 9, are listed at the end of each chapter.



Chapter 2

Literature Review

1. Introduction

The first known Thoroughbred in New Zealand was a stallion named Figaro that arrived in Wellington in 1840, and a number of other Thoroughbred broodmares were imported in the early 1840's from New South Wales (Redwood 1979). Early race meetings were controlled by local committees with little communication between clubs, and no standardization of race rules. A centralised New Zealand Racing Conference was recognised by the English Jockey Club in 1900 as the governing body of racing in New Zealand (Costello and Finnegan 1988), marking the beginning of uniform racing rules across the country. National yearling sales began in 1927 in Wellington, moving in 1987 to a custom designed facility at Karaka just south of Auckland. The middle and latter parts of the twentieth century saw horse racing in New Zealand change progressively from a sport with minor business associations, to a large scale industry with a sporting flavour (Costello and Finnegan 1988).

New Zealand Thoroughbred Racing (NZTR), with headquarters in Wellington, is the central governing body of Thoroughbred racing in New Zealand. NZTR represents the interests of the 71 racing clubs operating on 51 training and racing venues around the country. Responsibilities of the NZTR include administration of the codes and rules of racing, keeping of the New Zealand Stud Book, handicapping, licensing of trainers and jockeys, registration of all racing animals, production of industry and code publications, collection of fees and payment of stakes, and the taking of nominations and withdrawals for all race days. NZTR also maintains the official Thoroughbred racing database and supplies complete raceday form for all of the country's 290 annual racedays.

Summary data from NZTR records on aspects of the New Zealand Thoroughbred industry are presented in Tables 2.1 and 2.2.

Table 2.1: Summary statistics on New Zealand Thoroughbred breeding, sales and exports, 1995-2001 (NZTR 2004).

Season	Stallions (n)	Mares served (n)	Foals born (n)	Horses exported (n)	Value of exports (\$NZD)	NZ yearling sales aggregate (\$NZD)
1994-95	340	8587	5264	2064		\$30.1 million
1995-96	293	8340	5219	1987		\$29.1 million
1996-97	283	7947	5161	2027		\$31.2 million
1997-98	283	7718	4974	1827		\$44.4 million
1998-99	258	7224	4850	2175		\$48.7 million
1999-00	241	7316	4868	1937	\$110 million	\$71.7 million
2000-01	226	7738	4953	1918	\$115 million	\$68.3 million

Table 2.2: New Zealand Thoroughbred racing statistics, 1995-2001 (NZTR 2004).

Season	Meetings n	Horses raced n	Races run n	Trainers n	Jockeys (excluding apprentices) n	Total prizemoney \$NZD
1994-95	331	6426	3254	410	146	\$28.2 million
1995-96	328	6171	3242	423	194	\$30.3 million
1996-97	326	6124	3206	417	188	\$30.5 million
1997-98	320	5973	3142	397	181	\$31.4 million
1998-99	314	5837	3074	387	177	\$31.8 million
1999-00	301	5599	2945	383	180	\$31.8 million
2000-01	286	5462	2793	369	166	\$32.2 million

Data from NZTR on international foal crops over a 21-year period (1982-2002), indicate that New Zealand has the fifth largest Thoroughbred industry in the world with the average, annual number of foals born over this period being 5,599. Countries with larger average numbers of foals born per year over this period include USA (38,101), Australia (19,426), Japan (8,666), and Ireland (6,651). The average annual number of foals born in Great Britain during this same period (5,106), was just less than in New Zealand (NZTR 2004).

2. New Zealand racing industry

The New Zealand Thoroughbred industry is a major contributor to GDP, both directly and indirectly. Thoroughbred races in New Zealand are held throughout the year, horses race exclusively on grass (turf) track surfaces and the racing industry has an emphasis on racing of 2 year olds.

NZTR administers racing in New Zealand in accordance with the rules of racing (Anonymous 2000). There are currently 1,520 rules pertaining to racing, covering all aspects of training and racing of horses within New Zealand. A brief review of selected rules is presented here, concentrating on those issues that are related to this thesis.

- Rule 401: All Thoroughbreds are deemed to have an official birthdate on August 1st of the season in which they are born and horses age by one year on August 1st each year (rule 401).
- Rules 301 to 318: NZTR is responsible for licensing of trainers and jockeys within New Zealand. Licensed trainers are by definition full time professionals whose primary occupation is the training of racehorses. Additional licensing categories are Permit to Train (limited to less than 6 horses in work), and registered Owner-Trainer (limited to those horses owned or part owned by the trainer). These categories often apply to people who train a small number of horses, and whose primary occupation may be something other than the training of racehorses.
- Rule 504: All Thoroughbreds being trained for racing must be registered with New Zealand Thoroughbred Racing (NZTR) under the name of the owner and the trainer, within 7 days of arriving at a stable to commence training. NZTR must also be notified within 7 days of a horse leaving a stable to commence a spell or to move to a different stable.
- Rule 402: No horse under the age of 2-years is allowed to start in any race. In addition, 2-year old horses are prevented from starting in races between 1000 and 1200 m until after 01 December in the year in which they turn 2, and from races longer than 1200 m until after 01 March of the following calendar year
- Rule 809: No race is allowed to be shorter than 800 m in distance.
- Rule 809: Races between 800 and 1000 m are restricted to 2-year olds only.
- Rule 402: A horse may not start in any hurdle race before 01 February in the year in which it becomes three years old, and in steeplechase races until it is four years old. In addition, horses are not allowed to start in hurdle or steeplechase races until they have been deemed by a stipendiary steward to have had sufficient schooling to start in that type of event.

- Rule 604: All hurdle races must be a minimum of 2400 m long and steeplechases a minimum of 3200 metres (rule 604). Hurdle races must have a flight of hurdles every 300 metres. The fifth schedule of rule 604 defines the construction requirements for hurdles, and the sixth schedule defines those for steeplechase fences.
- Rules 835 to 858: The weight carried by a horse (jockey, saddle, saddle cloth and selected items of tack), is carefully defined in these rules. Minimum weights are defined for different categories of race, horse age and horse gender. In handicap races weights carried by each horse are determined by a handicapper based on their previous performance in an attempt to equalise the chances of winning for each horse in the event. Apprentice jockeys are then eligible in many events to claim a variable amount of weight (removed from the total allocated weight the horse must carry), with the amount varying according to the number of winning rides the jockey has accumulated during his or her career.
- Rule 1004: Administration of any drug capable of affecting a horse's speed, stamina, courage or conduct is an offence punishable by a racing tribunal convened to rule on the matter.

NZTR sets the dates for all race-days run by all racing clubs across the country and also influences the number, type (flat, hurdle, steeplechase), and class of races on offer in any given race-day. A racing season begins on 01 August of any given year and ends on 31 July of the following year.

Official NZTR sanctioned events include trials and races. Two types of trials are run in New Zealand, qualifying trials where the winner and one or more of the placegetters may gain preference for a subsequent start in a race, and non-qualifying trials that are staged primarily for the education and/or training of a horse and/or rider. There is no betting on trials. Trial meetings are set by the NZTR and subject to the same control as race meetings.

Race types are generally similar throughout the world with some exceptions. Flat races are the standard Thoroughbred race without obstacles, performed on a flat surface, typically turf, dirt, or composite (mixture of dirt, wood fiber and synthetic material). The UK has 3 other race types: hurdles, steeplechases, and National Hunt Flat races.

National hunt flat races are run over hurdle course with the hurdles removed, and are intended to introduce inexperienced horses to racing as a first step in their development towards a jumping career. Horses competing in National Hunt flat races are relatively inexperienced 4 to 6 year olds, racing over distances of 2 miles or more. National Hunt races are generally held as the last event on a race day, over ground which has earlier been used for hurdle racing (Williams et al 2001). Steeplechase events include varied types of solid obstacles such as plain jumps, open ditch obstacles and water jumps, each obstacle type conforming to racing authority guidelines regarding materials and construction (Pinchbeck et al 2002). Hurdle events involve a uniform obstacle made according to racing regulations (Pinchbeck et al 2003). Jumps in steeplechase events are solid structures and are generally higher than the brush hurdle jumps (Bailey et al 1998). Thoroughbred racing in New Zealand is performed over flat, hurdles and steeplechase events, with no events in the National Hunt Flat racing category.

In the 2000-2001 racing season in New Zealand, a total of 5,462 horses started 30,784 times in 2,793 races, for an average field size of 5.3 starters per race (Aldridge 2001). The average prizemoney per race was \$11,537 and average earnings per runner for the year was \$5,900. Of the 2,793 races, a total of 2,647 (94.8%) were flat races with the remaining 5.2% being made up of jumps races (steeplechase and hurdles). The same relationship was observed for starters with 29,420 of a total of 30,784 starters (95.6%) competing in flat races and the remaining 4.4% competing in jumps races (Aldridge 2001).

Most trainers train their horses at a regional training venue managed by a race club. Most raceclubs maintain more than one training and racing surface at the racetrack and on any given day a trainer has a choice between several training surfaces including commonly dirt, sand and turf. There is one training venue in New Zealand that has recently installed an all weather, composite Trackmaster™ training surface. A number of trainers maintain their own private training surfaces. In some cases these private tracks are only used for slow exercise and then the horses are transported to a raceclub facility for fast-speed exercise. In other cases trainers maintain a private track on which they are able to exercise horses right up to race fitness.

Training of Thoroughbred racehorses appears to be strongly influenced by tradition and habit. While acknowledging that there are variations in training methods both between horses trained by the same trainer and also between trainers, it is possible to describe in

very general terms some patterns that are likely to be common for all trainers. In general young horses in their first year of training (rising two year olds), spend more time gaining familiarity with the routines associated with training, and less time training with any level of intensity. Once horses are accustomed to the routine then training becomes more structured. The overall goal is generally to have a horse reach a particular level of fitness and athletic ability prior to their first race start and then to maintain that level of fitness between successive starts.

Racehorses are typically broken in and introduced to riding and to a training surface between the ages of 15 to 24 months. Animals are usually handled for brief periods in this early acclimatisation phase and then turned out to spell. For yearlings this typically means initial breaking in and handling in January to March, followed by a spell from April to June to allow the animals to mature. Yearlings are then brought back into work around July to begin a training preparation that may result in their first start as a 2-year old in the spring or summer of that year, after they officially turn 2-years old (Arnott 1997).

In the early stages of a training preparation horses are generally ridden for shorter distances and at lower speeds during training. As a horse becomes fitter, training sessions become more intense both in terms of distance covered and speed. Horses are generally asked to train at racing speeds or close to it as they approach race fitness. High speed training sessions may be used to assess a horse's readiness for racing (Harkins et al 1992).

It is difficult to generalise about time periods required to train a horse to race fitness. One author of a guide to racing in New Zealand suggests that it takes about three months to take a horse from pasture to racing fitness (Arnott 1997), and Australian trainers reported an average of 11 weeks (standard error= 3 weeks, range from 5 to 23 weeks) (Bailey et al 1997b). Of 40 professional trainers in New South Wales, 63% sent at least some of their horses to pretraining for an average of 4 +/- 1 weeks (range 1 to 6 weeks) (Bailey et al 1997b), which may influence the time required for a horse to reach race fitness. The term pretraining is used to refer to the practice of sending horses to a non-licensed horse trainer for the horse to receive general handling and a varying level of basic fitness training. Once a horse reaches racing fitness, 62% of trainers reported working horses at $\frac{3}{4}$ pace or faster on 3 occasions a week with 20% of trainers doing this only two times a week (Bailey et al 1997b).

At varying stages in each horse's training and racing career animals will be spelled from training and racing. Spells may be classified as voluntary and involuntary. Voluntary spells are defined as spells that occur when the horse has no impediment to continued training and racing. Reasons for voluntary spells are many and varied and include lack of suitable races, weather and track conditions, financial reasons, and personal preference on the part of the trainer or owner. Involuntary spells are defined as spells that occur because the horse has some condition that prevents further training and racing. Examples include diseases or injuries that may or may not be related to the athletic endeavour. Spell periods represent a time when the horse is not able to compete for income. In addition, loss of athletic fitness during spelling means that a horse must go through a varying level of training to reach or regain race fitness before starting in a race. Given that there is year round racing in New Zealand and that the only time a horse is able to generate income is while racing, it does seem reasonable to expect that while a horse is tolerating the stresses of training, and is racing at an effective or acceptable level of performance, there may be more incentives to keep a horse in work rather than spelling.

A veterinarian attends every race day as the official attending veterinarian for the NZTR. Veterinary duties include inspection of horses before and after racing to ensure all horses are fit to race, inspecting horses at the request of the stipendiary steward, and collecting urine or blood samples from those horses selected for drug testing. There does not appear to be a standardised reporting format or central recording system for veterinary reports. All serious injuries and in particular those injuries resulting in death or euthanasia are generally reported to the race club stewards. However, it is likely that less severe injuries are under reported in part because they may not be brought to the veterinarian's attention while the horse is at the racetrack on race day.

Racehorse training and racing place inevitable stresses on an animal's musculoskeletal system. The musculoskeletal system has a tremendous ability to adapt to the strain of intense exercise but if the demands exceed inherent adaptive capacity then some level of damage may result (Pratt 1982; Stover et al 1988; Young et al 1991). Exercise at high speed or for prolonged durations can exceed the structural capacity and adaptive response of the musculoskeletal system, resulting in micro- or macro-damage. Damage may result in transient periods of weakened structural support. In most cases this is followed by a repair phase with recovery of the affected tissues or structures (Riggs and

Evans 1990). However, racehorses do appear to be capable of sustaining running speeds that can result in sufficient damage to musculoskeletal structures to overwhelm the repair and adaptation processes. (Nunamaker et al 1990; Evans et al 1992; Nielsen et al 1993) This process may then place the horse under increased risk of serious musculoskeletal injury.

It is likely that all horses taking part in athletic competition are at some risk of injury. Injuries incurred during training or racing have direct and indirect impacts. Direct impacts may include time lost from training and racing, costs associated with treatment and recovery, as well as loss of future athletic and earning potential. Impacts are not limited to horses with the very real risk of jockey injury or death also being associated with training and racing of horses. Indirect costs include effects associated with public perceptions of racing and animal welfare. The financial implications of TB racehorses being unable to train or race, withdrawn from the industry, or dying as a result of injury, are considerable to the racing industry.

There is then considerable incentive to investigate risk factors that might contribute to the likelihood of a racehorse being injured during training and racing since any attempt to minimise such risks will require a sound understanding of the factors involved and the relationships between them (Bailey et al 1997a; Oliver et al 1997).

3. Review of epidemiological study design

Principles of epidemiologic research have been outlined by Kleinbaum, Kupper and Morgenstern (1982) with the following general aims:

- "describe the health status of populations by enumerating the occurrence of diseases, obtaining the relative frequencies within groups and discovering important trends
 - explain the aetiology of diseases by determining factors that cause specific diseases or trends, and modes of transmission
 - predict the number of occurrences and the distribution of health status within populations
 - control the distribution of diseases in the population by preventing new occurrences, eradication of existing disease, prolongation of life of individuals with the disease, or otherwise improving the health status of afflicted individuals."
- (Kleinbaum et al 1982, Pp 21)

The two commonly used design approaches (experimental and observational), both attempt to elucidate cause-and-effect relationships

3.1. Experimental studies

Experimental studies or controlled field trials involve investigator control of allocation of subjects to study groups, with the major benefit being an increased potential to investigate causal associations between possible risk factors and outcomes compared with observational studies (Dohoo et al 2003). Little discussion is directed to experimental studies here because the research presented in this thesis was generated from observational studies.

3.2. Observational studies

Observational studies lack investigator control of allocation of subjects to study groups. They are commonly employed in epidemiological research where potential causal factors are complex and not easily controlled by the researchers.

Observational studies can be broadly divided into cross-sectional, cohort, case-control, and hybrid study designs (Dohoo et al 2003). In addition observational studies can be classified as prospective or retrospective. In prospective studies only the exposure may

have happened at the time the study starts while for retrospective studies both the exposure and the outcome will have occurred when the study begins. Many studies combine features of prospective and retrospective designs (Kleinbaum et al 1982).

3.2.1. Cross sectional studies

Cross sectional studies are based on a relatively simple design approach involving collection of data from a sample of subjects at a point-in-time, and typically produce prevalence estimates, potentially of both exposure and outcome. A major drawback of cross-sectional studies is the difficulty in determining if exposure occurred before the outcome. In addition it is often not possible to distinguish between factors that may be associated with persistence or severity, and factors that may be associated with initial development of the outcome of interest. Factors associated with prolonged survival of animals with the outcome of interest may inadvertently be identified as potential causal risk factors. Cross sectional studies are considered most appropriate for time-invariant exposure factors.

3.2.2. Cohort studies

Cohort studies classically involve selection of groups of exposed and non-exposed subjects and following them forward in time. The term cohort study is also applied to studies where a single group of subjects is selected initially based on a belief that they are likely to be heterogenous with respect to exposure(s) of interest. Exposure or non-exposure is then determined after selection. This type of study is termed a single cohort or longitudinal study (Dohoo et al 2003). Selected subjects are checked to ensure they do not have the outcome of interest at the start of the follow-up period. Cohort(s) are then followed for a period of time and occurrence of the outcome(s) determined. Cohort studies can be performed prospectively or retrospectively depending on the availability of suitable records (Cohen et al 1999; Dohoo et al 2003).

If cohorts are defined at the beginning of the study and then do not change ie the same animals are followed forward in time, the study may be termed a fixed cohort study. If there are no additions and little or no losses to follow up, then it may also be described as a closed cohort. Such studies are described as risk-based designs and are well suited to estimation of cumulative incidence (Dohoo et al 2003).

In many cases the population of animals in the study may change over time with both additions to the cohorts and losses to follow up being experienced. This approach is termed an open cohort and in these cases it is necessary to determine the contributions made by each animal to exposure time and non-exposure time. Open cohort studies are more suited to determination of incidence rates or densities than cumulative incidence and have been described as rate-based designs (Dohoo et al 2003).

The major methodological advantage of the cohort study is that the outcome of interest is determined to be absent at the onset of the follow-up period. Therefore we can be reasonably sure that exposure preceded the outcome of interest, and that disease status did not differentially influence the selection of subjects in each exposure category. These characteristics means that cohort studies are relatively free of certain types of selection bias that can seriously limit other study types (Kleinbaum et al 1982).

3.2.3. Case-control studies

Case-control studies involve selection of a group of cases, and a group of non-cases (controls), and then the frequency of one or more exposure factors is compared between the two groups. The major drawbacks of case-control studies are that exposure information is obtained after the occurrence of the disease, and the compared groups of cases and controls are selected from two separate populations of available cases and non-cases, meaning that disease occurrence is not always linked to a single well defined population. As a result it may be difficult to ensure that cases and noncases are comparable with respect to extraneous risk factors (Kleinbaum et al 1982). Valid causal inference in case-control studies is usually dependent on the assumption that the control population is representative of the same candidate population from which the cases developed (Kleinbaum et al 1982).

Several methods of selecting controls have been described. Controls may be randomly selected from the source population. If time-at-risk information is available, controls can be selected at the end of the study period using time-at-risk as a probability basis for selection. If time-at-risk is not known, controls can be selected at various points through the study period from the non-cases eligible to become cases at that point in time, in an approach called incidence density sampling (Dohoo et al 2003).

Case-control studies are heavily dependent on available records and recall of respondents. The use of subject recall is particularly problematic when respondents are

aware of the association being tested or when the study factor involves a subjective assessment with answers likely to be influenced by disease status (case vs control) (Kleinbaum et al 1982).

Some people have attempted to balance a perceived bias in case-control designs by using more than one control group. If this is to be useful one needs to be very clear about what biases might be present in each set of controls and how one will interpret the results, especially if they differ from one control group to another. One recent authority indicates little value in using more than one control group in a case-control study (Dohoo et al 2003). Using multiple controls per case is also common though the benefit of increasing the number of controls beyond 3-4 per case is considered to be small (Dohoo et al 2003).

3.2.4. Nested case-control

The term nested case-control study is generally used to refer to the conduct of a case-control study nested within a cohort that has already been defined and followed. In this way, the nested case-control approach combines elements of cohort and case-control designs. A single candidate population is usually defined at the start without reference to study factor information and is followed for a given time period for detection of all new cases of a disease. Incident cases are then compared to a group of noncases sampled from the same population with respect to previous or current study factor levels. Controls may be sampled randomly from the candidate population or matched to the incident cases (Kleinbaum et al 1982). The reason for conducting such a study is usually because more information is needed than is readily available from records and it is either too expensive or logistically difficult to collect the information from all subjects in the cohort (Rothman 2002).

3.2.5. Hybrid designs

Many hybrid designs get confused with the basic designs (cross-sectional, case-control and cohort), and terminology is not standard, further adding to potential for confusion (Kleinbaum et al 1982).

The case-crossover design was developed to assess the change in risk of a rare event during a brief period of elevated risk following a transient exposure (Maclure 1991; Mittleman et al 1995). In the case-crossover design as described by Maclure (1991),

each subject serves as its own control. This approach is most applicable where exposure status of individuals changes over time and where the exposure will produce its effects in a short time period (Dohoo et al 2003). The exposure status of each case is compared with the exposure status of the same individual at other times when it was not a case. The major benefit of this approach is freedom from biases associated with selection of controls that are unrepresentative of the population since each case serves as its own control (Maclure 1991).

Data from each subject are treated as if they were derived from a matched pair during the analysis to account for the self matching (Maclure 1991). In the absence of biases, the exposure odds ratio is an unbiased estimate of the relative risk (incidence rate ratio) that would have resulted from a cohort study (Mittleman et al 1995). Examples exist in the veterinary literature with respect to racehorse injury studies (Estberg et al 1998; Carrier et al 1998).

A range of other hybrid designs have been reported in the literature, and descriptions may be found in general texts such as Kleinbaum et al (1982).

4. Sources of bias in epidemiological studies

Bias is defined as an effect which deprives a statistical result of representativeness by systematically distorting it, as distinct from a random error which may distort on any one occasion but which balances out on the average (Marriott, FHC 1990). Another term for bias is systematic error. A study may be biased because of the way the subjects have been selected, the way the study variables are measured, or some confounding factor that is not completely controlled (Rothman 2002).

The term validity is used to denote absence of systematic bias in that a valid measure of association derived from the study population will have the same value as the true but unknown measure existing in the target population (Dohoo et al 2003).

4.1. Selection bias

Selection biases arise from procedures used to select subjects and factors that might influence study participation (Rothman 2002). Selection bias exists when association between exposure and outcome differs for those who participate in the study and those who do not.

It is particularly important in cohort studies for example that the exposed and non-exposed groups be comparable with respect to other risk factors that might be related to exposure (Dohoo et al 2003). This is less of an issue for a single group cohort design. Similarly in a case-control study it is important that the control group reflect either prevalence of exposure in the non-case members of the target population in a risk based study or the proportion of exposed animal-time at risk for the non-case group in the target population in a rate based study (Dohoo et al 2003).

Selective entry bias and survival bias are also potential problems. Groups of animals studied may already have undergone some degree of selection from the population at large. Horses currently racing are considered a biased subset of racehorses in general in that they are very likely to be healthier than the broader population of horses that have ever raced (Dohoo et al 2003). In the human epidemiology field this is referred to as the healthy worker effect (Rothman 2002). If risk factors influence whether animals are even available for study then this is entry bias. If exposure influences whether an animal remains in the target population, then a study group drawn from only those animals that are racing will give biased associations between exposure and outcome. Premature or early removal of animals from the population might be highly correlated with the exposure factor and the outcome, leaving the study group as a biased subgroup of the target population. Whenever selective survival might be an issue the study group should be drawn from the animals "ever" in the herd during a specified time and not just from animals that are in the herd (or racing) at the start of the current study period (Dohoo et al 2003).

Other factors that may contribute to selection bias include misclassification bias, non-response bias and missing data. Misclassification of animals may also result in selection bias for example if cases were misclassified as potential controls. Non-response bias refers to the instance where the association between exposure and outcome in the responders differs from that seen in the non-responders. Non-response could be a surrogate for a variety of management factors relating to animals that could be related to the outcome and the exposure factors (Dohoo et al 2003). Missing data can create a bias similar to non-response since the researcher must then either impute the missing data, drop the variables with missing values (leading to possible confounding bias), or drop the observation (resulting in an effective non-response). In a similar fashion if

there is a differential loss to follow up that is related to exposure status and the outcome then bias may result (Dohoo et al 2003).

4.2. Information bias

Information bias occurs when the information collected about or from study subjects is erroneous (Rothman 2002). Incorrect classification of categorical variables is called misclassification bias, while incorrect measurement of continuous variables is called measurement error (Dohoo et al 2003). Information bias can result in errors in estimates of association.

Misclassification of subjects for either exposure or disease may be described as differential or nondifferential. With respect to exposure classification, a misclassification bias is said to be nondifferential if it is unrelated to occurrence of disease, and differential if it is (Rothman 2002). Similarly, misclassification of disease is said to be nondifferential if unrelated to exposure and differential if it is related to exposure.

Recall bias is also common, particularly in case-control studies where a subject is interviewed to obtain exposure information after a disease event or outcome has occurred (Rothman 2002). For severe outcomes such as racehorse death or serious injury, cases (or their owners/trainers), are more likely to recall detailed information about possible exposures because of the stimulation of the adverse event to trigger consideration of such issues. In contrast owners or trainers of horses that have not suffered any adverse event may be less likely to recall exposure information. Recall bias of this sort is then a differential misclassification because the exposure information may be misclassified differentially with respect to cases and noncases (Rothman 2002). Differential misclassification may either under- or over-estimate an association. In contrast, the bias in nondifferential misclassification is generally towards the null. In most cases researchers often make the assumption that misclassification errors are likely to be nondifferential, meaning that the effect will only be to potentially under-estimate the strength of any association (Dohoo et al 2003). As mentioned above, recall bias in case-control studies is a very common bias that is more likely to result in differential misclassification. However, when exposure prevalence is low, lack of specificity causes more errors than lack of sensitivity. This means that even if exposure is selectively recalled in cases, the observed measure of association will typically be biased towards

the null. Therefore if an association is found in a case-control study in the presence of recall bias, it is likely to be present and larger in magnitude in the target population (Dohoo et al 2003).

Other variables in the model such as confounders, may also be measured with error. If a confounder is measured with error it is impossible to fully control for its confounding effect. Measurement error in the confounder can therefore produce bias in the exposure effect estimates. Misclassification of a non-confounder can also make it appear to be a confounder (Dohoo et al 2003).

4.3. Confounding bias

Confounding is present by definition when the measure of association calculated from the study subjects is different from the unknown but true association (Rothman, 2002; Dohoo et al 2003). The study may aim to measure the association of an exposure factor with an outcome but with confounding the association measure also includes the effects of one or more extraneous factors. The observed measure of association is therefore biased or confounded. Confounding may result in a bias in either direction when measuring association. Several approaches may be taken to prevent or account for confounding including restricted sampling, matching and analytical control (Dohoo et al 2003).

5. Matching

Matching refers to the selection of a reference group of subjects – unexposed in a cohort design or noncases in a case-control design – where the reference group is very similar or identical to the exposed/case group with respect to the distribution of one or more confounding factors (Rothman et al 1998).

Matching may be performed subject by subject (individual matching), or for groups of subjects (frequency matching). In observational studies the major benefit of matching is on study efficiency and not on validity (Rothman et al 1998).

It is important to be aware of the different effects of matching in cohort studies compared with case-control studies. Matching in a cohort study makes the exposure independent of the matched variable so there can be no confounding. In addition, the matching occurs at the beginning of the experiment so matching is independent of the outcome (Dohoo et al 2003). In case-control studies the disease has already occurred

when matching is performed and the process of matching affects only the distribution of controls and not that of cases. If exposure is related to the matched variable then the process of matching may actually alter the distribution of exposure in the controls so that their exposure level is more like the cases, resulting in selection bias (Dohoo et al 2003). If the matching factor is not associated with the exposure then no bias will be introduced. If there is confounding present in the population and matching is then applied in a case-control approach, the result is to superimpose a selection bias in place of the initial confounding that behaves like confounding (Rothman et al 1998). Matching can even introduce bias where none previously existed if for example one matches on a variable that is unrelated to the disease (therefore not a confounder), but is related to the exposure. Biases introduced into case-control studies by matching may be controlled by treating the matching variable(s) as confounders in the analysis. Although matching means it is not possible to estimate the effects of the matched factor(s) on the outcome, it is still possible to investigate whether the matching factor acts as an effect modifier by testing an interaction between the matching variable and the exposure of interest (Dohoo et al 2003). Matching on some surrogate factors such as farm, may also match out other potentially important exposures in hypothesis generating studies. Matching on several factors is generally discouraged since it may be difficult to find matching controls (Dohoo et al 2003).

6. Measures of frequency and association

A primary objective for most epidemiological studies is to gather information on the amount of change in a population disease frequency caused by a specific risk factor or exposure (Greenland et al 1998). Population disease frequency may be expressed as incidence rate, cumulative incidence (risk), prevalence, or incidence time as in survival analysis (Greenland et al 1998).

Measures of association are used to estimate the magnitude of the relationship between exposure and disease frequency, with relative effect measures being more commonly applied than absolute (Greenland et al 1998; Dohoo et al 2003). Absolute effects refer to differences in the values of an incidence rate or prevalence estimate for example, while relative effects refer to differences expressed as ratios of these measures (risk ratio, incidence rate ratio, or odds ratio) (Greenland et al 1998).

A risk ratio or relative risk refers to the ratio of the risk (cumulative incidence) of disease in the exposed group to the risk of disease in the non-exposed group. Risk ratios can be computed in cohort studies and in some cross-sectional studies but cannot be derived from case-control studies because of a lack of denominator or population-at-risk information (Dohoo et al 2003). Cross-sectional studies estimate prevalence and the prevalence ratio is a valid estimator of risk ratio when there is a short period of risk of disease that has been completed for all animals. Because the risk ratio is based on risk or cumulative incidence it does not make any assessment of the frequency of disease in the population.

An incidence rate ratio (or incidence density ratio) is the ratio of the incidence rate of disease in the exposed group to the incidence rate of disease in the non-exposed group. The incidence rate ratio does express information on frequency of disease in the two groups.

An odds ratio can be defined in two symmetrical ways:

- the odds of disease in the exposed group divided by the odds of disease in the non-exposed group
- the odds of exposure in the diseased group divided by the odds of exposure in the non-diseased group

Odds ratios are the only measure of strength of association applicable to case-control studies (Dohoo et al 2003). Odds ratios appear commonly in the epidemiological literature because of the common usage of case-control studies, and logistic regression as an analytical technique from which odds ratio estimates are easily derived.

When the disease is uncommon in the population at large (prevalence or cumulative incidence less than 5%), the odds ratio is approximately equal to the risk ratio. Dohoo et al (2003) define two conditions influencing the suitability of an odds ratio as an estimator of incidence rate ratio. When controls are selected from all non-cases once all cases have occurred (termed cumulative or risk sampling), then the odds ratio is a good estimate of the incidence rate ratio only if the disease is rare (less than 5% prevalence). If controls are selected from non-cases each time a case occurs (density sampling), then the odds ratio is a direct estimator of the incidence rate ratio regardless of whether the disease is rare or not (Dohoo et al 2003).

7. Chronological development of research methods to investigate racehorse health and performance

Racing injuries in Thoroughbreds have a complex, multifactorial pattern of potential risk factors. Early studies of injuries in racing horses largely involved descriptive information obtained from observational studies, and examined risk factors using unadjusted pair-wise associative tests in isolation, or not at all (Webbon 1977; Jeffcott et al 1982; Rosedale et al 1985). Since the early 1980's a large number of observational studies have been performed, with case-control studies dominating the published literature. A small number of other designs have been utilised including cohort studies (Cohen et al 1999) and case-crossover studies (Estberg et al 1998a; Carrier et al 1998). There have been very few studies that have employed a longitudinal study design to investigate injuries or other conditions in racehorses in training, presumably because of logistical difficulties in data collection over a period of time (Rosedale et al 1985; Robinson et al 1988; Kobluk et al 1990; Lindner and Dingerkus 1993; Bailey 1998). Issues and difficulties that occurred in these studies are discussed briefly in the next section.

A pilot study implemented by the University of Minnesota in 1987 utilised both cohort and case-control approaches to investigate injury in racehorses but none of the reports subsequently appeared in peer reviewed literature and the only reports being published in conference proceedings (Haynes and Robinson 1988; Robinson et al 1988; Kobluk et al 1990). The study was confined to one racetrack and took place over a single racing season and was intended to investigate the feasibility of undertaking subsequent multitrack studies at other locations in the USA. The cohort study used a randomised selection process to enrol 95 horses in a closed cohort. Data were collected every day on exercise levels and injuries but data collection involved veterinary students and this may have introduced measurement biases. Pre- and post-study examinations were performed on horses including clinical, conformational, radiological and ultrasonographic examinations though details and results were not provided. Over 50% of horses were lost to follow up during the course of the study resulting in insufficient numbers of horses retained in the study for meaningful analyses to be performed (Haynes and Robinson 1988). The case-control study involved 66 horses that met a case definition of injury during a race that resulted in death, retirement or failure to race for ≥ 6 -months, and two control horses that were randomly selected from the same race in which a case

occurred. Details of analyses were not presented and it appeared that selective univariate tests may have been performed. The methodology for these studies appeared to be well conceived and the most regretful aspect is that the experiences gained by the authors were not subsequently applied in multistate studies as originally planned.

Some studies have failed to take advantage of the potential design benefits of a prospective-cohort approach. For example the German study collected data over a 9-month period from four trainers by visiting trainers between 4-5 days per week to gather data relating to horses that were unable to train at a galloping pace (Linder and Dingerkus 1993). The study employed a vague case definition, reported musculoskeletal injuries only as lameness without any more detailed investigation of anatomic location, type or severity of injury, did not measure denominator time-at-risk contributed by the training population with the effect that incidence measures used an approximation for the denominator, and did not apply multivariate statistical tests to the data. There was also no mention of the method of selection of trainers or of the impact this might have on representativeness of the study, or of the method of diagnosis of conditions including whether diagnoses were made by veterinarians or not.

A South African study employed questionnaires sent to willing trainers to collect data on racehorse health and performance over a 2-year period (Oliver et al 1997). Questionnaires were completed by trainers and there was a lack of detail on definitions and questions used in the questionnaire, though the authors reported that causes of lameness were omitted from analysis because of lack of consistency in responses from trainers and the lack of veterinary involvement in diagnosis of conditions. Data from the second year were not analysed because of a marked decrease in the return of completed questionnaires from trainers. Analyses were restricted to chi-square tests and reporting of cumulative proportions of training days lost due to lameness and respiratory disease.

A more recent paper described a nested case-control study using data derived from a cohort study (Hill et al 2001). The study described a randomised process of selection of horses from trainers that were willing to participate and that met pre-defined study criteria. A variety of measurements were described involving collection of data on parameters relating to the lower forelimbs and associated with structures involving or adjacent to the suspensory ligaments and conformation and shape of the lower limb and hoof. Horses were examined by one of 2 people who had received similar but not identical training in examination and measurement procedures to be employed. There

appeared to be discrepancies in observations collected by the different observers and data from one observer were subsequently excluded from all analyses because of "potential inaccuracy" (Hill et al 2001), though little detail was provided to clearly explain this conclusion or document the relative accuracy of the measurements that were retained for analysis.

A number of issues and problems appear to be common to observational studies of injuries in racehorses. There appears to be a progressive improvement in the level of detail provided in the materials and methods section of peer reviewed papers over time, reflecting either an improvement in the attention to detail of authors to study design, or increased requirement from publications for authors to provide detailed descriptions, or both. The selection process by which animals or trainers or both were enrolled in studies is often not well described and a randomised process appears to have been utilised only on some occasions. Lack of randomisation in selection of animals or trainers or both increases the risk of selection bias and non-representativeness of results, factors that are often not discussed by authors. Definitions of outcomes that were measured or observed are often poor, leading to increased potential for misclassification. This is exemplified by the use of terms such as lameness without any more detailed description of a case definition. It is often not clear whether the diagnosis of whether an animal was classified as a case was made by the observer, a veterinarian, the trainer, or someone else, also an issue that could result in misclassification bias. Measurement and recall bias may also be present as illustrated in the recent paper where measurements from one observer were excluded from analyses (Hill et al 2001). Racehorses are constantly being moved from spelling into training and from training into a spell, as well as moving from one trainer to another. This dynamic nature of the training industry means that losses to follow up are to be expected and may result in loss of a substantial number of horses from a cohort study. Loss of horses can reduce statistical power and also mean that cumulative incidence measures are less useful for presenting information on outcomes of interest. The use of incidence density measures appears to be more common in recent publications and is an appropriate way to deal with differing contributions to time-at-risk by different horses (Bailey 1998). In addition, many publications have not applied multivariate statistical techniques to the analysis of data on racehorse injuries, presenting results as descriptive measures or applying crude measures of association such as chi-squared tests (Jeffcott et al 1982; Rosedale et al 1985; Lindner and

Dingkerkus 1993; Mizuno 1996; Oliver et al 1997). The benefits of multivariate statistical techniques are associated with the ability to account for modifying effects of other covariates and confounders while investigating the impact of covariates of particular interest.

A number of design characteristics have improved in recent years in published studies of aspects of health and performance in racehorses. Collection of more detailed data on *a priori* defined risk factors under a prospective cohort approach, expansion of study designs to incorporate horses in training and not restrict study populations to those horses starting in a race, and the use of more sophisticated, multivariate analytical techniques, have improved our ability to investigate and understand the complex interactions between the many variables that may contribute to training and racing injuries. In addition, there has been a tremendous improvement in the depth and breadth of information provided in the materials and methods section of published papers, and readers can now better understand what was done and what the potential biases might be in published studies.

A related area that has received relatively little attention over the years has been characteristics of track surfaces, and their relationships to injury in horses. Most racetracks are circular or oval in shape with two longer straights connected by two curves. This general shape appears to have been dictated more by requirements to retain starters within the field of view of attendant racegoers and officials, and by physical space constraints than by any consideration of a design that might be optimal for horse health and performance. Difficulties in developing techniques and equipment for measuring track characteristics and relating these to measures of horse performance have hindered work in this area. In the past three decades there has been a developing awareness of the importance of track design and physical characteristics as demonstrated by a number of publications in this area (Cheney et al 1973; Fredricson et al 1975; Sills et al 1982; Pratt 1984; Zebarth et al 1985; Haynes et al 1988; Clanton et al 1991a; Oikawa M et al 1994; Ratzlaff et al 1997; Oikawa et al 2000).

Another recent development has been the implementation of increasingly complex monitoring programs at racetracks. At the simpler design end this trend is illustrated by web-mounted, injury monitoring systems being established in some racing jurisdictions. Most racing authorities record catastrophic injuries that occur on the racetrack but other injury monitoring systems vary widely and there appear to be few centralised reporting

systems or standardised reporting. Earlier attempts to centralise collection of standardised information on racehorse injuries appear to have met with limited success (Wilson et al 1993; Wilson et al 1996c; Wilson et al 1997).

A more successful program has been implemented in California since 1990 involving a collaboration between the California Horse Racing Board and the California Veterinary Diagnostic Laboratory System (CVDLS), to establish a post mortem examination program for all racehorses that died or were euthanased at a racetrack under the jurisdiction of the California Horse Racing Board (Johnson et al 1994; Estberg et al 1995, 1996a, 1996b, 1998; Carrier et al 1998; Kane et al 1996a, 1996b, 1998). However, ongoing operation of this program is dependent on continued funding from stakeholders and the program has been interrupted for periods due to lack of funding (Estberg et al 1996a; Kane et al 1998).

The Kentucky Racing Commission (KRC), has initiated a program whereby all horses entered to race in Kentucky must be inspected by a KRC veterinarian on the day of a race to determine racing fitness. A standardized form is used for information collection (Cohen et al 1997). The KRC maintains a veterinary database for all horses racing in Kentucky that includes previous race history, results of previous pre-race inspections, and any veterinary events recorded by KRC veterinarians such as lameness after a race. Horses not meeting criteria for fitness prior to racing are not permitted to race. This program was designed as a screening process aiming to detect pre-existing pathological conditions and reduce the risk of a catastrophic injury occurring during a race. However, initial analyses indicated poor associations between putative risk factors and subsequent risk of injury, questioning the use of the program to pull horses from a race because of a supposedly elevated risk of injury (Cohen et al 1997).

Both the Japan Racing Association (JRA), and the Hong Kong Jockey club appear to collect extensive levels of data regarding routine health and performance parameters on racehorses under their care, though few publications have appeared in the English scientific literature (Mizuno 1996).

To date the most common use of information collected in programs such as those described above has been in attempts to understand risk factors that might contribute to particular injuries or conditions. This has generally involved a reasonably traditional approach of collecting and manipulating raw data and then performing a variety of

statistical tests of association. There are early attempts at using these programs in a preventive manner in the way the KRC uses its pre-race inspections to screen horses and prevent those animals believed to be at high risk from racing on that day (Cohen et al 1997).

It appears likely that the future will see the development of monitoring programs with a variety of automated or semi-automated analytical and reporting capabilities to monitor various indices of health and performance. Such information may then be used on a day-to-day basis by both trainers and racing authorities to fine tune individual training and racing programs, identify horses that require early intervention, and facilitate better management of racehorses to reduce the risk of serious injury. The beginnings of such monitoring and surveillance programs can be seen in the development and application of programs in Japan and Hong Kong.

8. Data sources and Outcomes used

Three broad sources of information maintained by racing authorities have contributed to the majority of published papers on racehorse performance and injury. The first is represented by databases containing information on the result for every official trial or race, used for determining betting returns and for official statistics. In New Zealand the official database is maintained by New Zealand Thoroughbred Racing (NZTR), and the results of every trial or race are entered within 24 hours of the event being staged. Similar databases are also maintained by commercial companies providing services to individuals gambling on racing events. In some cases such databases may incorporate data on distances and times for fast-speed exercise completed during training as well as records of official trials and races.

The second major source of information for published studies are databases of horse-specific information associated with identity and parentage verification that typically include key information such as birth date and gender.

The third data source is represented by records of serious injuries in horses during racing, maintained by individual racing clubs with information contributed by attending veterinary surgeons. Official reports of attending veterinarians have been described as an accurate source of information on injured horses (Mundy 1997). In general information is more likely to be collected for fatalities and very serious injuries that require immediate veterinary attention. Injuries of minor severity, and those that may

take some time to become clinically apparent are more likely to be under reported or not reported at all since they may not be brought to the attention of the attending veterinarian at the racetrack, or they may be examined and not recorded. Injuries that become apparent during training are not recorded at all in such programs.

A very high proportion of publications investigating racehorse injuries have made use of retrospective records of race and trial performance, horse identity, and veterinary or steward reports on serious or catastrophic race day injuries. The relative rarity of serious injuries in racing horses, and the availability of historical information from official sources are important factors explaining the predominance of case-control studies in the literature on racehorse injuries.

Retrospective records of race results do provide detailed and accurate information on denominator data or population at risk of injury during racing. When combined with official reports of injuries sustained during races, estimates of cumulative incidence or risk can be derived using a retrospective cohort study design.

Researchers using historical data from racing authorities on injuries as described above, have developed terms and definitions for case animals that were adapted to the type and quality of data available. Clanton et al defined a breakdown as an acute musculoskeletal injury occurring during a race that resulted in the affected horse dying or being euthanased, retiring from racing, or incurring a spell that resulted in the horse not starting again for a minimum period of 6-months (Clanton et al 1991b). The same definition has subsequently been used as a basis for what was termed a serious musculoskeletal injury (Bailey et al 1998). Other authors have defined a breakdown as a horse that had not raced within 6-months following a musculoskeletal injury incurred on the racetrack (Mohammed et al 1991; Bailey et al 1997a).

A number of papers utilising data from the California post mortem program have defined cases as horses that died or were euthanased as a result of general or specific musculoskeletal conditions incurred during racing at California racetracks (Estberg et al 1995, 1996a, 1998; Kane et al 1996a, 1998).

The level of detail in the Kentucky Racing Commission data recording scheme on injuries incurred during racing has allowed researchers to categorise musculoskeletal injuries incurred during racing into several levels, including catastrophic (horse died or was euthanased within one month of injury), career-ending (horse survived but did not

start for at least 6-months), and simple injuries where the horse started in at least one trial or race within 6-months of the initial injury (Peloso et al 1996; Cohen et al 1997). KRC data have also been used to divide racing injuries into catastrophic (resulting in death of the horse) and non-catastrophic (all other injuries recorded as occurring during a race) (Peloso et al 1994b; Cohen et al 2000b).

The presence of a 6-month (or more) no-race period following an injury has been used to ascribe severity to a musculoskeletal injury (Mohammed et al 1991; Clanton et al 1991b; Bailey et al 1997a, 1998). This is a convenient measure that can be directly determined from analysis of racing authority records for a 6-month period following a race in which an injury occurs. It seems likely that horses that do have severe musculoskeletal injury would be prevented from resuming racing within 6-months of injury, when considering the requirement for rest and recuperation to recover from the injury itself followed by the time taken to resume training and work up to race fitness. However, it is also possible that horses may be rested for prolonged periods for reasons other than injury. This means that the use of a 6-month no-race threshold as a determinant of injury severity is likely to have a high sensitivity and a relatively lower and more variable specificity. Reasons for spelling a horse from training and racing for a period of time other than musculoskeletal injury include seasonal preferences for racing on the part of the trainer/owner, voluntary periods of rest as determined by the trainer or owner, illness or injury unrelated to training and racing, retirement from racing and movement overseas.

There are risks of bias in using retrospective data derived from races to define cases in the ways described above, particularly when cases are limited to those animals that die or are euthanased (Estberg et al 1998). A decision to euthanase a horse with a musculoskeletal injury may depend on several factors including prognosis for recovery and return to performance or breeding soundness, economic and emotional value of the horse, and potential for breeding success (Speirs 1983; Speirs et al 1986). Animals with high potential breeding value or that are valued highly by their owners, may be subjected to medical or surgical treatment of fractures even in the face of guarded or poor prognoses. Male horses and claiming horses (less valuable), have been reported to be at higher risk of catastrophic injury than females and non-claiming horses, possibly due in part to an increased likelihood of veterinary intervention for the latter groups (Estberg et al 1998).

Studies using retrospective records sourced from the racing industry tend to focus on severe or fatal injuries that occurred during a race because of the characteristics of the data sources. An important exception is the growing body of published work that has utilised data drawn from the California post mortem program (Estberg et al 1995, 1996a,b, 1998a,b; Carrier et al 1998; Johnson 1993; Johnson et al 1994; Kane et al 1996a, b, 1998). In these papers injury data are limited to fatalities but they do represent all fatalities occurring at racetracks under the jurisdiction of the California Horse Racing Board. As a result the database includes injuries that occurred during training as well as injuries that occurred during a race. A report from Japan described data collected from a training population of racehorses and indicated that the distribution of types of fractures was different in the population of training horses as opposed to racing horses (Mizuno 1996). When viewed in light of growing awareness of the role of chronic micro-injury incurred during training and racing as precursors to an acute and serious musculoskeletal injury that could occur in either training or racing episodes, it is apparent that confining a study to injuries that occur during racing may misrepresent the actual risk of different injuries that could occur in the population of training and racing horses. Caution is therefore required when interpreting the results of studies using retrospective data, particularly those restricted to injuries that occurred during a race or trial.

A number of studies have employed prospective methodologies to collect information on musculoskeletal injuries in racehorses (Robinson et al 1988; Lindner et al 1993; Oliver et al 1997; Bailey 1998; Hill et al 2001; Williams et al 2001). Data from several studies were used to derive rate estimates for various types of injury (Robinson et al 1988; Lindner et al 1993; Oliver et al 1997; Bailey 1998; Williams et al 2001). The Michigan equine monitoring system (Kaneene et al 1997a, 1997b), and the National Animal Health Inspection Service (NAHMS), Equine '98 study (Kane et al 2000) represent examples of well defined, observational studies designed to produce statistically valid estimates of population demographics and conditions in the Michigan and US horse populations respectively.

Limitations of observational studies have been discussed in general terms. There are a number of issues specifically relating to racehorse studies that deserve mention. Variation in case definition between researchers and publications has limited the ability of readers to make comparisons between published papers. In addition case definitions

as discussed above are a problem for internal study validity. There are also risks of misclassification of injury with respect to anatomic location, type of injury and severity, due to difficulties with diagnosis of injuries and also due to variations in the diagnostic capability of people contributing information to the study. Information is often collected from a variety of sources and it is unlikely that diagnostic information would have been assessed on a uniform basis. Diagnoses are often made on clinical grounds alone, and by non-veterinarians, resulting in potential misclassification in terms of specific injuries, though the broad groupings of injuries may still be reasonably accurate. There is always a risk of minor clinical conditions being unreported particularly when veterinary examination is not involved or where the horse may not have to interrupt training.

Studies based on racing or racetrack records are likely to under report injuries since some injuries may not be reported until after the horse has left the track. The degree of under reporting may be less for injuries that result in immediate life threatening change or breakdown.

A number of non-injury associated variables have been used as outcome variables in studies investigating aspects of performance in racehorses. Individual animal finishing times have been used in models investigating factors influencing race performance though only some countries are currently recording finish times for all animals (Oki et al 1994; Oki et al 1995; Martin et al 1996; Williamson et al 1996). Hintz (1980) describes the following parameters as potential measures of performance in racehorses: earnings, log earnings, average earnings index, lengths behind the winner, performance rates, handicap weights, time of finish, average time, time as a deviation from winning time or average time, best time, rank at finish, number or percentage of races won, and races disqualified or not ranked (Hintz 1980).

9. Events interfering with training and racing

9.1. Classification by location and system affected

Musculoskeletal injuries incurred during racing range from mild conditions associated with barely discernible lameness to sudden death or severe damage necessitating euthanasia (Hill et al 2001).

A recent, 3-year (1996-1998) surveillance study of clinical events involving horses racing at any of the 59 racecourses across Britain, reported 2,358 events from 222,932 starts (Williams et al 2001). Of the 2,358 events, 82% involved the musculoskeletal system with the remainder of events either undiagnosed or involving other systems such as the cardiorespiratory system. Of the 1,937 musculoskeletal events, 1,790 (92%), involved the limbs with the remainder mainly involving the vertebral column (Williams et al 2001). Of the limb injuries, 81% involved the forelimbs.

A number of studies based in the USA have also utilised veterinary reports on injuries that occurred during a race, and have confined reports to either musculoskeletal injuries only (Peloso et al 1994b), or to injuries involving the appendicular skeleton (limbs) only (Cohen et al 1997). The forelimbs were involved in 119 of 132 musculoskeletal injuries (90.2%) involving 117 horses from the population of horses racing in 35,484 starts in Kentucky between 1992 and 1993 (Peloso et al 1994b). A similar study involving records from two years of racing at four selected racetracks also in Kentucky (1994-1996), reported forelimb involvement in 204 of 216 (94.4%) horses with limb injuries (Cohen et al 1997).

Findings from Japan (Ueda et al 1993), and Australia (Bailey 1998) support the conclusion that musculoskeletal injury in racing Thoroughbreds was far more likely to involve the forelimbs than the hind limbs. Discrepancies in numerical measures between studies are likely to reflect differences in study design including case definitions, and differences in track surfaces (turf in the UK vs dirt in the USA for example), as well as differences in horses, training methods, and start characteristics.

Forelimb injuries were most likely to affect one forelimb as opposed to both (96 of 103 affected horses, 93%) (Peloso et al 1994b), and simultaneous injuries involving fore and hind limbs were recorded in less than 0.5% of 2,358 clinical events in British racing (Williams et al 2001).

In the British study, injuries to tendons and ligaments (superficial digital flexor tendon, deep digital flexor tendon, and suspensory ligament), were the most common form of limb injury, accounting for 46% of all limb injuries. These were followed by injuries involving the proximal sesamoid bones or fetlock (6.4%), cannon bone or splints (5.7%), carpus (4.5%), shoulder or humerus (4.4%), pastern (3.9%), and pelvis (3.8%) (Williams et al 2001). An earlier British study reported a different range of frequencies for anatomic locations of injuries though differences in definitions for some of the conditions may have contributed to the observed discrepancies (Table 2.3).

Table 2.3: Frequency distribution of the major sites of lameness in 246 cases affecting 164 horses from 6 training stables in the UK in 1980 (Jeffcott et al 1982).

Injury type	Number of horses	%
Foot	38	15.4
Pastern	8	3.3
Fetlock	37	15.0
Cannon	3	1.2
Splints	16	6.5
Shin soreness	22	8.9
Tendonitis	14	5.7
Carpus	31	12.6
Hock	11	4.5
Stifle	9	3.7
Back	8	3.3
Muscular	28	11.4
Miscellaneous & undiagnosed	21	8.5
Total	246	100.0

Combining the outputs from the two similar studies performed in Kentucky produced a total of 395 limb injuries with the most common anatomical sites being proximal sesamoid bones (25.6%), suspensory ligament (20%), cannon bone (15.2%), superficial digital flexor tendon (14%), carpus (10.4%), pastern (5.1%) and fetlock (3.8%) (Peloso et al 1994b; Cohen et al 1997).

Differences in definitions for injury classifications between the UK and USA studies may account for some of the discrepancies, particularly relating to classification of injuries as involving the suspensory ligament, fetlock, or proximal sesamoid bones. The UK study also included 18% unknown lesion sites in the denominator while the USA studies had only known locations, contributing to discrepancies in absolute values for the different injury classifications. It is noteworthy that injuries involving sites above the carpus or hock accounted for only 4% of all limb injuries in the USA studies (Peloso et al 1994b; Cohen et al 1997) compared with 16% of limb lesions of known

location in the British study (Williams et al 2001). These results do suggest that there may be an effect of geographical location on injury distribution, contributed in part at least by factors such as turf vs dirt racing, and the proportion of starts involving flat vs jumping races, in addition to other factors.

Injuries involving one or more components of the suspensory apparatus (suspensory ligaments, proximal sesamoid bones, and distal ligaments of the proximal sesamoid bones), have been reported as the most common broad category of injury in Thoroughbreds racing in the USA (Peloso et al 1994ab; Johnson et al 1994; Kane et al 1998; Hill et al 2001), and accounted for 47.6% of all injuries in a national survey (Wilson et al 1996b) and 44.7% in a Kentucky descriptive study (Peloso et al 1994b). The most common combination injuries in a single leg involved the proximal sesamoid bones and the suspensory ligaments, two adjacent and attached components of the suspensory apparatus (Cohen et al 1997). Others have also reported that fractures of the proximal sesamoid bone(s) and the distal third metacarpal bone often occurred together in the same limb, indicating a common set of predisposing causes or that mild or subclinical injury to the suspensory apparatus may place the animal at risk for a subsequent catastrophic injury involving both the sesamoid bones and the third metacarpal bone (Johnson et al 1994; Kane et al 1996b; Hill et al 2001).

Fractures were the major cause of fatal musculoskeletal injuries in the California post mortem program accounting for 306 of the 358 cases, with other causes being tendon or ligament injury (n=37), laminitis (9), septic arthritis (2), and severe rhabdomyolysis (4) (Johnson et al 1994). Fracture sites for 272 fractures of known location included proximal sesamoid bone (n=99), third metacarpal bone (n=71), humerus (n=29), pelvis (n=18), proximal phalanx (n=16), carpus (n=12), third metatarsal bone (n=12), tibia (n=7), scapula (n=3), radius (n=2), second phalanx (n=1), femur (n=1) (Johnson et al 1994). Summary data are shown below for all fractures diagnosed in Thoroughbred horses training and racing in Japan during 1994 (Mizuno 1996).

Table 2.4: Percentages of 1,707 fractures sustained during training and 730 fractures sustained during racing, organised by anatomic location, for Thoroughbreds training and racing in Japan in 1994 (Mizuno 1996).

Location	training % of 1,107	racing % of 730
carpal bones	18.4	29.7
metacarpus	17.2	17.7
distal radius	5.8	17.7
phalanx (front)	17.4	12.9
metatarsus	8.5	5.6
proximal sesamoid (front)	4.2	3
tibia	4.8	2.3
tarsus	4.6	2.3
phalanx (hind)	5.7	2.1
humerus & scapula	2.9	1.9
pelvis	2.9	1.2
proximal sesamoid (hind)	0.2	0.6
vertebral column & skull	0.7	0.4

Distributions of musculoskeletal injuries in two Kentucky studies are shown in table 2.5.

Table 2.5: Frequency distributions for 270 musculoskeletal injuries involving limbs only in 216 horses injured while racing at one of four racetracks in Kentucky between 1994-1996 (Cohen et al 1997), and for 132 musculoskeletal injuries among 117 horses injured while racing in Kentucky between 1992-1993 (Peloso et al 1994b).

Injury type	Cohen et al (1997)		Peloso et al (1994)	
	n	(%)	n	(%)
Forelimb				
scapula	3	1.1	1	0.4
humerus	3	1.1	2	0.7
radius	1	0.4	1	0.4
carpus	25	9.3	16	5.9
3rd metacarpal	39	14.4	17	6.3
SDF	39	14.4	15	5.6
SL	58	21.5	20	7.4
proximal sesamoid	61	22.6	39	14.4
fetlock	12	4.4	2	0.7
pastern	11	4.1	4	1.5
other	4	1.5	2	0.7
Hindlimb				0.0
femur	0	0.0	0	0.0
stifle	4	1.5	1	0.4
tibia	0	0.0	0	0.0
tarsus	1	0.4	0	0.0
3rd metatarsus	2	0.7	2	0.7
proximal sesamoid	1	0.4	0	0.0
SL		0.0	2	0.7
fetlock	1	0.4	0	0.0
pastern	4	1.5	1	0.4
other	1	0.4	0	0.0
Vertebrae	NR		1	0.4
Pelvis	NR		1	0.4
Lesion undefined	NR		5	1.9
Total	270		132	

Results of three studies reporting on the California post mortem program are shown in Table 2.6. All horses that died or were euthanased on racetracks under the jurisdiction of the California Horse Racing Board were subjected to a complete necropsy at one of the branch laboratories of the California Veterinary Diagnostic Laboratory System. The eligibility criteria for the 3 studies differed slightly. Johnson (1993), reported on all Thoroughbreds examined during 1991, regardless of whether they were training or racing at the time of their death (Johnson 1993), while the other two studies reported information on injuries incurred during either training or racing activity during 1990-1992 (Johnson et al 1994), and the final study was restricted to injuries incurred during a race in 1992 (Estberg et al 1998b).

Table 2.6: Frequency distribution of injury types in horses that died or were euthanased while on California racetracks under the jurisdiction of the California Horse Racing Board.

Injury type	Johnson (1993) ^a		Johnson et al (1994) ^b		Estberg et al (1998) ^c	
	n	%	n	%	n	
Fracture						
scapula	2	1.2	3	1.0	2	2.6
humerus	9	5.4	29	10.0	2	2.6
radius	0	0	2	0.7	3	3.8
carpus	6	3.6	12	4.1	10	12.8
metacarpus	40	24.1	71	24.4	20	25.6
pelvis	8	4.8	0	0	1	1.3
femur	1	0.6	1	0.3	0	0
tibia	2	1.2	7	2.4	1	1.3
tarsus	0	0	0	0	2	2.6
metatarsus	6	3.6	12	4.1	4	5.1
proximal sesamoid (fore & hind-limbs)	56	33.7	99	34.0	23	29.5
pastern (fore & hind-limbs)	9	5.4	17	5.8	1	1.3
navicular	1	0.6	1	0.3	0	0
skull	4	2.4	0	0	0	0
ribs	1	0.6	0	0	0	0
vertebrae	3	1.8	0	0	0	0
Laminitis	4	2.4	0	0	0	0
Ligament or tendon rupture	13	7.8	37	12.7	9	11.5
Myositis	1	0.6	0	0	0	0
Totals	166		291		78	

^a Includes all Thoroughbreds that died or were euthanased at California racetracks regardless of activity level

^b Limited to Thoroughbreds that were in training or racing

^c Limited to fatal injuries incurred during races

Fewer studies have attempted to follow training horses in a prospective manner to collect information on all injuries incurred during training and racing. Table 2.3 presented results of injury types observed during a prospective study of racehorses in the UK (Jeffcott et al 1982). Rossdale et al (1985) subsequently reported on a 2-year study of UK racehorses, and found that lameness and respiratory problems resulted in the largest number of days lost from training, accounting for 67.6% and 20.5%, respectively of all days lost from training. The most common musculoskeletal conditions involved feet (38 of 198, 19%), muscular conditions (36, 18%), fetlocks (27, 14%), carpus (25, 14%), tendon injury (20, 10%) and shin soreness (18, 9%). Bailey (1998) reported on a longitudinal study that enrolled 169 2-year old Thoroughbreds in Australia as they entered training stables for the first time to begin a training and racing career (Bailey 1998). Data on training activity and health were collected on all horses every 2-weeks for a 2-year period. The most common conditions observed in these animals in decreasing order of incidence, were shin soreness, fetlock problems, coughs and nasal discharge, lacerations and traumatic injuries, carpal problems, and foot problems (Bailey 1998). Shin soreness was the single most important cause of

interruptions to training and racing though many trainers consider shin soreness as a part of the normal training process rather than as an injury or cause of wastage (Bailey et al 1997b).

It is very clear from studies performed around the world that musculoskeletal conditions associated with lameness are the most common causes of interrupted training programs, and of early retirement or death in training and racing horses. These are followed by infectious and non-infectious respiratory conditions (Jeffcott et al 1982; Rosedale et al 1985; Bailey 1998; Christley et al 2001).

Coughing was the most common clinical sign reported by trainers referable to disease of the respiratory system (Bailey et al 1997b). In clinical practice respiratory diseases are often poorly characterised. Viral infections have traditionally been considered to be the principal cause of respiratory disease in young racing Thoroughbreds (Mumford et al 1980). More recent studies have suggested that other aetiologies may also be important including mycoplasma, bacteria, and noninfectious agents (Wood et al 1999; Christley et al 2001). Epistaxis (blood visible at the nostrils), is also reported in horses after racing (Cook 1974) in response to exercise induced pulmonary haemorrhage and in some cases to lesions or trauma involving the upper respiratory tract.

Sudden death is an uncommon occurrence in training and racing Thoroughbreds. A post mortem study of 41 cases of sudden death occurring in horses during racing or training reported finding a causal condition in 21 cases, including ruptured aorta, myocarditis, valvular insufficiency, coronary arteropathy, pulmonary haemorrhage, pleuritis, encephalopathy, and disseminated thrombosis (Johnson et al 1994). It is of interest to note that despite thorough post mortem of all animals there were 20 cases of unexplained sudden death out of the 41 animals examined.

9.2. Frequency estimates

Most estimates of frequency of various conditions presented in the veterinary literature represent cumulative incidence or incidence risk estimates calculated as events per 1000 starters where each starter represents one horse starting in one official trial or race. This is because of the ready availability of official race records defining the population of horses that competed in every official trial or race. In such cases there is a closed population of animals at-risk where the at-risk time period is simply the duration of the race-event.

A 3-year surveillance study of all clinical events resulting in a veterinary report at 59 racecourses across Britain, reported 10.6 events per 1,000 starts (2358 events in 222,993 starts) (Williams et al 2001). Frequency estimates for clinical events organised by classification are presented in Table 2.7.

The rate of musculoskeletal injuries in flat races in Kentucky was reported to be 3.3 per 1,000 starts with 1.9 and 1.4 being nonfatal and fatal injuries respectively (Peloso et al 1994b). These results were consistent with the 3.1 injuries per 1,000 starts reported in the British study with 2.3 and 0.8 being nonfatal and fatal injury rates respectively (Williams et al 2001).

Table 2.7: Frequency of clinical reports for different classes of injury and types of race, derived from 222,993 starts over 3 years in Britain. Data presented as rate per 1,000 starts with 95% confidence intervals (Williams et al 2001).

Injury type	Race type		Hurdle		National hunt flat		Flat		Total	
	Steeplechase									
Musculoskeletal										
Limb injury	18.3	16.8 - 19.8	14.8	13.8 - 15.9	6.9	4.9 - 8.8	3.1	2.8 - 3.4	8	7.7 - 8.4
Nonlimb injury	2.2	1.7 - 2.7	1.4	1.0 - 1.7	0.2	0 - 0.4	0.1	0.02 - 0.1	0.7	0.6 - 0.8
Cardiac	0.7	0.4 - 1	0.4	0.3 - 0.6	0.6	0.01 - 1.2	0.1	0.08 - 0.2	0.3	0.2 - 0.4
Atrial fibrillation	0.2	0.06 - 0.4	0.3	0.2 - 0.5	0	-	0.2	0.1 - 0.2	0.2	0.1 - 0.3
Epistaxis	2.3	1.7 - 2.8	1.3	1 - 1.6	0.3	0 - 0.7	0.3	0.2 - 0.4	0.8	0.7 - 0.9
Miscellaneous	0.9	0.5 - 1.2	1	0.7 - 1.2	0.6	0.01 - 1.2	0.2	0.1 - 0.3	0.5	0.4 - 0.6
Unknown	0.2	0.02 - 0.3	0.2	0.1 - 0.4	0	-	0.02	0 - 0.05	0.1	0.05 - 0.1
Total	24.7	23 - 26.4	19.5	18.3 - 20.6	8.5	6.3 - 10.6	4	3.6 - 4.3	10.6	10.2 - 11

An earlier study performed in New York involved the collection of veterinary injury reports on all Thoroughbred races in New York over a 3-year period (1983-1985), and reported 7.3 events (including non-musculoskeletal conditions), per 1,000 starters (Hill et al 1986). A nationwide survey incorporating information from 33 racetracks located in 15 states across the USA reported rates of 3.3 and 1.6 per 1,000 starts for musculoskeletal injury and fatal injury respectively (Mundy 1997). These studies appeared to benefit from a study-specific design emphasis on collecting detailed information on all clinical events for the duration of the study (Hill et al 1986; Williams et al 2001), or on a region specific initiative resulting in the implementation of a detailed and ongoing recording system that collected information on musculoskeletal injuries (Peloso et al 1994b).

A number of previous studies have focused on musculoskeletal injuries resulting in death, or some definition of severe injury that often included horses that died or were

euthanased, retired or that failed to race for at least 6-months from the time of the injury. McKee (1995) reported fatality rates of 7.0, 4.9, 4.7, 0.8 and 3.0 per 1,000 starters for steeplechase, hurdle, National Hunt flat, flat races, and all races respectively (McKee 1995). Fatality rates in USA flat racing have been reported as 1.7 per 1,000 starters in California (Estberg et al 1998), 1.4 per 1,000 starters in Kentucky (Peloso et al 1994b), 1.2 per 1,000 starts in Florida (Hernandez et al 2001), and 1.4 per 1,000 starters in South Africa (McDonald et al 1994). Fatality rates over a 7-year period between 1986-1993 in Victoria, Australia were 0.3, 6.0, and 11 per 1,000 starters for flat, hurdle and steeplechase races respectively (Bourke 1995). A similar study restricted to four Melbourne racetracks over a 7-year period from 1988 to 1995, reported fatality rates of 0.6, 6.3, and 14.3 for flat, hurdle, and steeplechase races respectively (Bailey et al 1998). Bailey et al (1998), also reported rates for serious injury defined as cases that died or were euthanased, and those animals injured that did not then start in another race for at least 6-months following injury. Injury rates using this definition were 2.9, 17.3, and 29.1 for flat, hurdle and steeplechase races respectively (Bailey et al 1998). A one year study performed at two Sydney racetracks reported serious injury (defined as in the Melbourne based study by Bailey et al), and fatality rates as 2.4 and 0.3 per 1,000 starters (Bailey et al 1997a).

There is reasonable disparity over frequency estimates from different regions and different countries. Such effects are considered most likely to be associated with differences in injury definitions, recording and reporting systems and effects due to track design, track surface properties, training methods, and factors such as climate (Bailey et al 1997a). There is little doubt that the comparative value of different studies would be greatly enhanced by the development of standardized definitions for injuries and recording systems (Peloso et al 1994b). There are also some reasonably clear associations that are consistently reported across different studies and different countries, in particular the increased risk of injury and death in horses competing in races over obstacles (hurdles and steeplechase races) as opposed to flat racing.

Relatively few studies have reported frequency estimates for particular types of musculoskeletal injury. Table 2.8 shows results from a 3-year surveillance study of all races in Britain.

Table 2.8: Frequency of limb injuries by site and race type shown as events per 1,000 starts with 95% confidence intervals. Data derived from 2,358 events in 222,993 starts in Britain between 1996-1998 (Williams et al 2001).

Musculoskeletal Injury type	Race type		Hurdle		National hunt flat		Flat		Total	
	Steeplechase									
Shoulder / humerus	1.3	0.9 - 1.7	0.5	0.3 - 0.7	0	-	0.1	0.05 - 0.2	0.4	0.3 - 0.4
Radius / forearm	0.6	0.3 - 0.8	0.3	0.1 - 0.4	0	-	0.04	0 - 0.07	0.2	0.1 - 0.2
Carpus	0.5	0.2 - 0.7	0.5	0.3 - 0.7	1.2	0.4 - 2	0.3	0.2 - 0.3	0.4	0.3 - 0.4
Pelvis	0.5	0.2 - 0.7	0.4	0.3 - 0.6	0.2	0 - 0.4	0.2	0.1 - 0.3	0.3	0.2 - 0.4
Femur / thigh	0.3	0.1 - 0.5	0.04	0 - 0.1	0	-	0.04	0 - 0.07	0.07	0.04 - 0.1
Stifle	0.2	0.02 - 0.3	0.1	0.02 - 0.2	0	-	0.04	0 - 0.07	0.07	0.04 - 0.1
Tibia	0.2	0.1 - 0.4	0.2	0.1 - 0.4	0.3	0 - 0.7	0.03	0 - 0.06	0.1	0.07 - 0.2
Hock	0.4	0.2 - 0.6	0.2	0.07 - 0.3	0	-	0.04	0 - 0.07	0.1	0.08 - 0.2
Cannon bone & splints	0.7	0.4 - 0.9	0.8	0.6 - 1.1	1.2	0.4 - 2	0.2	0.16 - 0.3	0.5	0.4 - 0.6
SDF / DDF/ SL	9.1	8.1 - 10.2	8.1	7.3 - 8.8	2.8	1.5 - 4	0.8	0.6 - 0.9	3.7	3.4 - 3.9
Fetlock & sesamoid bones	0.6	0.3 - 0.9	0.9	0.7 - 1.2	0.3	0 - 0.7	0.4	0.3 - 0.5	0.5	0.4 - 0.6
Pastern	0.6	0.3 - 0.9	0.4	0.3 - 0.6	0.2	0 - 0.4	0.2	0.1 - 0.3	0.3	0.2 - 0.4
Foot	0.06	0 - 0.2	0.08	0 - 0.2	0	-	0.07	0.03 - 0.1	0.07	0.04 - 0.1
Unknown site	3.4	2.8 - 4	2.3	1.9 - 2.7	0.9	0.2 - 1.6	0.7	0.5 - 0.8	1.4	1.3 - 1.6
Total	18.3	16.8 - 19.8	14.8	13.8 - 15.9	6.9	4.9 - 8.8	3.1	2.8 - 3.4	8	7.7 - 8.4

SDF=Superficial digital flexor tendon

DDF= Deep digital flexor tendon

SL=Suspensory ligament

Incidence rate estimates for specific injury types in training horses in Australia were reported by Bailey and are shown in Table 2.9.

Table 2.9: Incidence rates for first and all occurrences of injury and disease in 169 Thoroughbreds observed from April 1995 to July 1997 (Bailey 1998).

Injury type	Incidence rate per 100 horse weeks	
	First occurrence	All occurrences
Shin soreness	1.68	1.63
Fetlock problems	0.94	1.15
Cough / nasal discharge	0.77	0.75
Laceration / traumatic injury	0.75	0.75
Foot problems	0.32	0.36
Carpal problems	0.25	0.40

Earlier studies in Australia had identified shin soreness as a common condition in 2-year olds (Mason et al 1973). Cumulative incidence estimates of shin soreness amongst 2-year olds have been reported to be as high as 80% in Australia (Buckingham et al 1990), and 70% in the USA (Norwood 1978; Stover et al 1988), though these estimates

included diagnoses where training was not affected by the condition. In contrast shin soreness accounted for 9% of cases of lameness cases where training was interrupted in UK Thoroughbreds (Jeffcott et al 1982; Rosedale et al 1985). The higher frequency of shin soreness in Australia compared with the UK may be due to a greater emphasis on training and racing of younger animals and training of horses on predominantly circular tracks in Australia compared with straight training surfaces that are common in the UK.

10. Specific risk factors for musculoskeletal injury

Factors that predispose horses to breakdown during racing may be considered as intrinsic (related to the horse), or extrinsic (related to environment, including management factors). Intrinsic factors include age, gender, weight, and pre-existing injury. Extrinsic factors include environment, nutritional factors, length of race, racetrack surface, frequency of starts and training methods (Mohammed et al 1991).

10.1. Age

Increasing horse age has been associated with progressively increasing risk of serious MS injury (Hill et al 1986; Haynes et al 1988; Robinson et al 1988; Mohammed et al 1991; Estberg et al 1996b; Bailey et al 1997a, 1998; Williams et al 2001). The nature of the relationship between age and injury may be non-linear with a quadratic relationship suggested by one recent paper (Henley et al 2003), or a more complex relationship as suggested by Estberg et al (1996b) where the authors reported a possible increase in risk from 2 to 4-years followed by a levelling or more complicated pattern of change, perhaps dependent on horse quality and relative frequency of skeletal or exclusively soft tissue injuries (Estberg et al 1996b). Particular conditions are likely to have different age predilections. For example shin soreness is predominantly a disease of younger animals, occurring most commonly in 2-year olds, less so in 3-year olds and infrequently in horses older than 3-years (Moyer et al 1991; Bailey et al 1999). Conversely tendon and ligament injuries occurred more commonly in older horses (Williams et al 2001).

Horse age is confounded to a varying degree with a range of other factors such as the amount of exposure to training and racing. Older horses have generally had greater opportunity to train and race and therefore exposure to various risk factors, including repetitive microtrauma from athletic endeavours (Pool et al 1990; Mohammed et al 1991; Estberg et al 1996b, 1998). Young animals starting their racing career tended to race for shorter distances, and were more likely to start in flat races only with increasing race distance, and hurdle or steeplechase races generally being associated with older horses (Williams et al 2001).

Horses that are susceptible to injury and breakdown may be more likely to incur injuries earlier in their careers resulting in an increasingly healthy population of survivors in older horses (Mohammed et al 1991).

Study design may also impact on any perceived effect of intrinsic variables such as horse age. Matching noncase animals to cases on age would prevent assessment of age as a risk factor for injury. Case-control studies investigating injury often select one or more noncase horses from the same race as each case. Horse age within many races is relatively constant and may be limited by conditions of eligibility to one age class. Matching on race may therefore result in a reasonably strong though inadvertent level of matching on age and may interfere with the ability of studies to detect an association between age and injury (Cohen et al 1997).

The diversity of findings with respect to associations between age and injury, and the high likelihood of involvement of confounders make it difficult to draw substantive conclusions about the risks due to age. Horse age should however, be considered for inclusion in statistical models either as a risk factor or a confounder, when assessing the effects of other risk factors.

10.2. Gender

Males have been shown to be at higher risk of catastrophic injury during racing than females (Estberg et al 1996b, 1998; Cohen et al 1999; Hernandez et al 2001), though other studies have failed to detect any association between gender and serious injury (Mohammed et al 1991). A California study using data from the racehorse post mortem program reported that horses with humeral fractures were predominantly 3-year-old males, while horses with pelvic fractures were predominantly 4-year-old females (Carrier et al 1998), though the study was not able to adjust for gender or age distributions within the California racehorse population and therefore it was not clear if these findings represented gender differences in underlying risk.

A similar injury in a female or male horse may be managed differently, for example owners may be more willing to invest in a salvage operation for a seriously injured female horse to retain the animal for breeding. This effect has been postulated as contributing to the perceived increased risk of fatal injury outcomes in males compared with females (Estberg et al 1998a).

10.3. Quality of horse and class of race

Quality of horse is a poorly defined attribute and one that is difficult to measure objectively. Higher quality may be inferred in those animals that win more prize money or elite races (Group or listed races for example), or those animals that run faster times

than others over the same distance. There is some evidence of higher risk of severe injury among lower quality racehorses based on an observation that races held later in the day had a lower risk of injury, combined with the assumption that higher stakes and therefore higher quality races are generally held later in the day (Mohammed et al 1991). Robinson et al (1988), observed a 2-fold increase in the odds of breakdowns in claiming races compared with non-claiming races where claiming races were considered to include a higher proportion of lower quality racehorses than non-claiming races. Others have also reported that horses starting in claiming races of value less than \$25,000USD were more likely to have musculoskeletal injury compared with horses starting in other races (Cohen et al 1999). In contrast an Australian study reported that horses starting in a stakes races (group and listed races), were 2.3 times more likely to suffer a musculoskeletal breakdown than horses in non-stakes races (Bailey et al 1997a). Lower quality horses may be raced more often to maximise earnings and may have conformational defects that limit their ability to move up in class and possibly predispose them to injury (Estberg et al 1996b; Parkin et al 2003). Horses with chronic injury may have some degree of performance limitation and be less likely to compete in high stakes races as a result. However, stakes races were generally more competitive, run at a faster pace than non-stakes races, and training leading up to a stakes race may be more demanding, resulting in some degree of elevation of injury risk (Bailey et al 1997a). Conclusions regarding associations between measures of race class or horse quality, and injury, remain tenuous.

10.4. Leg: left vs right

Horses in a particular region tend to race in one direction (clockwise or counterclockwise) though there is little uniformity with different states in Australia for example running Thoroughbred races in opposite directions. There is some evidence to suggest that the leading foreleg may be more likely to incur injury than the non-leading foreleg (Peloso et al 1994b; Ueda et al 1993; Parkin et al 2003). The leg most likely to be used as the lead limb depended on the direction of the race ie horses in counterclockwise races were most likely to lead with their left foreleg, while those in clockwise races were more likely to lead with their right foreleg (Parkin et al 2003). Vertical forces in a galloping horse have been shown to be highest for the lead forelimb, suggesting that any increased risk of fracture observed in the lead forelimb may be due to the increased strain relative to the non-lead forelimb (Ratzlaff et al 1997; Parkin et

al 2003). Further information is required to better understand the relationship between limb and particular types of injury, whether classified by anatomic location, lesion type (fracture vs soft tissue) and racetrack location.

10.5. Race type

Flat races dominate in all countries in terms of number of Thoroughbred races held per year and number of competing horses or starters in the Thoroughbred. Several studies have shown a clear relationship between race type and risk of injury or death, with the risk consistently being lowest in flat races, and highest in steeplechase races (McKee 1995; Bailey et al 1997a, 1998; Williams et al 2001). National Hunt Flat races were associated with twice the risk of injury and 4-times the risk of fatality compared with flat races even though NH Flat races do not involve any obstacles at all (Williams et al 2001).

In addition injury type may be influenced by race type. Injuries to the upper forelimb above the carpus, upper hind limb (hock and above), and tendon or ligament injuries were more likely in steeplechase races than flat races with hurdle races being associated with intermediate levels of risk. Injuries between the carpus or hock and fetlock, were most common in hurdles, and least common in flat race events. Injuries to the pelvis and carpus were similar in hurdles and steeplechase races, and lowest in flat races. There was no association between race type and foot injuries (Williams et al 2001).

There are several contributing factors that are thought to contribute to the increased risk of injury and death in horses competing in jumping races. Hurdle race distances are set at a minimum of 2400 metres, and steeplechase events at a minimum of 3200 metres, each considerably longer than almost all flat race events (the most common flat race distance is around 1200 metres). The combination of increased distance and obstacles are thought to be the major contributors to increased risk though other factors may include factors such as horse age, ability and pre-existing injury. Jumping horses are generally older than flat racing horses, many have exited from a former flat racing career, and many carry heavier weights in jumps races than in flat races (Bailey et al 1998). It is possible that some horses may become non-competitive in flat racing as a result of minor or chronic injuries, and then be moved to jumping where different stressors may allow them to compete effectively once again. The effect of pre-existing

conditions on the risk of subsequent injury incurred during a jumping career is largely unknown.

10.6. Race number

On a given day at an official race meeting, all races are held in chronological sequence on the same track surface and races are numbered in order of start times from race number 1 to the last race held that day. It is common practice to hold the higher prize money and more elite race events towards the end of a race programme on any given day.

There is limited evidence to suggest that race number may be associated with injury risk. Mohammed et al (1991) reported that horses racing in the 4th race of the day or later were at a slightly decreased risk of breakdown compared with horses racing earlier in the day ($P=0.085$) (Mohammed et al 1991). A similar finding was reported in a cohort study of Kentucky horses where animals starting in the first 5 races were more likely to be injured than those starting in later races though this variable was significant only in univariate analyses and not in a multivariate statistical model (Cohen et al 1999).

10.7. Barrier position

Thoroughbred races start with horses placed within a starting barrier, consisting of adjacent, individual compartments with front and rear gates and generally constructed of pipe or metal. A barrier position is randomly assigned to each horse starting in a race.

An association has been reported between barrier position and serious musculoskeletal injury in Australian racehorses (Bailey et al 1997a). The odds of injury in horses starting in barrier positions 7-12 and 13-18, were 1.82 and 1.83 times those for horses starting in barrier positions 1-6. The authors postulated that this effect may be due to a number of factors including extra effort required for horses starting out wide to move in closer to the rail, and possibly an increased risk of physical interaction as horses compete for position when attempting to move in towards the rail. There do not appear to be any other published studies confirming this association between barrier position and injury.

10.8. Race distance

Race distances may be recorded in furlongs or metres. One furlong is equal to 0.125 miles, and is often equated to 200 metres though the exact metric equivalent is 201.12 metres (Martin et al 1996). Minimum race distance in New Zealand is stipulated in the Rules of Racing as 800 metres, and the maximum race distances in the 2000-2001 racing season were 3210, 4828, and 6400 metres for flat, hurdle and steeplechase races respectively. Race type (flat, hurdle and steeplechase), is strongly associated with race distance, and in the case of steeplechase races in particular there is almost complete confounding compared with flat races. New Zealand racing rules state that steeplechase races must be a minimum of 3200 metres, while the longest recorded flat race distance in the 2000-2001 racing season was 3210 metres.

Peloso et al (1994) reported that race distance was shorter in horses with catastrophic injuries compared with those horses with non-catastrophic injuries (Peloso et al 1994b). Bailey et al (1997) reported a reduction of 50% in the odds of injury in those horses competing in a shorter race compared to the previous race start for the same horse.

10.9. Jockey

Horses ridden in National Hunt Flat races by amateur jockeys had a higher risk of fatalities than when ridden by professional jockeys (McKee 1995). There appears to be little supporting evidence for this finding from other sources.

10.10. Racetrack and racing surface

Conventional racetrack design incorporates two straights connected by two semi-circular curves. There appear to be no standards for track design and construction and as a result there is considerable variability between tracks with respect to almost any measurable aspects of track design such as length, width, bend angles, level of banking, subsurface construction, and surface material. Individual racetracks have been identified as having lower or higher risks of injury in several studies (Mohammed et al 1991; Wilson et al 1993; Oikawa M et al 1994; Bailey et al 1998; Estberg et al 1998), while other studies have reported no association between racetrack identity and risk of injury (Hill et al 1986; Peloso et al 1994b). As an example, a national North American survey of Thoroughbred injuries involving 33 racetracks from 15 states indicated variation in patterns of injury between tracks, with soft tissue injuries predominating at some tracks

and fractures at others, while some tracks had uneven forelimb distributions of injuries with either right or left forelimb injuries being more common than the contralateral limb (Wilson et al 1993).

Major problems in track design were identified as underbanking on curves, less than adequate management of the transition curves, and excessive sloping on the straight track sections (Fredricson et al 1975). The authors also commented that design features of future tracks should include wider, more sweeping curves, optimal curve banking based on consideration of likely centripetal forces, curves to incorporate 50% or more of the track distance, incorporation of carefully designed transition curves, and elimination of any drainage slope on the straight track sections (Fredricson et al 1975).

There is also evidence to suggest associations between surface composition and injury. Higher risk of injury has been reported in horses running on dirt surfaces compared with turf for fracture and other catastrophic injury (Hill et al 1986; Mohammed et al 1991), but not for non-fracture injuries (Hill et al 1986). The apparent effect of track surface in one study was eliminated when age adjusted rates were estimated suggesting underlying differences in the populations of horses racing on the two surfaces. A similar lack of association between injury risk and track surface (dirt vs turf) was reported by others (Haynes et al 1988; Estberg et al 1996b, 1998; Cohen et al 1997, 1999).

In contrast, a report from 2 racetracks in Florida suggested a higher risk of injury in horses racing on turf compared with dirt with the incidence of catastrophic injury being 2.3 and 0.9 per 1,000 starters on turf and dirt tracks respectively (Hernandez et al 2001). Here the authors speculated that turf races were more likely to be associated with large fields, handicap races, longer races, and races with higher prize money compared with dirt races.

A 3-year survey of veterinary clinical events recorded at 59 racetracks across Britain concluded that rates of lower limb injuries were higher on all-weather surfaces than on turf, with the all-weather track rate for injuries involving the proximal sesamoid or fetlock, and those involving tendon or suspensory ligament, being almost double those observed on turf tracks (Williams et al 2001). Moyer and Fisher (1991), reported increased risk of shin soreness in young horses trained on dirt tracks compared with those trained on wood fiber tracks suggesting an impact of track characteristics on specific injury types (Moyer et al 1991).

A large number of factors may influence racetrack variability in injury risk, including track composition characteristics, surface type (dirt, turf, composite, etc), and the presence, position and composition of crossings. In addition track condition is influenced by climatic conditions, level and type of maintenance and management, frequency of racing at particular tracks, and even rules and regulations of different racing authorities. Finally there may also be differences in population characteristics for those horses competing on different track surfaces or at different racetracks including differences in horse age, horse ability, risk of concurrent disease, and other horse associated characteristics.

There is a growing awareness of potential associations between physical characteristics of racetracks and injuries in horses training and racing on these surfaces but there are considerable complexities in measuring track characteristics and in determination of how to correlate such information with horse injuries and performance (Clanton et al 1991b). Recent studies have suggested that dynamic properties of specific tracks may be suitable for horses travelling within relatively narrow velocity ranges and that the situation may be different for horses galloping outside these speeds (Ratzlaff et al 1997). Semi-automated and automated measuring and reporting are likely to be developed in the future, perhaps incorporating telemetry and even real time testing during racing (Haynes et al 1988). Such information in combination with climate data may allow more effective management of racetracks to achieve both optimal track characteristics and uniformity.

10.11. Surface condition

Individual race clubs are responsible for management and maintenance of track surfaces under their care. Track management use a variety of methods of monitoring track surfaces and adjust their management in an attempt to produce a uniform and optimal track surface for day-to-day use. In addition each country has an official method of assessing track surface condition using a pre-defined categorical scale with the information being made available to the public at least on race days and sometimes other days as well. For dirt surfaces the terms fast, good, muddy and sloppy are commonly used while for turf terms such as fast, good, easy, soft, firm and heavy are used (Mundy 1997). There is no standardisation of categories between different countries. Dynamic properties of tracks depend on moisture content, composition and compaction and the behaviour of turf and dirt surfaces may be different under similar

climatic conditions. Studies have demonstrated that track surface composition can alter dynamic responses of the surface (Drevemo et al 1991, 1994). Data on track classification on race day form part of official racing statistics and therefore most studies using racing authority data have been able to test associations between injuries and subjective track classification.

A dynamic penetrometer has been used in New Zealand since 1992 to assess turf surfaces in an attempt to provide a more objective basis for track classification compared with previous subjective assessments (Thomas et al 1996; Murphy et al 1996). A penetrometer drops a fixed weight onto a solid pin with a fixed surface area that is in contact with the track, and the amount of penetration by the pin into the track surface is then measured (Thomas et al 1996).

There are varied reports on associations between dirt track classification and injury. A descriptive study in Minnesota reported that areas with higher traffic (around the starting chutes were associated with the location where 50% of injuries occurred (Clanton et al 1991b). Other studies have reported subjective associations between harder tracks and lameness (Cheney et al 1973) or tendonitis (Rooney et al 1981), though both these studies were based on questionnaires and may be subjected to recall bias. In contrast, Wilson et al (1996), reported that the risk of fractures in 2-year olds running on dirt tracks was 2 or 3 times higher on non-fast tracks compared with fast tracks (Wilson et al 1996a). Other studies have found no association between track condition and racing injuries (Hill et al 1986; Peloso et al 1994a).

Bailey et al (1997) reported that Australian turf track surfaces with lower water content (rated as fast or good), were associated with greater risk of breakdown injury than those with higher water content (dead, slow, or heavy) (Bailey et al 1997). A recent UK study reported that the frequency of musculoskeletal injuries was lowest from races on soft turf surfaces and the rate of problems increased as surfaces became firmer (Williams et al 2001). This association appeared to be more dramatic for steeplechase and hurdle races compared with flat races. In particular the risk for tendon and suspensory ligament injuries in steeplechase and hurdle races reduced as tracks became softer while no association was observed in flat races (Williams et al 2001).

10.12. Season

Early studies reporting associations between season and injury (Rooney 1982), appear to have failed to adjust for seasonal variation in the number of races and starters, a major potential confounder when examining data for seasonal effects. Results of a national survey of North American racehorse injuries suggested that the highest monthly injury and fatality rates for 2-year olds occurred in September (Wilson et al 1996b). A New York study reported that horses raced in summer had a 3-fold increased risk of breakdown compared with horses raced in winter, with no difference observed between spring and winter (Mohammed et al 1991). Others have reported no associations between risk of injury and either season (Hill et al 1986) or weather index (Clanton et al 1991b).

Season may be expected to exert effects through changes in temperature, humidity, moisture and perhaps through factors such as wind. It is also likely that there may be seasonal variation in population demographics of training and racing horses. Further work is needed to understand associations between seasonal effects and racehorse injury.

10.13. Exercise intensity

Associations between measures of exercise intensity and injury have been the subject of much discussion over the past decade, in part because of the complex nature of any relationship between activity and injury, and because of difficulties in developing techniques for measurement of exercise intensity.

Several studies have examined risks of injury in association with some measure of the interval between the race of interest and the previous race run by the same horse (penultimate inter-race interval). Minnesota horses that sustained a severe injury were more likely to have raced within the previous 12 days compared with control horses (Haynes et al 1988; Robinson et al 1990). Case-control studies have reported that penultimate inter-race intervals greater than 60 days were more likely in cases of humeral fracture (Carrier et al 1998), and forelimb superficial digital flexor tendonitis (Cohen et al 1997), than in control animals. A penultimate inter-race interval greater than 33 days was reported to be associated with higher risk of catastrophic injury in a case-control study of horses racing in Florida (Hernandez et al 2001). Stover et al (1992) also reported that horses with complete humeral fracture in California had

penultimate inter-race intervals that were longer than the average inter-race interval (Stover et al 1992).

In contrast, Minnesota horses with relatively more rigorous training schedules appeared to suffer injuries less frequently than those with less rigorous training schedules (Kobluk et al 1990). This was supported by evidence from New York suggesting that racehorses with lower lifetime racing frequencies were at greater risk of severe racing injury (Mohammed et al 1991). Estimates of racing intensity over prolonged periods are likely to be widely variable and more problematical to relate to a specific injury outcome. More recently efforts have concentrated on measuring exercise intensity over shorter time periods under the assumption that variation in higher-speed exercise intensity may explain some of the variability in risk of musculoskeletal injury (Estberg et al 1995, 1996a).

Estberg et al (1995) estimated median cumulative racing speed distances, and median racing speed event frequency using a rolling 2-month window (Estberg et al 1995). The relative risk of fatal musculoskeletal injury was greater for those horses that ran 2-month cumulative racing speed distances (trial or race) in excess of the median age-specific, exercise distance cluster for control horses (Estberg et al 1995). These findings supported the hypothesis that high rates of accumulation of distance performed at racing speeds may predispose horses to fatal musculoskeletal injury (Estberg et al 1995; Nunamaker et al 1990; Pool et al 1990). This is supported by the hypothesis that injury in athletic horses may result in part from chronic insidious skeletal and soft tissue damage resulting from repeated loads during high speed exercise that exceed normal tissue's ability to adapt or repair in response to exercise related damage (Pool et al 1990; Stover et al 1992). The authors acknowledged that their choice of a 2-month window for estimation of exercise intensity indices represented a subjective compromise between a desire to only consider recent exercise history since this is most likely to be related to exercise induced musculoskeletal damage, and the fact that too short a window would reduce statistical power by reducing the number of racing speed exercise events in the analyses (Estberg et al 1995).

Subsequent studies involving the same principal author have developed this technique further and applied it to other outcomes. A case-control study using exercise histories from a commercial performance database found that horses with an excessive 2-month exercise density cluster were at 15.5 times higher risk of sustaining a fatal injury

(Estberg et al 1996a). The authors also suggested that horses that accumulated 35 racing speed furlongs within a 2-month period are at 2 to 7 times greater risk of catastrophic bone fracture compared to horses that have accumulated only 25 racing speed furlongs in 2 months (Estberg et al 1996a).

The authors then used a case-crossover approach allowing them to use each horse as its own control in a study assessing associations between exercise intensity and risk of injury (Estberg et al 1998). Average racing speed distance was estimated for a series of windows incorporating the 2-months prior to each race or trial event. Each window was then assigned a hazard classification as normal or excessive by comparing the distance to an arbitrary cut-off defined as the age and year specific 75th percentile values for the same variable based on the entire dataset of values for all horses. Excessive windows were then followed by a 30-day hazard period. Injuries that occurred within a hazard period were classified as exposed and all others as non-exposed. Relative risks were then estimated for injuries, stratified by age and gender (Estberg et al 1998). Horses that suffered ligamentous injury without fracture were not at significantly higher risk of injury during a hazard period while horses suffering skeletal fracture and those suffering 3rd metacarpal fracture did have a higher risk during a hazard period. Horses were also more at risk of having a spell during a hazard period as well (Estberg et al 1998). The authors concluded that risk of catastrophic injury was significantly increased in fit racehorses following 2-month rates of high speed distance accumulation exceeding 0.75 to 0.95 furlongs per day (Estberg et al 1998).

There are several issues arising from this study that are worthy of comment. Estimates of cumulative racing speed distance derived from official race records were likely to underestimate the actual racing speed distance accumulated by a race-fit horse within any particular time period. Horses were only considered for inclusion if they had raced or worked consecutively for 30-days or more prior to the outcome of interest. Cases were excluded if they were injured greater than 30-days after their last race or timed workout. These criteria were used to exclude study subjects least likely to be race fit at the time of injury or spell. Therefore the population of interest was really confined to those horses that are actively training and racing. Case-crossover designs have been discussed already in this review. This approach is most useful when the exposure results in a transient increase in risk and exposure and outcome are closely related temporally since these characteristics are necessary to allow valid use of data from the same horse

to contribute control information as well as exposure information. The authors considered exposure to result in elevated risk for the next 30-day period (Estberg et al 1998), and alternative latent periods were not considered. The choice of a 30-day latent period was biologically plausible given understanding of the underlying process of musculoskeletal response to stress and microdamage, and was consistent with evidence of association between high running distances in human athletes and risk of injury in the following month (Lysholm et al 1987).

An observed association between intensive racing and training schedules and risk of spell was also of interest (Estberg et al 1998). It was possible that spells represented compulsory periods of recovery from injury and that recovery type spell periods may follow periods of intensive and demanding racing schedules. Relationships that hold for career ending catastrophic injuries may also hold for injuries resulting in temporary spells and recovery. Few studies have examined spell periods for evidence of association with similar risk factors to those used for injury outcomes.

A nested case-control study that examined risk factors for noncatastrophic suspensory apparatus injury in California racehorses, also involved prospective collection of exercise intensity data (Hill et al 2001). The authors coded a 3-level exercise intensity score that described activity in the preceding 7-days (0= no fast work, 1= fast work but no race start, 2=race start in the preceding 7 days), and a continuous variable describing the cumulative distance travelled at fast speed during training or in official trials or races again for a 7-day window. Neither of these exercise intensity variables was statistically associated with risk of suspensory apparatus injury. It was possible that the use of a 7-day window for presenting exposure information, may have contributed to the non-significant result since previous studies had used 30 or 60-day windows. In addition previous studies had used catastrophic injuries as outcomes of interest and not confined themselves to a non-catastrophic, soft tissue injury.

There have also been reports describing an inverse relationship between cumulative high speed exercise and risk of injury (Cohen et al 2000a). All horses sustaining an injury from 4 Kentucky racetracks over a 2-year period were included in a case-control study, with 2 non-injured horses selected as controls from the same race as each injured animal (Cohen et al 2000b). A variety of different measures of cumulative exercise intensity were calculated including: cumulative distance in furlongs of high speed exercise for 1, 2, 3 and 6 months prior to injury (or for controls date of race they were

selected in); cumulative number of races in the same time frames; cumulative number of races and trials; mean daily distance during the same time periods; number of high speed exercise events in excess of 5 furlongs during the 2 months prior to event; and ratio of mean daily distance during the 1 month prior to the mean daily distance for either the 2, 3 or 6 month period prior (mean daily distance involved monthly totals divided by 30 days for each month) (Cohen et al 2000b). Risk of injury was inversely associated with cumulative distance of exercise during 1 and 2 month periods prior to the event race, mean daily rate of distance accumulation during the 1 month prior, ratio of mean daily distance accumulation in month -1 to months 3 or 6, and number of high speed events longer than 5 furlongs in the 2 months prior to the event. Accumulating 0 furlongs during the 1 or 2 month period prior to the event race was significantly associated with increased risk of injury but not catastrophic injury. The inverse association suggested that the more exercise a horse accumulated the less likely it was to become injured. The authors hypothesized that the accumulation of relatively less cumulative high speed exercise among injured horses may have been due to pre-existing health conditions or musculoskeletal lesions that limited ability to perform high speed exercise (Cohen et al 2000a). Although all derived variables appeared to be associated with the outcomes of interest, none were superior to the simpler variable of distance accumulated during the 1 month period prior to the race in which an injury occurred. The magnitude of this association was small on a per furlong basis but a horse with 10 more competitive furlongs of high speed exercise during a 1 month period before a race was nearly 2 times less likely to be injured. Discrepancies between these results and those reported by Estberg et al (Estberg et al 1995, 1996a, 1998) were attributed in part to regional effects in racing surfaces, training practices or population differences and also the complexity of the relationship between exercise and exercise induced musculoskeletal damage. Other studies have also reported that horses with less evidence of injury tended to be worked at a higher exercise intensity (Kobluk et al 1990), and that horses racing 7 to 12 times per year were 3 times less likely to break down compared to horses raced 6 times or less (Mohammed et al 1991).

It is likely that any apparent protective effect of cumulative, high-speed exercise may be due in part to survival bias as discussed earlier in this review, though a more complex, non-linear relationship may also be present. As time progresses, the population of horses still racing is likely to become progressively more healthy because of the

continued exit from the population of those horses susceptible to injury and breakdown; a "healthy horse" effect. There is some evidence to support this hypothesis in a recent study using a nested case-control approach to investigate risk factors for pelvic and tibial fractures in UK racehorses (Verheyen et al 2003). Cumulative distances at different speeds were assessed for 30 and 60-day windows. There was no statistical association between 60-day exercise intensity measures and injury, while there appeared to be a quadratic relationship between 30-day cumulative distance achieved at the canter, and injury. Increasing distance cantered was associated with increasing risk of fracture with the relationship appearing to level off for those horses accumulating more than 250 furlongs in a 30-day window. This finding is consistent with a "healthy horse" effect in that animals less prone to injury are left to continue doing more work.

10.14. Pre-existing conditions

Serious injury involving the musculoskeletal system often manifests acutely but may be preceded and precipitated by chronic micro-injury acquired during training and racing over the period preceding the acute event (Pool et al 1990). This hypothesis is consistent with studies described above that demonstrated associations between cumulative exercise intensity scores over varying time windows, and subsequent risk of injury.

Several studies have provided additional evidence contributing to the association between pre-existing conditions and acute musculoskeletal injury. Ten of 13 humeri examined at necropsy after fatal breakdown injury had evidence of gross periosteal callus bridging a portion of the fracture line suggesting that a pre-existing pathologic condition predisposed the humerus to complete fractures that occurred during training or racing. (Stover et al 1992) The callus was considered most likely to have resulted from previous stress fractures and the location of the callus was the same as that reported for incomplete stress fractures in a prior study (Mackey et al 1987). Pre-existing pathology may have made the affected humeri more susceptible to complete fracture during normal stress loads and possibly even during subnormal stress loads perhaps indicating why most of the fractures occurred during training and not racing.

Other studies of racing injuries have supported the hypothesis. A higher than expected proportion of horses injured during a race, were positioned at the back of the racing field at the first quarter mark of the race (Peloso et al 1994b). Horses classified on pre-

race veterinary inspection to be at increased risk of injury were subsequently found to have increased odds of musculoskeletal injury, injury of the suspensory apparatus and injury of the forelimb superficial digital flexor tendon compared with horses not deemed to be at risk on pre-race inspection (Cohen et al 1997, 1999). In addition, horses with mild abnormality of the suspensory apparatus detected during training were significantly more likely to subsequently incur a musculoskeletal injury of any kind, and in particular injuries involving the suspensory apparatus and lateral metacarpal condyle in the following 90-days compared with horses without detectable abnormalities (Hill et al 2001).

These studies support the hypothesis that detectable, mild abnormalities involving the musculoskeletal system may represent evidence of microdamage occurring at a rate faster than the healing or adaptive capacity of affected tissues (Hill et al 2001). Mild abnormality may also result in changes in gait or limb alignment that place affected horses at greater risk of subsequent injury independent of the original lesion(s), by altering limb load and increasing stresses on other areas (Hill et al 2001). If the rate or severity of microdamage is proportional to the exercise load placed on the musculoskeletal system then measures of exercise intensity may be indirect measures of both load and microdamage, making these measures of potential value as prognostic indicators in the future.

Horses with pre-existing injury may be more likely to experience periods of reduced activity, have extended intervals between races, and be at a higher risk for bone fracture perhaps due to loss of bone mass during periods of inactivity placing the horse at increased risk of micro-damage during intense exercise when training resumed (Stover et al 1992; Carrier et al 1998). Some authors have hypothesized that horses returning to work after extended spells may have insufficient bone mass to prevent microdamage with exercise, resulting in increased risk of stress fractures. (Carrier et al 1998) Injuries to the SDFT have been related to an interval of greater than 60-days since the previous race start. (Cohen et al 1997) A longer than typical interval between races was reported in the interval immediately before the start where humeral fractures were reported in 5 horses. (Carrier et al 1998)

10.15. Shoeing

Almost all horses are shod during training and racing. Observational reports have suggested associations between horseshoe characteristics and lameness or injury (Moyer et al 1975), and horseshoe characteristics have been shown to affect kinematic measures of the lower limb and hoof (Kane et al 1996a; Kane et al 1996b). Kane et al described the development of techniques for detailed assessment of horseshoe characteristics (Kane et al 1996a) and their association with injuries in horses subject to post mortem under the Californian post mortem program (Kane et al 1996b). Horses shod with toe grabs on their front shoes had greater risk of musculoskeletal injury, suspensory apparatus injury and metacarpal condylar fracture, compared with horses without toe grabs, and increasing height of the toe grab appeared to increase the risk (Kane et al 1996b). Toe grabs are a traction device extending from the toe of the shoe towards the ground (Kane et al 1996a). The authors hypothesized that toe grabs may decrease the functional angle of the shod hoof, delay breakover, and increase the length of the lever arm of the ground reaction force on the fetlock, generally increasing strain on the fetlock and suspensory apparatus (Kane et al 1996b). A nested case-control study of risk factors for suspensory apparatus injury in California racehorses also reported an association between toe grab shoes of any height in the week preceding an injury, and a higher risk of injury compared with horses that did not have toe grab shoes in that week (Hill et al 2001)

In addition horses wearing rim shoes were reported to be at reduced risk of musculoskeletal injury (Kane et al 1996b). Rim shoes contain a rim made by extending the inner or outer edge of the ground surface of the shoe towards the ground in an attempt to increase traction (Kane et al 1996a). A subsequent study by the same authors compared measurable indices of hoof size, shape and balance as possible risk factors for fatal musculoskeletal injury in horses examined under the California post mortem program (Kane et al 1998). More research is needed to further investigate associations between shoe and hoof characteristics and risks of various types of injury.

10.16. In-race activity and interaction

Analysis of video recordings of horse races have been used to investigate activities that may be associated with risk of injuries (Ueda et al 1993; Cohen et al 1997; Parkin et al 2003). Actions observed immediately prior to injury included lead changes, use of

the whip by the jockey and oblique movement. The authors hypothesized that increased loading on the leading limb, and actions that might upset in some way the center of gravity of the jockey or horse may contribute to increased risk of fracture (Ueda et al 1993).

A Kentucky case-control study of musculoskeletal injury also incorporated analysis of race videos, reporting that horses were at greater odds of injury if there was physical interaction between horses during the race, stumbling during the race, a change in lead limb in the 12 second period prior to injury, physical interaction with another horse during the race (Cohen et al 1997). Use of the whip by the jockey in the 12-second period prior to injury was reported to have a protective effect ($OR < 1$) for musculoskeletal injury (Cohen et al 1997). Occurrences such as stumbling, physical interaction, and changes in lead limb, could be resulting in alteration of mechanical stress on soft tissue and bone that may predispose to subsequent injury. The authors acknowledged that identification of precise timing of injury was based on a noticeable change in gait or jockey action as viewed on the video and that horses may have been injured prior to this time. Caution is urged in the interpretation of these findings since incorrect identification of precise injury time may have a major impact on observed associations between exposures in the few seconds prior to injury.

A recent case-control UK study reported on analysis of race videos for 109 races which contained a fatal distal limb fracture with various observations made on case animals and 3 randomly selected control animals in each race (Parkin et al 2003). Multiple views of each race were synchronised and examined frame-by-frame. The exact time of fracture was identified in 94% of races. Most (66%) of fractures involved the lead leg at the time of the injury. Case horses were 2.5 times ($p=0.015$), more likely to have been making good progress through the race on a 3-level categorical score of progress (good, level, bad), 2.3 times ($p=0.016$) more likely to have been encouraged by the jockey during the 10-seconds prior to the time of event, and 2.3 times ($p=0.048$), more likely to be classified as reluctant to start, when compared with control horses (Parkin et al 2003). Further investigations are required on video analysis of race activities to better understand associations and their interpretation.

10.17. Trainer

Few studies have specifically examined associations between trainer and outcomes associated with injury. There would appear to be obvious associations between trainer and measures of success given that individual trainers are well recognised by their success in feature races around the world. More (1999), has reported that racing performance measured as total race earnings in the first year of racing, was significantly clustered at the level of trainer in statistical models that considered trainer as a random effect in an attempt to explain a component of variation in the outcome variable (More 1999). Hill et al (2001) reported that attrition of horses from a prospective study due to musculoskeletal injury appeared to vary substantially by trainer indicating that trainer identity may be a risk factor for musculoskeletal injury (Hill et al 2001).

Care needs to be taken in interpreting apparent effects at the level of trainer since it appears likely that horses are allocated to trainers in a non-random process influenced by historical success of other horses as well as a variety of different horse attributes and perceived measures of horse quality or ability (Williamson et al 1996).

11. Conclusion

This review describes the New Zealand Thoroughbred racing industry in general terms, characteristics of various epidemiological approaches to the study of associations between exposures and outcomes of interest, and then a detailed review of current knowledge regarding wastage in Thoroughbred racehorses and possible risk factors.

The overwhelming conclusion that is consistently supported by all studies on racehorses is that lameness is the major cause of losses either of horses or of training and racing time, followed typically by respiratory disease and then a miscellany of other causes.

The true impact of musculoskeletal injuries on racehorse health and performance is difficult to determine. Musculoskeletal injuries may result in interruption to training as well as contributing in some way to decisions to retire or move a horse to a different trainer, or even euthanase a horse. Bourke has estimated that approximately one third of the Australian racing population is lost on an annual basis (Bourke 1990), though only a proportion of these losses will have been a consequence of injury or other conditions.

Economic losses from musculoskeletal injuries result from horses that train and fail to race, as well as losses associated with premature retirement, reduced performance and

injuries preventing breeding or racing. Moyer and Fisher estimated that a 3-week spell initiated in a race-fit horse was likely to result in a total loss of about 100 days when the additional time taken to reach the same level of race-fitness once the animal resumed training was taken into account (Moyer et al 1991).

Injuries that occur during racing, particularly those resulting in death, euthanasia or subsequent retirement of the animal, often occur in the field of view of a large number of observers, and have a dramatic and emotional impact that adversely affects public perception of racing in addition to direct and indirect economic costs.

Though considerable advances have been made in our understanding of issues surrounding musculoskeletal injuries in racehorses, particularly in the last decade, much remains to be done. In many cases variables used in associative epidemiological analyses have been those for which pre-existing data could be obtained for example in case-control studies using information derived from pre-existing records. There is a need for further cohort studies designed to test *a priori* hypotheses, and involvement of more sophisticated analyses to take into account confounders and effects of other variables.

Increasingly, retrospective data from racing jurisdictions are being combined with prospective studies to allow researchers to investigate specific *a priori* hypotheses and test possible control strategies in attempts to reduce injury risk. There appear to be few simple answers or solutions to the issues that are contributing to wastage.

An inescapable conclusion reached on completion of the literature review is the almost complete absence of any investigation of wastage and its causes in the population of New Zealand racehorses. Such fundamental statistics as measures of frequency of occurrence of different types of injury and their impact on horse health and performance are lacking, as are more detailed studies investigating risk factors for injuries and conditions that might interfere with a horse's ability to train and race without impedance. This thesis attempts to address this situation by investigating aspects of Thoroughbred health and performance in New Zealand racehorses.

Chapter 3

Effect of training location and time period on racehorse performance in New Zealand. I. Descriptive analysis *

*Published as: NR Perkins, SWJ Reid, RS Morris. *New Zealand Veterinary Journal*, 52, 236-242, 2004.

Abstract

AIM: To describe characteristics of Thoroughbred training stables in Matamata and in all other locations in New Zealand combined, over two 19-month time periods in 1996-1997 and 1998-1999, representing equal length periods immediately prior to, and after the construction of a new training surface at the Matamata Racing Club.

METHODS: Retrospective records covering all horses training and racing in New Zealand during two 19-month time periods (1996-1997 and 1998-1999), covering 161 locations, were obtained from New Zealand Thoroughbred Racing. Outcome variables included whether a horse started again in the 6 months following any start in the first 13 months of either time period, number of starts for every horse, and finishing position. Summary measures with confidence intervals and unadjusted odds ratios (OR), measuring strength of associations for various factors were computed.

RESULTS: The datasets contained information on 45,446 horses, 11,336 races, 5,110 trials and a total of 110,643 starts. Horses trained at Matamata represented 8% (3,715) of the total horse datasets, and accounted for 11,977 starts (10.8%). They were more likely to start in a race or trial in either time period and were 1.4 and 1.3 times as likely to finish first, second or third compared with horses trained at other locations in 1996-1997 and 1998-1999, respectively. A 6-month-no-race period was observed in 9,306 (74%) of the 12,584 horses that started at least once in the first 13 months of either time period. Horses trained at Matamata were less likely to have a 6-month no-race period than horses trained at other locations in both time periods. There was no effect of time period within each location on the probability of either a horse having a 6-month no-race period or of a start being followed by a 6-month no-race period, but there was a general effect of time with more 6-month no-race periods being observed in 1998-1999 relative to 1996-1997.

CONCLUSION: Summary statistics are presented for Thoroughbred racing in New Zealand over two 19-month time periods. Differences between the populations of horses trained in Matamata compared with those trained at other locations were attributed in part to the fact that many of the more successful racehorse trainers in the country have stables at Matamata. As a result, the population of horses in Matamata may not be representative of the racehorse population in New Zealand. Although more likely to win or place in both time periods, the magnitude of the advantage to horses in Matamata

was reduced in 1998-1999 relative to 1996-1997, and this could be due in part to effects of the new track surface at Matamata. There was no evidence of a rise in risk of a 6-month no-race period following any start in those horses trained in Matamata in 1998-1999 relative to either horses trained at other locations or to horses trained in Matamata during the earlier time period.

Introduction

Increasing emphasis is being placed on understanding relationships between factors that might influence the risk of injuries during training and racing in Thoroughbred horses. Studies that allow identification and implementation of effective risk management strategies may minimise risks of injury in the racehorse population. Population-based research in the Thoroughbred racing industry is facilitated by the collection of a large volume of data by official racing bodies relating to race performance and horse-associated characteristics.

Numerous studies have identified musculoskeletal injuries as the most common performance-limiting conditions involving racehorses (Rossdale et al 1985; Bailey 1998; Hill et al 2001). Life-threatening injuries are uncommon but injuries resulting in interruption of training, or even retirement from racing, affect many horses. Epidemiological studies have identified risk factors for musculoskeletal injuries in racehorses including horse age (Cohen et al 1997), cumulative exercise intensity (Estberg et al 1995), hoof balance (Kane et al 1998), physical contact between horses during a race (Cohen et al 1997), and race distance and class, field size, and barrier position (Bailey et al 1997). Several studies have suggested that racetrack characteristics may influence the risk of severe musculoskeletal injury in Thoroughbred and Standardbred racehorses (Fredricson et al 1975; Mohammed et al 1991; Oikawa et al 1994; Evans and Walsh 1997; Bailey et al 1998; Hernandez et al 2001). A small number of studies have shown that modification in track design or surface condition, may reduce the risk of injury to horses that train or race on that track (Oikawa M et al. 1994; Evans and Walsh 1997).

Athletic injury in racehorses is a complex, multifactorial event with variable impact on performance. Cumulative effects of chronic micro-injuries sustained through training and previous racing episodes have been proposed as potential contributing factors to subsequent overt injury or breakdown (Estberg et al 1996). This has led to interest in the

possible contribution of training-related factors to the risk of athletic injury in racehorses, including characteristics associated with training tracks or surfaces. Most Thoroughbred training tracks in New Zealand are located within racecourses and involve the same combination of curved and straight sections that make up racetracks. Training track surfaces include sand, dirt, wood fibre, and turf. In early 1998, one of the largest Thoroughbred training venues in New Zealand (Matamata Racing Club), installed a proprietary, all-weather track surface (Trackmaster™), for horses training at that venue. The Trackmaster™ track was constructed on a hard base using multiple layers of particulate material such as sand and bark, and is currently the only track of its kind in New Zealand. The current study was conducted using electronic racing records to investigate associations between training location and time period, and other factors including stable characteristics (number of horses of each gender in a training stable), and measures of racehorse performance (probability of starting in a trial or race, finishing position, and whether a start was followed by a 6-month no-race period), and presents descriptive summaries of risk factors while the results of multivariate analyses are covered in a companion paper (Perkins et al 2004).

Materials and methods

Study design

The reference population was considered to be the racing Thoroughbred population of New Zealand. Racing data were obtained by electronic download from NZTR, for two 19-month periods, comprising 01 May 1996 to 30 November 1997, and 01 May 1998 to 30 November 1999. These represented equal periods before and after the new track at Matamata came into service. A 19-month period was selected to allow sufficient time for horses to be followed through multiple starts. Data represented all Thoroughbred horses registered with any trainer in New Zealand during the respective time periods, for the purposes of racing.

Variables

Horse level data included horse name, gender (colt, gelding, horse, filly, and mare), birthdate, sire, dam, trainer identification, and location of training stable. Horse gender was aggregated to male and female for this study with male horses including entire animals and geldings. Racing level data related to official results for all trials and races throughout New Zealand. Where horses raced overseas (commonly Australia), and then

returned to race in New Zealand, overseas race results were also included in the dataset. Trials are officially-timed workouts typically performed at or near racing speeds. Horses may trial for racing experience, to add some competitive element to training preparation for subsequent races, and also to gain qualifying points for entry into selected races. The combination of race and trial data may be considered to represent an officially-timed, racing speed, exercise history for each horse (Estberg et al 1996). Data relating to race and trial results were recorded at either race or horse levels. Start level data included race venue, race date, race number, distance, class, prize money, number of starters, track condition, race type (flat race, hurdles, and steeplechase), and winning time. Horse level data recorded for each start included horse identification, jockey, barrier draw, weight carried, and placing. Three variables (race type, barrier draw, and weight carried), contained only data for official races and not for trials.

Thoroughbred horses in New Zealand are deemed to have officially aged by 1 year at 01 August of each year. For analyses that required data to be summarised at the horse level, horse age in years was determined at 01 August 1997 and 01 August 1999 for the 1996-1997 and 1998-1999 datasets, respectively. For analyses performed at the race or trial level, horse age was estimated at the date of the race, using 01 August as the official birth date for these estimations. There were nine animals in the 1998-1999 dataset that trialled either 3 or 4 days before they officially turned 2 years of age (trial dates were 27 and 28 July of either 1998 or 1999). Age at the day of race for these animals was adjusted to 2 years to make them comparable to their peers.

A number of derived variables were created from the data. NZTR records identified a training location for each trainer that was deemed to be the venue at which most training activity took place. A binary variable was created called location, which took the value "Matamata" if the trainer was recorded as training at that venue, and "Other" if the trainer was recorded as training at any venue in New Zealand other than Matamata. Another binary variable was generated based on whether a horse raced or trialled within the 6-month period following any individual race or trial start, only if the initial race or trial start occurred in the first 13 months of either time period (01 May to 30 May of the following year), to ensure that every animal could be followed for a minimum of 6 months after any start. This variable was used to identify animals that had a prolonged period without trialling or racing, considered more likely to have occurred in horses that had suffered a serious musculoskeletal injury than in uninjured horses.

Statistical analysis

Exploratory analytical techniques were used to examine data for completeness and validity. Where appropriate, missing or unusual values were compared with data from other sources including online information from the New Zealand Stud Book (<http://www.nzstudbook.com/NZTRISB>) and printed material (Aldridge 1997, 2001).

Separate aggregate files were developed for each 19-month time period. Univariate analytical methods were then used to examine associations between a range of independent variables and outcomes of interest.

Records were managed using a relational database (Microsoft Access97 for Windows) and spreadsheet software (Microsoft Excel97 for Windows). Statistical analyses were performed using the SAS System for Windows release 8.1 (SAS Institute Inc., Cary, NC, USA), and SPSS for Windows version 10 (SPSS Inc, Chicago, IL, USA).

Results

There were 27,366 horse records in the 1996-1997 horse dataset, and 27,956 in the 1998-1999 dataset. Horses recorded as being trained with more than one trainer during the time periods, and horse records with missing data for trainer, trainer location, gender, and foaling date, were excluded from the analyses. In addition, the oldest horses that were recorded as having raced or trialled at least once in 1996-1997 and 1998-1999 were born in 1983 and 1984, respectively, while the horse dataset contained records from animals born as early as 1975. All records from horses born earlier than 1983 and 1984 were then deleted from the 1996-1997 and 1998-1999 datasets, respectively, under the justification that they were not likely to be in full training in preparation for racing. The remaining records were deemed to be representative of the horse populations eligible to race during the respective time periods and all further results relate to these modified datasets.

Descriptive information on the data is presented in Tables 3.1 and 3.2. After exclusions, the 1996-1997 and 1998-1999 datasets contained information relating to 20,599 and 24,847 horses respectively, with 17,311 horses being represented in both datasets. Horses trained in Matamata represented 9.1 and 7.4% of the total horse population recorded for 1996-1997 and 1998-1999 respectively.

Table 3.1. Descriptive information about 110,643 starts involving 15,864 horses in training at Matamata or other venues in New Zealand during 1996-1997 and 1998-1999. Data sourced from NZTR records.

	1996-1997		Subtotal	1998-1999		Subtotal	Total
	Matamata	Other		Matamata	Other		
Numbers							
male	970 (52%)	9,880 (53%)	10,850	961 (52%)	12,255 (53%)	13,216	24,066
female	907 (48%)	8,842 (47%)	9,749	877 (48%)	10,754 (47%)	11,631	21,380
Total	1,877 (100%)	18,722 (100%)	20,599	1,838 (100%)	23,009 (100%)	24,847	45,446
Horses that started in at least one race-event							
male	450 (52%)	3,817 (56.5%)	4,267	482 (52%)	4,124 (56%)	4,606	8,873
female	411 (48%)	2,933 (43.5%)	3,344	451 (48%)	3,196 (44%)	3,647	6,991
Total	861 (100%)	6,750 (100%)	7,611	933 (100%)	7,320 (100%)	8,253	15,864
Individual races			5,958			5,378	11,336
Individual trials			2,742			2,368	5,110
Starts per horse							
Mean	6.8	7.3	7.2	6.6	6.8	6.8	7.0
Standard deviation (SD)	5.7	6.6	6.5	5.4	6.0	6.0	6.2
Median	5	5	5	5	5	5	5
Mode	1	1	1	1	1	1	1
Minimum	1	1	1	1	1	1	1
Maximum	29	48	48	31	43	43	48
Total number of starts							
run by all horses	5,853	49,060	54,913	6,124	49,606	55,730	110,643

Table 3.2. Number of horses and trainers organised by stable size (number of horses), training location and time period. Data include all horse records from those trainers that had at least one start during the study period. Data sourced from NZTR records.

Number of horses	1996-1997				1998-1999			
	Matamata		Other		Matamata		Other	
	Horses	Trainers	Horses	Trainers	Horses	Trainers	Horses	Trainers
Per training stable:								
1 - 9	93 (5%)	22	2,862 (17%)	706	90 (5%)	25	2,734 (14%)	649
10 - 19	163 (9%)	10	2,524 (15%)	190	120 (7%)	10	2,540 (13%)	182
20 - 49	455 (25%)	14	4,274 (25%)	144	404 (23%)	13	5,050 (26%)	169
≥50	1,085 (60%)	13	7,192 (43%)	77	1,119 (65%)	13	9,491 (48%)	94
Total	1,796 (100%)	59	16,852 (100%)	1,117	1,733 (100%)	61	19,815 (100%)	1,094
Started at least once								
	861 (48%)		6,750 (40%)		933 (54%)		7,320 (37%)	
95% CI ^a	45.6 - 50.3		39.2 - 40.7		51.5 - 56.2		36.3 - 37.6	

^a% of total number of horses at that location and time period. CI = confidence interval.

Data from a total of 5,110 trials and 11,336 races were collected. The median, mode and minimum number of starts per individual horse remained constant both over time and training location.

NZTR records identified 1,948 and 2,110 trainers as training at least one horse in the 1996-1997 and 1998-1999 datasets, respectively. Of these a total of 1,176 and 1,155 had at least one horse start in a race or trial in the 1996-1997 and 1998-1999 time periods, respectively (Table 3.2). Table 3.2 presents summary information for all horses recorded as being trained by those trainers that had at least one horse start in a race or trial during the study periods. Horses trained in Matamata were more likely to start than those trained in other locations (48% vs 40% in 1996-1997, and 54% vs 37% in 1998-1999, for Matamata and other locations, respectively). A higher percentage of horses at Matamata were trained in stables with 20 or more horses than at other training locations (86% vs 68% in 1996-1997, and 88% vs 73% in 1998-1999, respectively).

There were a total of 8,700 events in the 1996-1997 dataset, and 7,746 in the 1998-1999 dataset, 2,742 (32%) and 2,368 (31%), respectively, of which were trials, with the remainder being official races.

The number of races and trials on offer in New Zealand declined between the 1996-1997 and 1998-1999 datasets (9.7 and 13.6% decline in races and trials, respectively). However, the number of horses registered with trainers increased from 20,599 in 1996-1997 to 24,847 in 1998-1999, as did the number of horses starting in at least one race or trial (7,611 in 1996-1997 to 8,253 in 1998-1999). The total number of starts also increased from 54,913 to 55,730, an increase of 1.5%.

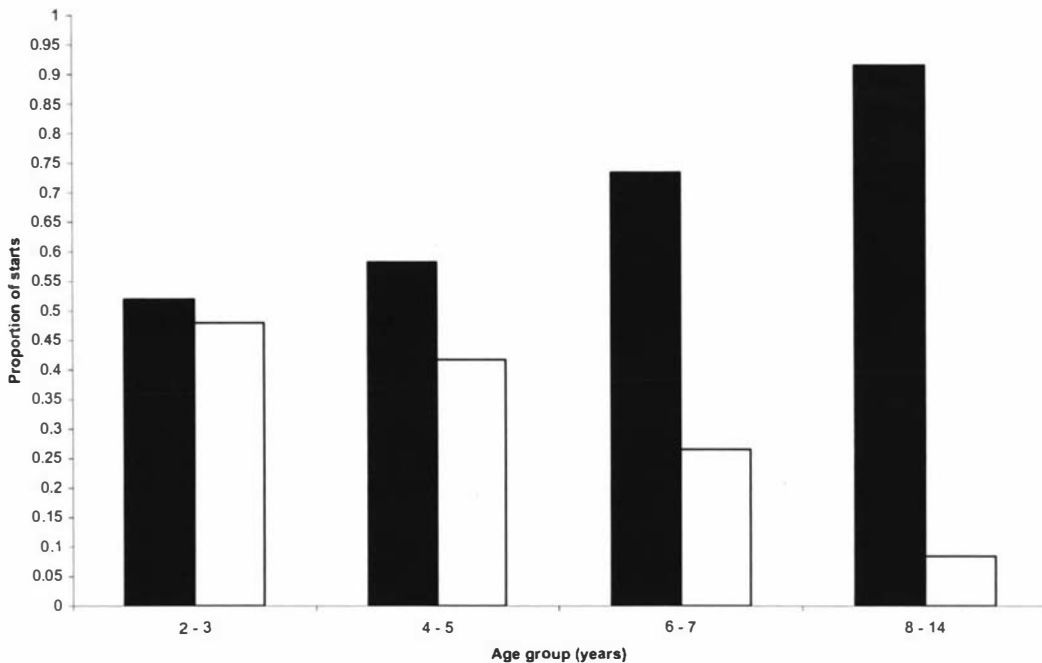


Figure 3.1. Proportion of male (v) and female (□) Thoroughbreds having starts within each age group. Data derived from NZTR records of 110,643 starts combined over two 19-month time periods (1996-1997 and 1998-1999). Data sourced from NZTR records.

There were more males than females, both in the total horse dataset (24,066 or 53%; 95% CI=52.5 - 53.4%), and in the population of horses that had at least one start (8,873 or 56%; 95% CI=55.1 - 56.8%). Figure 3.1 shows the proportion of starts involving male or female horses, organised by age group of the horses at the time of the race or trial. In 2- and 3- year olds, 52% of all starts involved male horses. As horse age increased a higher proportion of starts involved males.

Horses trained in Matamata accounted for 1,794/15,864 (11.3%), of all horses that raced or trialled at least once, and for 11,977/110,643 (10.8%), starts (Table 3.3). Data from Table 3.3 were then aggregated to compare the effect of location within each time period on the odds of finishing in places one to three (Table 3.4), and the effect of time period within the population of horses trained in Matamata on the odds of finishing in the first three places (Table 3.5).

Table 3.3. Frequency of result categories (first, second, third, fourth, and fifth or worse), for all 110,643 starts recorded during two 19-month time periods in 1996-1997 and 1998-1999. Data organised by time period and whether horses were trained in Matamata or other locations within New Zealand. Data sourced from NZTR records.

Placing	1996-1997		1998-1999	
	Matamata	Other	Matamata	Other
1	851 (15%)	5,075 (11%)	773 (12%)	5,311 (11%)
2	746 (13%)	5,000 (10%)	751 (12%)	5,146 (11%)
3	663 (11%)	4,988 (10%)	714 (12%)	5,051 (10%)
4	477 (8%)	4,042 (8%)	539 (9%)	4,107 (8%)
≥5	3,116 (53%)	29,955 (61%)	3,347 (55%)	29,991 (60%)
Totals	5,853 (100%)	49,060 (100%)	6,124 (100%)	49,606 (100%)

Table 3.4. Results of Mantel-Haenszel test comparing odds of placing in the first three versus all other outcomes for horses from Matamata or other training venues in New Zealand. Data from 110,643 starts over two time periods (1996-1997 and 1998-1999). Data sourced from NZTR records.

Time period	Placing		OR	95% CI	
	1 - 3	≥4		Lower	Upper
1996-1997					
Matamata	2,260	3,593	1.42	1.34	1.5
Other	15,063	33,997	-		
1998-1999					
Matamata	2,238	3,886	1.27	1.2	1.34
Other	15,508	34,098	-		

BD test for homogeneity: BD-statistic= 8.1; p= 0.008

OR = odds ratio, CI = confidence interval

Horses trained in Matamata and starting in a race or trial were 1.4 and 1.3 times as likely to finish in first, second or third position than horses trained elsewhere, in 1996-1997 and 1998-1999, respectively. A pooled estimate of the effect of location was not calculated because the strata were deemed to be different, based on a Breslow-Day test for homogeneity across strata (BD statistic = 8.1, p=0.008). Horses trained at Matamata in 1996-1997 were more likely to win/place than those trained there in 1998-1999 (OR= 1.09, 95% CI=1.01 – 1.2; p= 0.019).

Table 3.5. Effect of time period on the odds of placing in the first three versus all other outcomes for the 11,977 starts made by horses trained in Matamata during 1996-1997 and 1998-1999. Data sourced from NZTR records.

Time period	Placing		OR	95% CI	
	1 - 3	≥4		Lower	Upper
1996-1997	2,260	3,593	1.09	1.01	1.2
1998-1999	2,238	3,886	-		

OR = odds ratio, CI = confidence interval

Table 3.6. Number of starts for Thoroughbred horses trained in Matamata or other venues in New Zealand, in the first 13 months of each 19-month time period, and the number that were followed by a 6-month period during which the horse did not start again. Data sourced from NZTR records.

Number of starts	1996-1997			1998-1999		
	Matamata	Other	Subtotal	Matamata	Other	Subtotal
First 13 months						
Horses	689	5,564	6,253	735	5,596	6,331
Starts	3,987	34,835	38,822	4,150	34,042	38,192
Followed by 6-month no-race period						
Horses	427 (62%)	4,128 (74%)	4,555 (73%)	475 (65%)	4,276 (76%)	4,751 (75%)
95% CI	58.2 - 65.6	73.1 - 75.3	71.7 - 74.0	61.1 - 68.1	75.2 - 77.6	74.0 - 76.1
Starts	443 (11%)	4,349 (13%)	4,792 (12%)	498 (12%)	4,464 (13%)	4,962 (13%)
95% CI	10.2 - 12.2	12.1 - 12.9	12.1 - 12.6	11.1 - 13.0	12.7 - 13.5	12.7 - 13.3

CI = confidence interval

Table 3.6 shows the horses and starts at each location and time period, for those starts that were followed by 6 months or more without the same horse starting in a subsequent race or trial. A total of 9,754 (12.7%) starts involving 9,306 horses were followed by 6 months or more in which the same horse did not start. A small number of horses in each time period had two 6-month no-race periods between starts (237 and 211 in 1996-1997 and 1998-1999, respectively), with at least one of these no-race periods occurring within the first 13 months of either time period, and each of these horses appear twice in Table 6. Within each time period, horses trained in Matamata were less likely to have a 6-month no-race period than those trained at other locations though there was no effect of location on the likelihood of individual starts being followed by a 6-month no-race period. There was a non-significant increase in the number of horses having 6-month no-race periods in 1998-1999 compared with 1996-1997, and a small but significant

increase in the likelihood of individual starts being followed by a 6-month no-race period between the two time periods.

Discussion

NZTR maintains complete and accurate records of race and trial results for Thoroughbred racehorses competing in New Zealand. These records are a valuable source of information for use in epidemiological studies.

Annual summary statistics for each racing season in New Zealand (01 August to 31 July in the following year) are also published by NZTR (Aldridge 1997). NZTR records indicate a steady decline over the last decade in the number of races offered each year in New Zealand, the number of horses starting in one or more races, and the number of race starts (Aldridge 1997, 2001). Although the data presented here covered two 19-month time periods as opposed to the 12-month periods in published NZTR records the results are consistent with respect to declining numbers of races and trials over time. Data presented here indicated an increase in the number of starts from 1996-1997 to 1998-1999, is in contrast to published seasonal NZTR records (Aldridge 1997, 2001), with the discrepancy likely to be a result of inclusion in the study datasets of trial results, overseas race results for horses returning to race in New Zealand, and starts from two spring and summer periods in each 19-month time period.

Characteristics of horses, and measures of performance for horses trained at Matamata appeared to differ from those trained at other locations around New Zealand. Stables at Matamata were more likely to contain larger numbers of horses, have a higher proportion of starts associated with younger animals, and were more likely to start horses, and to have horses finish in the first three places in any start, compared with horses from other locations. These differences may reflect the fact that the racecourse in Matamata is one of the largest training venues in the country, and that some of New Zealand's more successful trainers are based at this venue. Successful trainers generally have more opportunity to select horses for inclusion in their stables, and in particular to select high quality, more expensive horses than trainers with lower profiles or less success in major races. Differences in horse and trainer characteristics between the locations of interest may have acted as potential confounders in any attempt to determine an association between training location and measures of performance. In addition, other factors that could be contributing to these apparent venue effects include

differences in horse injury rates and severity, veterinary detection efficiency and treatment, availability and use of ancillary training facilities such as swimming pools.

Horses trained in Matamata were more likely to win or place in both time periods though the magnitude of the advantage to horses from Matamata declined in the 1998-1999 period compared to 1996-1997, most notably in the proportion of winners. Factors contributing to a decline in proportion of winners to starters include those associated with the starts themselves, trainer, horse, and training surface. Factors affecting starts in general would be expected to influence all starting horses and not primarily those from Matamata stables. Effects due to horse, trainer and track surface are confounded to varying degrees since horses were trained by one trainer during the study and each trainer was listed as training at one location. Investigation of proportions of wins and places for individual trainers residing at Matamata showed that the slight reduction in the proportion of winners to starters was a general trend across the majority of trainers and could not be attributed to the effect of any individual trainer. It is possible that a period of adaptation was necessary on the part of track management and trainers, to develop practices optimally suited to the new track, and that horse performance may have been affected while this was occurring.

It was not possible to directly measure any injury outcome from the electronic data used in this study. The use of a 6-month period without evidence of racing has been used previously as part of case definitions for serious injury in Thoroughbreds in USA (Mohammed et al 1991) and Australia (Bailey et al 1998). It is likely that this definition would overestimate injury rates because horses may be rested for prolonged periods for reasons other than injury, including seasonal preferences for racing on the part of the trainer/owner, voluntary periods of rest as determined by the trainer or owner, involuntary periods of recovery from conditions unrelated to track associated athletic injury (Estberg et al 1998), retirement from racing, and movement of horses overseas to continue their racing career. Because racehorses only generate income while training or racing there is a powerful economic incentive to maintain horses in training. In addition, a longer rest period must be followed by a more prolonged training period in preparation for resumption of racing. It seems reasonable to assume that a healthy horse that continues to eat well, maintain weight and behave normally under training conditions is likely to be kept in work longer and have shorter spell periods, and that

frequent or prolonged spell periods are more likely to be involuntary rather than voluntary.

Data from an ongoing longitudinal study following Thoroughbred racehorses in work in New Zealand showed that voluntary spells were the most common reason for interruptions to training and racing, accounting for 46% of all recorded spell periods (Perkins et al 2000). The median duration for voluntary spell periods was 60 days and this was exceeded by spell periods associated with fractures, tendon and ligament injuries, exercise-induced pulmonary haemorrhage and laryngeal conditions (Perkins 2001). A recent Australian study reported the median duration of weeks at rest from training for various musculoskeletal conditions such as tendon strain (35 weeks) and joint disease (12 weeks), in a study cohort of 169 horses followed for their 2- and 3-year racing careers (Bailey 1998). When combined with an estimated 3 months of training time required to bring a horse to race fitness after a prolonged spell, it is likely that these conditions would result in a 6-month no-race period in affected horses. This information supports the suggestion that many involuntary spells may be associated with no-race periods in excess of 6 months. However, the wide variation in reasons for interruptions to racing and in their duration suggests that caution must be exercised in interpreting results of analyses using indirect outcome variables such as the 6-month no-race period identified in this study.

When results were examined by trainer location and time period, horses from Matamata appeared to be less likely to have a 6-month no-race period after starting compared with horses from other locations. In addition, there appeared to be a small increase in the likelihood of a 6-month no-race period following a start between 1996-1997 and 1998-1999 for horses from all locations. There appeared to be no association between trainer location and likelihood of an individual start being followed by a 6-month no-race period. These unconditional associations indicate a lack of evidence for horses from Matamata being at higher risk of 6-month no-race periods in the 1998-1999 time period either in relation to that population in 1996-1997 or to horses from other locations.

Early studies in the United Kingdom suggested that between 23% and 62% of individual animals became lame enough to prevent training over the course of a 2-year study. In addition, between 21% and 38% of individual animals were reported to have respiratory conditions that were sufficiently serious to prevent training over the same time period (Rossdale et al 1985). More recently, More (1999) reported that about 30%

of 2- and 3-year olds ceased racing within 12 months of their first race and about 50% within 24 months. There was no distinction between losses due to poor performance, overseas movement of horses, and injury or illness. The longitudinal study in Australia conducted by Bailey (1998), reported that 19 horses (11%), were lost to follow up as a result of being exported to continue their racing careers overseas.

The descriptive results presented here provide information on data contained in NZTR records and also on the Thoroughbred racing industry in New Zealand, focussing on comparisons between horses trained in Matamata and those trained in other locations around New Zealand. Horses trained in Matamata were more likely to win or place than horses from other locations though this effect of location was diminished in the 1998-1999 period relative to the 1996-1997 period. There was no evidence of an increased risk of a 6-month no-race period for the horses trained in Matamata in 1998-1999 compared with those trained at other locations or those from Matamata in the earlier time period.

Acknowledgements

The authors gratefully acknowledge funding support from the New Zealand Equine Research Foundation, and NZTR for provision of data.

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Chapter 4

Effect of training location and time period on racehorse performance in New Zealand. II. Multivariate analysis *

*Published as: NR Perkins, SWJ Reid, RS Morris. *New Zealand Veterinary Journal*, 52, 243-249, 2004.

Abstract

AIM: To investigate training location (horses trained in Matamata vs those trained at all other venues in New Zealand), and time period (1996-1997 and 1998-1999), while controlling for other horse and race or trial related factors as a means of assessing the possible impact of construction of a new training surface at the Matamata Racing Club on indirect measures of racehorse performance (number of starts, and failure to race within 6-months of any start).

METHODS: Multivariate logistic regression and poisson analysis were used to analyse data derived using a retrospective cohort approach. Multivariate logistic regression was also used to analyse a case-control study. All data were derived from New Zealand Thoroughbred Racing, records of race and trial results for racehorses trained in Matamata and other venues in New Zealand, covering two 19-month time periods (1996-1997 and 1998-1999). Outcome variables included whether a horse started again in the 6 months following any start that occurred in the first 13 months of either time period, and a count of the total starts for every horse.

RESULTS: Factors associated with increased risk of a start being followed by a 6-month no-race period included training location other than Matamata in comparison to horses trained in Matamata in the 1996-1997 time period, increasing age, 1998-1999 over 1996-1997, starting in a trial rather than a race, placing fourth or worse in a start, softer track conditions, summer vs autumn, increasing cumulative exercise intensity in the 60 days prior to a start, and increasing race distance. Factors associated with an increase in the total number of starts included horses trained at Matamata in 1996-1997 compared with other time period-location combinations, younger age of horses at the time of a start, longer race distance, and an increasing proportion of starts in stakes races.

CONCLUSIONS: Official race and trial results data provided a valuable resource for epidemiological studies of factors influencing racehorse performance. Results of analyses performed here provided little evidence of any adverse impact of the new training surface at the Matamata Racing Club on indirect measures of racehorse performance.

Introduction

There is considerable interest in evaluation of risk factors that may be associated with athletic injury in racehorses. A high proportion of horses are lost from racing each year due mainly to lack of competitive ability and injury or illness. For mares and some stallions, movement from racing into breeding may result in a racehorse leaving racing while still competitive and successful. Export of racehorses to other countries is also a reason for loss to the local industry. Racehorses in New Zealand are a successful export product, particularly to Australia and Asia. While beneficial to the local economy, such exports do have a potentially adverse effect on racing in New Zealand. It has been suggested that total losses to racing each year represent about a third of the population of horses that race in a given year (Bourke 1990; More 1999). Such high wastage rates are placing increased pressure on the industry due to issues related to economic sustainability and animal welfare.

Increasing efforts have been made recently to identify factors associated with losses due to athletic injury and to develop risk management strategies to minimise these losses (Estberg et al 1996a, 1998; Kane et al 1998; More 1999; Hill et al 2001; Perkins 2001). Musculoskeletal injuries have been identified as the most common performance-limiting condition involving racehorses (Rossdale et al 1985; Bailey 1998; Hill et al 2001). As with many epidemiological studies there appear to be complex relationships among the large number of putative explanatory factors in such analyses and any outcome variable which is associated with athletic injury or loss of performance. Multivariate analyses permit simultaneous evaluation of a number of explanatory variables to examine their effects on an outcome variable, while also considering interaction terms and controlling for the effects of confounders.

Presented here are multivariate analytical approaches used to investigate the effect of training location and time period on outcome measures related to racing performance and athletic injury. Particular interest was focussed on one training venue in New Zealand, Matamata, following the development of a new, all weather training surface at that venue. Data derived from NZTR records were used as measures of racing performance and as indirect measures of possible athletic injury. Multiple analytical approaches were used in an attempt to add confidence to interpretation of the results.

Materials and methods

Data and results of descriptive, and simple univariate analyses have been described by Perkins et al (2004). Described here are the multivariate analyses conducted on the same datasets. Briefly, data were aggregated into two datasets, one containing details on 54,913 starts involving 7,611 horses in 1996-1997 and the other containing details on 55,730 starts involving 8,253 horses in 1998-1999.

Horse level variables included horse identity, birth date, gender (male, including colts and geldings, or female), trainer identity, and training location (Matamata or other). All Thoroughbreds in the Southern Hemisphere are deemed to have reached one year of age at 01 August in the 12-month period following their birth, thus horses age by one year at 01 August each year. Age in years for each horse was determined at 01 August 1997 for the 1996-1997 dataset, and 01 August 1999 for the 1998-1999 dataset. In addition, horse age in years at the time of a start was estimated at the date of each start for that horse.

Race-event level variables included race identity (a unique number for each race or trial), race date, race (race or trial), race type (flat race, steeplechase, hurdles), track (racetrack at which the race or trial was run), race number (number of the race during a race day), stakes ($< \text{NZ\$}25,000$ and $\geq \text{NZ\$}25,000$), distance, barrier number (1 - 6, 7 - 12, ≥ 13), weight carried, placing, number of starters, and track condition (firm, easy, soft, heavy). Track condition in New Zealand is classified on a 4-point scale reflecting increasing level of water content (firm, easy, soft and heavy). Measurements are taken at 10 - 30 locations around a track using a dynamic penetrometer to produce an objective measure on which to base track classification (Murphy et al 1996; Thomas et al 1996). Distance, weight carried and number of starters were continuous variables, and all other variables were treated as categorical. Three variables (race type, barrier number and weight carried) only contained data for official races and not for trials.

Statistical analysis

Cohort study

Cohorts were defined as horses trained at Matamata, and horses trained at any location in New Zealand other than Matamata (location = other). Candidates for the Matamata cohort were all horses from Matamata that had at least one start in the first 13 months of

either time period 01 May to 31 May. If a horse trained in Matamata had only one start in that period then that start was selected, but if it had multiple starts in the first 13-month period, one start was randomly selected for that horse. For each of these horses that was selected, a single horse from any other location was randomly selected from those horses in the same race event (race or trial), same age group (2, 3, 4, ≥ 5 years, estimated on the date of the selected race event), and same gender (male or female). This produced two cohorts, matched for age group, gender and start, and differing in location status. A binary variable was then generated called “race 6-month”, that took a value of zero if the horse started at least once in the 6 months following the date of the selected start and one if it did not start in this time period. This variable was used as the outcome variable. Two other variables were also generated by examining records for the 60 days prior to the selected start for each horse in the dataset. The first variable counted the number of starts made by each horse and the second the total race distance run (sum of race or trial distance for all starts made by each horse). These variables attempted to measure the cumulative racing intensity exercise burden for each horse. Identity of the matched pair was entered in all models as a random effect and additional random effects (trainer and track) were considered for inclusion in the model, based on assessment of the Akaike Information Criterion (AIC). All independent variables were added to the model as fixed effects and a backwards stepwise approach to model development used. Independent variables were retained in the model if the relevant Wald statistic was associated with a p-value < 0.1 . Biologically plausible first-order interaction terms were then added to the model containing significant main effect terms and retained only if they were associated with a significant Wald statistic. Restricted maximum likelihood estimation (REML) was used in SAS version 8.1 for Windows running the GLIMMIX macro with a logit link and binomial error function (Hosmer and Lemeshow 2000; Allison 1999).

Separate analyses were run on the matched dataset containing information from all starts (including races and trials), and also on a subset of data containing information only on races. The second dataset allowed consideration of those independent variables confined to races only (race type, barrier number and weight carried). None of these variables was associated with a significant effect and no results are presented from this analysis.

Case-control analysis

A case-control approach was used, and a case was defined as a start (race or trial) that occurred in the first 13 months of the time period, that was then followed by a period of at least 6 months in duration where the same horse did not start again (Mohammed et al 1991; Bailey 1998). Controls were starts in the first 13 months of the time period that were followed by the same horse having at least one more start in the next 6 months. A 1:1 matching of cases to controls was ensured by randomly selecting an equal number of controls from all the possible candidates. No further matching was performed. Variables considered for inclusion in the model were similar to those considered in the first logistic regression model.

Poisson regression

A cohort approach was used with the count of race or trial starts for selected horses as the outcome of interest. Cohorts were based on location status. All horses between the ages of 2 and 7 years that had started in at least one race or trial were considered for inclusion in this analysis. All eligible horses at Matamata were included and then matched on age and gender to a single horse from the "other" location. Where multiple matches were possible, a single matched horse was randomly selected. Because the unit of interest in this analysis was at the horse level, a number of derived variables were constructed to summarise start level data to the horse level. The outcome variable was a count of the number of starts for each selected horse. Average distance over all starts for each horse was estimated in units of 200 m. Dates for each start were used to generate the proportion of all starts for each horse that occurred in summer, autumn, winter or spring. A similar approach was used to generate the proportion of all starts for each horse that were on firm, easy, soft or heavy tracks, and the proportion of all starts that were in races with prize money \geq NZ\$25,000. All proportions were multiplied by 10 to make the unit of change 0.1. A four-level variable combining location and time period was created for inclusion in order to facilitate comparisons between stable location (Matamata vs other), and time period (1996-1997 and 1998-1999). Horse age changed over the 19 months of each time period, which allowed for comparisons of the effect of different ages but did not allow estimation of specific effects of a particular age. Analyses were performed using a negative binomial model, estimated by maximum likelihood, in PROC GENMOD, running under SAS, version 8.1 for Windows. Model

development was performed using a backwards stepwise approach. Factors were retained in the model if they were associated with a Wald statistic p -value < 0.05 with matching variables forced into the model. Model checking involved examination of likelihood ratio and deviance statistics and model residuals.

Results

Cohort study

Risk factors conditionally associated with a horse failing to start for a 6-month period following a randomly selected start are presented in Table 4.1. Horses racing in 1998-1999 were more likely to have a 6-month no-race period following a start than those racing in 1996-1997. The effect of training location on this risk was dependent on the placing of the horse in that start, as determined by the significant interaction term ($p=0.036$). Training location was therefore investigated at each level of placing. Horses that placed first, fourth or poorer than fourth (including horses that did not finish a race or trial), were more likely to have a 6-month no-race period following that start if they were trained at Matamata compared with other locations. Horses that were 2 years old at the time of a start were nearly three times more likely to have a 6-month no-race period following a start than horses that were aged ≥ 5 years. Horses starting in a race were less likely to have a 6-month no-race period than animals starting in a trial. Horses that placed poorer than fourth in a start were more likely to have a 6-month no-race period following that start than horses that placed first. Other placings were not different from first. Addition of random effect terms for trainer or track location did not improve the fit of the model based on assessment of the AIC, and these two factors were omitted from the final model.

Table 4.1. Risk factors conditionally associated with a horse failing to start for 6 months following a randomly selected race or trial start.

Variable	Case (n)	Control (n)	Coefficient	Standard error	P-value	Adjusted odds ratio	95% CI for odds ratio
Placing							
1st	44	196				1	
2nd	23	200	-0.71	0.58	0.22	0.49	0.16 - 1.53
3rd	21	181	0.08	0.50	0.88	1.08	0.41 - 2.86
4th	23	137	0.39	0.48	0.41	1.48	0.58 - 3.79
≥5th	266	925	1.06	0.37	0.004	2.90	1.41 - 5.94
Year							
1996-1997	184	806				1	
1998-1999	193	833	1.19	0.40	0.003	3.28	1.49 - 7.24
Age at time of start							
2 years	127	395				1	
3 years	98	480	1.07	0.30	0.0004	2.92	1.61 - 5.29
4 years	75	381	0.22	0.22	0.31	1.25	0.81 - 1.92
≥5 years	77	383	0.12	0.20	0.54	1.13	0.77 - 1.66
Race vs trial							
Trial	190	706				1	
Race	187	933	-0.31	0.14	0.02	0.74	0.56 - 0.96
Effect of location within each level of placing							
Placing = 1st							
Other	9	92				1	
Matamata	35	104	1.26	0.41	0.002	3.52	1.59 - 7.79
Placing = 2nd							
Other	5	103				1.00	
Matamata	18	97	0.55	0.86	0.52	1.74	0.32 - 9.43
Placing = 3rd							
Other	9	86				1.00	
Matamata	12	95	1.34	0.81	0.10	3.80	0.77 - 18.64
Placing = 4th							
Other	11	76				1.00	
Matamata	12	61	1.65	0.80	0.04	5.23	1.09 - 25.07
Placing ≥5th							
Other	126	491				1.00	
Matamata	140	434	2.32	0.74	0.002	10.20	2.4 - 43.41

Deviance of 1854.4 with 2000 degrees of freedom.

CI= confidence interval

Case-control study

Risk factors conditionally associated with a horse failing to start for 6 months following a randomly selected race or trial start are presented in Table 4.2.

Table 4.2. Risk factors conditionally associated with horses that failed to start in a race or trial for a 6-month period following a start.

Variable	Case (n)	Control (n)	Coefficient	Standard error	P-value	Adjusted odds ratio	95% CI for odds ratio
Location and year							
Matamata 1996-1997	176	262				1	
Other 1996-1997	1628	1436	0.394	0.113	0.0005	1.48	1.19 - 1.85
Other 1998-1999	1618	1680	0.228	0.113	0.04	1.26	1.01 - 1.57
Matamata 1998-1999	216	260	0.196	0.146	0.18	1.22	0.91 - 1.62
Gender							
Female	1589	1489					
Male	2049	2149	-0.200	0.052	0.0001	0.82	0.74 - 0.91
Season							
Summer	801	698					
Autumn	1199	1916	-0.728	0.074	<.0001	0.48	0.42 - 0.56
Winter	685	362	0.128	0.111	0.25	1.14	0.91 - 1.41
Spring	953	662	0.078	0.081	0.33	1.08	0.92 - 1.27
Placing							
1st	194	477					
2nd	199	427	0.115	0.127	0.37	1.12	0.87 - 1.44
3rd	189	436	0.068	0.127	0.59	1.07	0.83 - 1.37
4th	174	295	0.275	0.135	0.04	1.32	1.01 - 1.71
≥5th	2882	2003	1.248	0.095	<.0001	3.48	2.89 - 4.19
Track condition							
Easy	858	992					
Heavy	690	438	0.272	0.094	0.004	1.31	1.09 - 1.58
Soft	599	538	0.280	0.082	0.0007	1.32	1.13 - 1.55
Firm	1453	1647	-0.080	0.067	0.23	0.92	0.81 - 1.05
Race or trial							
Race	2552	2281					
Trial	1086	1357	0.344	0.066	<.0001	1.41	1.24 - 1.61
60 day distance ^a			0.022	0.003	<.0001	1.02	1.02 - 1.03
Race distance ^b			0.050	0.013	0.0002	1.05	1.02 - 1.08

Deviance of 8958.9 with 7196 degrees of freedom.

^a Cumulative distance over the past 60 days in official races or trials (1 unit change = 200 m)

^b Distance of selected race or trial (1 unit change = 200 m)

CI= confidence interval

The interaction between stable location and time period was significant and was assessed as a combined variable in the model to allow comparison between the horses from Matamata in 1996-1997 and those horses trained at either other locations or at the other time period. Horses residing at training stables in Matamata in 1998-1999 had no difference in risk of failing to race for 6 months following a randomly selected start when compared with the earlier time period. Horses trained at other locations were more

likely to have a 6-month no-race period in either the 1996-1997 (OR=1.48; 95% CI= 1.19 - 1.85) or 1998-1999 time periods (OR=1.26; 95% CI= 1.01 - 1.57). Gender of horse, season of the year, placing in a race or trial, track condition, and type of race (race vs trial) were significantly associated with the risk of a subsequent 6-month no-race period following a randomly selected start, and there was also an association with increasing distance for any individual race or trial. In addition, increasing cumulative distance run in races and trials during the 60 days prior to any individual start was associated with an increased risk of a 6-month no-race period following that start.

Poisson regression

Adjusted relative risk estimates for risk factors associated with the rate of race or trial starts in horses residing at different training locations and over different time periods are reported in Table 4.3. There was no difference between training location ($p=0.13$), or year ($p=0.8$), with respect to likelihood of a horse starting in a race or trial. The term coding for interaction between location and year was considered for inclusion in the model and was not statistically significant. As horse age increased, the risk of a horse starting in a race or trial was reduced (RR=0.83; 95% CI= 0.81 - 0.85). Increasing race or trial distance, and increasing proportion of starts that were stakes races were both associated with an increased likelihood of starts during the 19-month time period.

Table 4.3: Adjusted relative risk estimates for risk factors associated with the rate of race or trial starts in horses residing at different training locations and over different time periods.

Variable	Beta coefficient	Standard error (beta)	P-value	Adjusted relative risk	95% CI for relative risk
Location					
Other					
Matamata	-0.042	0.028	0.1317	0.96	0.91 - 1.01
Year					
1996-1997					
1998-1999	-0.007	0.028	0.7935	0.99	0.94 - 1.05
Gender					
Male					
Female	0.011	0.028	0.6801	1.01	0.96 - 1.07
Age (years)	-0.186	0.013	<.0001	0.83	0.81 - 0.85
Average race distance (200 m)	0.565	0.014	<.0001	1.76	1.71 - 1.81
Proportion stakes ^a	0.615	0.113	<.0001	1.85	1.48 - 2.31

Deviance of 3567.5 with 5229 degrees of freedom

^a Proportion of total starts that were stakes races (unit of change = 0.1)

Discussion

Described here is the use of existing race records to investigate the impact of development of a new training track on performance measures in racing Thoroughbreds in New Zealand. Results of analyses indicated that there were differences between the population of horses that were resident at Matamata and those at any other location in New Zealand. As with the companion paper (Perkins et al 2004), a major focus was in the interaction between time period and location. If there had been an adverse effect of the new training track surface on horse performance then a significant time period by location effect would be expected to be detected in the statistical models. Follow-up investigation would furthermore be expected to demonstrate that performance measures within the group of horses resident at Matamata had worsened from 1996-1997 to 1998-1999, or at least were different from any change in measures in horses resident at any other location over the same time period. However, there was no evidence that any change in the outcome measures investigated could be attributed to the new training track itself. Different analytical approaches produced consistent results.

There was a general effect of time period in all analyses in that the 1998-1999 period was associated with fewer races and trials and with a higher risk of horses having a 6-month no-race period after a start (Perkins et al 2004). There was a significant location

by time period interaction in the case-control analysis, with horses in the 1996-1997 time period and residing at other locations being more likely to have a 6-month no-race period following a start compared with horses in the same time period and located at Matamata. Neither location in the 1998-1999 time period was different for horses trained at Matamata in the 1996-1997 time period. In the cohort analysis there was a significant effect of the “location*placing” interaction that indicated horses located at Matamata that placed fourth or poorer in a start were more likely to have a subsequent 6-month no-race period than horses resident at other locations and placing the same. This analysis also reported a main effect of time period with horses in the 1998-1999 dataset being 3.3 times more likely to have a 6-month no-race period after any start compared with horses in the 1996-1997 dataset. These results indicated a general increase over time in the risk of a 6-month no-race period following a start, that applied to the entire racing population and not just to horses trained at Matamata. There did appear to be differences both in the population structure of horses resident at Matamata versus those residing at other locations (Perkins et al 2004), and also in performance measures for horses trained at the different locations. However, these differences were present in the population prior to the development of the new track (1996-1997 dataset), and therefore cannot be attributed to the new track itself.

Caution must be exercised when interpreting results of these analyses. Routine racing records maintained by NZTR were used for all analyses. These records are restricted to details concerning racetracks, individual races or trials, and the horses that started in each event. The database does not contain information concerning injuries. Two of the analyses involved a binary outcome variable indicating whether a horse had a start or not in the 6 months following any individual start. This definition has been used previously as an indirect indicator of serious injury in racing Thoroughbreds (Mohammed et al 1991; Bailey et al 1998). It is acknowledged that there are other possible reasons for a horse having a 6-month no-race period following a start, including reasons that are not necessarily associated with injury such as prolonged rest or retirement from racing. However, the use of a consistent criterion does lend itself to making studies comparable.

Performance and risk of injury in racing horses are influenced by a large number of factors interacting in a complex manner. A large number of putative risk factors have been identified in previous studies performed at locations around the world. In some

cases information on previously identified risk factors is routinely collected as part of the NZTR racing records, whilst in other cases variables were constructed that were similar to previously identified risk factors. The use of multivariate statistical techniques combined with the use of multiple analyses using different statistical methodologies has allowed investigation of the factors of interest while controlling for other possible risk factors.

Horse age was identified in two analyses as being significant, as 3-year-old horses had a higher risk of a 6-month no-race period following a start than did 2-year-olds. In addition increasing age of horse in the poisson analysis was associated with a reduction in the risk of racing. This finding is consistent with previous studies reporting an increased risk of injury with increasing horse age (Robinson et al 1988; Mohammed et al 1991).

Male horses were found to be less likely to have a 6-month no-race period following a start than female horses (Table 2). This is in contrast to a previous study performed in California that reported male horses were at twice the risk of female horses for suffering injury during training and racing (Estberg et al 1996b). Gender was not a significant risk factor in either the retrospective cohort or the poisson analyses in the current study.

Horses that placed towards the rear of the field or failed to finish the race, were more likely to have a 6-month no-race period following a start. A previous study in Kentucky reported that horses with racing injuries were more likely to finish a race in the last quartile of the field than would be expected by chance alone (Peloso et al 1994). Pre-existing pathological conditions may result in horses being unable to perform to their expected potential and have been reported to increase the risk of injury during a race (Cohen et al 1997). An Australian study reported that horses racing in stakes races (group and listed races) were more than twice as likely to suffer a musculoskeletal injury than horses starting in other races (Bailey et al 1997). Other researchers have reported no association between class of race and risk of injury (Peloso et al 1994; Estberg et al 1996b). The results of this study were not consistent with these findings, as a positive association was found between the proportion of starts that were stakes races (defined as a race with prize money \geq NZ\$25,000), and the number of starts completed by a horse during the study. It is possible that race quality or prize money may be proxies for one or more other risk factors such as intensity of training or racing history, race speed, or level of competitiveness. Horses starting in a trial were more

likely to have a subsequent 6-month no-race period than those starting in a race. This may simply reflect the fact that horses are trialled for a variety of reasons including exposure of horses to a race-like environment during training programmes. Further studies will be necessary to identify the relationships between some of these variables and measures of performance or injury.

The cumulative distance completed in races and trials in the 60 days prior to any one start was considered as a measure of racing speed exercise intensity. Increasing cumulative exercise history in the 60 days prior to a start was associated with an increased risk of a subsequent 6-month no-race period. Every 200 m of extra distance accumulated resulted in a 2% increase in risk of a 6-month no-race period. Previous studies in California have reported a similar relationship between cumulative distance completed in official races and trials in the 60 days prior to a start and the risk of serious injury during a trial or race (Estberg et al 1996a). In addition, the present study indicated that every additional 200 m of distance run in a race or trial was associated with a 5% increase in the risk of a horse having a subsequent 6-month no-race period. It was not possible to obtain more precise measurement of a horse's total high speed exercise intensity in this study because of the reliance on historical records. Many horses do complete portions of selected training sessions at race speed, or very close to it, and therefore the estimates of cumulative exercise intensity used in this study are likely to be an underestimate for any horse. It is considered likely that athletic injury in racehorses may be associated with cumulative effects of high intensity, overuse damage occurring over a period of time (Pool et al 1990; Stover et al 1992). Examination of historical racing patterns may provide information of use in identifying horses with either past conditions or excessive cumulative exercise intensity, allowing ongoing monitoring of possible risk factors for injury (Estberg et al 1998). Further investigation of such factors is currently being undertaken in a large prospective study in New Zealand.

Track condition was retained in the final model only for the case-control study, where softer track classification for a start was associated with increased risk of a subsequent 6-month no-race period. Bailey (1998) reported that horses racing on faster and harder track surfaces in Australia had a higher risk of serious musculoskeletal injury including fatalities, compared with horses racing on slower or softer track surfaces. Increasing track hardness has been associated with an increasing risk of lameness (Cheney et al

1973), and tendon strain (Rooney 1981). Several studies have reported no association between track surface condition and risk of injury though these studies involved horses racing predominantly on dirt tracks (Hill et al 1986; Mohammed et al 1991; Peloso et al 1994).

Forces exerted on a racehorse's musculoskeletal system during a race are modified by the hardness of the track surface and this might be expected to influence the risk of certain types of injury (Zebarth and Sheard 1985). Horses racing in autumn were less likely to have a subsequent 6-month no-race period than horses starting in summer. Seasonal effects may exert an action by influencing track hardness with tracks expected to be harder during summer than autumn though season is also likely to be confounded with both number of races on offer (more races in spring and summer compared with autumn and winter), and class of races (more stakes races in spring and summer). Therefore a seasonal effect on likelihood of a 6-month no-race period may partly reflect owner or trainer preferences for racing a particular horse in one or more seasons of the year rather than risk of injury.

NZTR records were used to generate a variable coding for training location based on the training venue recorded for each trainer, which was generally the closest to that trainer, and the major training venue used by horses trained by that trainer. Trainers are free to choose between training surfaces available at a training venue on any given day and they may also choose to train selected horses at alternative venues. It was not possible to identify the training track(s) on which any individual animal accumulated training distances at any intensity. Since many musculoskeletal injuries in horses are possibly the result of repeated micro-injury, it seems possible that training track surface and training exercise history may also act as risk factors for injury. Such effects may be confounded by effects due to trainers and other unexplained variables.

This study describes the use of multiple, different analytical approaches to test similar outcomes within the same datasets. Each approach employed different methods of sample selection and analysis. The results of all analyses were consistent, adding confidence to their interpretation. The findings of this study did not demonstrate any major detrimental impact of the commissioning of a new training track at Matamata in early 1998.

Acknowledgements

The authors gratefully acknowledge funding support from the New Zealand Equine Research Foundation, and NZTR for provision of data.

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Chapter 5

Profiling the New Zealand Thoroughbred racing industry. I. Training, racing and general health patterns *

* Published as: NR Perkins, SWJ Reid, RS Morris. *New Zealand Veterinary Journal*, 53(1), 59-68, 2005.

Abstract

AIM: To describe patterns in training, racing, and general health in a population of Thoroughbred racehorses in New Zealand.

METHODS: A longitudinal study was designed to collect data on horses training under the care of 20 selected trainers from 20 different stables and five regional training venues in the mid to lower regions of the North Island. Data were collected from trainers at approximately monthly intervals between October 1997 and July 2000, and electronic data containing race and trial results for all starts in New Zealand for the same time period were obtained from New Zealand Thoroughbred Racing. Summary statistics were used to describe patterns present in the data. Horse training days and study days were used as denominator horse time-at-risk for incidence rate estimations and counts of horses and events used to derive proportions and cumulative incidence estimates. Simple statistical comparisons were completed using parametric and non-parametric procedures.

RESULTS: Twenty trainers provided information on 1,571 horses, 554,745 horse study days, and 9,963 starts in official trials or races. Males comprised 50.2% of all horses. Although females contributed more study days for 2-, 3- and 4-year-olds, males contributed more study days in horses aged 5 years or older. Horses spent an average of 71% of their time in training and the remaining 29% in spell periods. Duration of training preparations and spell periods was associated with horse age and the reason for a spell. Most horses began a training preparation doing slow work and then progressively advanced to a first start by 68 days after the start of a training preparation. Incidence rate estimates for starts, training-days to first start, and training days between successive starts in the same preparation, are presented.

CONCLUSION: This study presents summary information profiling a population of training Thoroughbreds in New Zealand, and described their training, racing and health patterns.

Introduction

New Zealand has the fifth largest Thoroughbred breeding industry in the world. New Zealand Thoroughbred Racing (NZTR) statistics report the annual number of live foals born over a 21-year period (1982–2002) being 5,599, behind only the United States of America, Australia, Japan and Ireland. There are 71 Thoroughbred racing clubs throughout New Zealand, about 300 race meetings are held each race year (01 August to 31 July), approximately 5,500 horses started at least once in a trial or race in a 12-month racing season, and there are in excess of 32,000 horse-starts in any one year.

The last two decades have seen increasing awareness and interest in issues relating to racehorse health as a result of a higher public awareness of animal welfare issues and the direct and indirect costs associated with injuries and conditions that interfere with a horse's training and racing career.

The most common methodological approach to the study of racehorse health and injury has been to source existing industry records from centralised database records of training and racing activity, and injuries that resulted in death of the horse or prolonged absence from racing (Mohammed et al 1991; Estberg et al 1995, 1998; Cohen et al 1997; Bailey et al 1998). In contrast there are relatively fewer studies that have employed prospective methodologies to collect data on musculoskeletal injuries in racehorses, allowing estimation of incidence rates for various conditions (Jeffcott et al 1982; Rossdale et al 1985; Bailey et al 1999; Williams et al 2001), and there are no known previous investigations of the health and performance of racehorses in New Zealand. This paper describes the methodological approach applied in a large longitudinal study of these and presents descriptive results of patterns in training, racing and general health within a population of Thoroughbred horses trained in the North Island of New Zealand.

Materials and methods

Selection of trainers and horses

Twenty-four Thoroughbred trainers from the central and lower north island region of New Zealand were approached to participate in the study and 23 agreed to do so. Three trainers withdrew from the study within three months of commencement and data from these trainers were not included in any analyses. Trainers were progressively enrolled in

the study over a 15-month period from October 1997 to January 1999, and data collection ended on 31 July 2000, the last day of the 1999–2000 racing season. Trainers were from five regional training venues with each venue responsible for maintaining one or more training tracks for use by trainers.

Selected trainers represented a convenience sample of licensed, professional trainers that were enthusiastic about the project and likely to participate actively over a prolonged period of time. All trainers regularly used the services of veterinarians experienced in racetrack veterinary practice. Veterinarians that routinely attended each stable were contacted and all were supportive of the project and encouraged and supported the involvement of trainers under their care.

All horses trained by participating trainers were enrolled in the study, with data collection for each horse commencing on the day the horse entered the stable to begin training, and continuing until the study ended or the horse retired from racing, died, or changed to a trainer not participating in the study. New horses were enrolled in the study throughout the study period.

Data Collection and processing

The principal author was responsible for data collection and was aided by a research technician employed to assist in the study, and a veterinary nurse at a private practice that provided veterinary care for five of the trainers. All study personnel were familiar with the racing industry and enjoyed good relationships with trainers and their employees. The principal author provided training in data collection and closely supervised the activities of other study personnel. A custom designed questionnaire was designed to facilitate data collection and ensure that the same questions were asked in a standardized manner at every visit. Prior to a visit to a particular trainer, a copy of the questionnaire was printed for every horse recorded as being trained by that trainer. Questionnaires were horse-specific and contained summary information for that horse from the previous visit concerning training activity and any condition that had interfered with training. This ensured continuity of information and allowed study personnel to check new information against previous data while speaking with the trainer. A separate questionnaire was used to collect information on any horses that had entered the stable since the last visit and that were not already recorded in the database. Questionnaires contained information to identify the horse, and a series of questions to be answered

about activity and health in the period since the previous visit, including information on dates when the horse entered the stable and when any event occurred that interfered with training. Study personnel made visits to stables at approximately monthly intervals to collect data on all horses in the stable over the time period since the preceding visit. Depending on the number of horses within a stable, completing the questionnaire involved about 30 to 60 minutes of time per month from each participating trainer. Two trainers provided data by completing forms themselves with one of the authors (NRP) visiting both trainers at periodic intervals. This approach was adopted because these two trainers were 6–hours drive away from the author.

A customized database (Microsoft Access) was designed for entering and managing data collected during the study. Monthly data were collected on paper during stable visits and then entered into the database by the principal author or the study technician. Electronic data on official race and trial results for all horses starting in trials and races in New Zealand during the study period, were obtained from NZTR. These data were used to derive racing activity for all horses enrolled in the study, and to source birth dates for horses. Regular contact was maintained with all trainers via telephone or email to answer queries and obtain additional information if required.

A training activity score (TAS) was used to record the level of training activity achieved by each horse in the period between visits. The TAS definitions were developed following preliminary discussions with New Zealand trainers and were designed to follow terminology in common usage by professional trainers. TASs were defined as spell (TAS=1), walk or trot (TAS=2), activity up to but not exceeding a canter (TAS=3), fast work but not yet starting in a trial or race (TAS=4), and horses that had started in at least one trial or race since the last visit (TAS=5).

Horse age was determined in years based on the official 01 August birthdate for Thoroughbreds in New Zealand. Age data were aggregated in older categories because of the paucity of horses older than 5–years of age. Data on gender were aggregated to male and female. Horses younger than 2–years of age were only enrolled as they approached 01 August in the year they turned two, and when trainers announced an intention to retain them in work at least until they were galloping or ready to trial or race. For reporting purposes, these animals were classed as 2–year–olds.

Training preparations were defined as a time period when the horse was resident at the trainer's stable and was undergoing regular exercise as part of a training program in preparation to start in a trial or race. The reason a training period ended was recorded as an event occurring on the date the training preparation ended. Events marking the end of a training preparation included the onset of a spell >7-days in duration, retirement from racing, death of the horse, or removal of the horse from that stable to be trained by a different trainer not participating in the study. Events were classified as voluntary if the horse had no condition or disease that interfered with training, and involuntary if the event involved a condition or disease that forced the trainer to spell or retire the horse, or resulted in death of the horse. Voluntary events included voluntary spells where the horse subsequently returned to training, and retirements where the horse had no condition that interfered with training and the decision to retire the animal was completely dependent on the trainer and/or owner. Involuntary events were classified according to the body system involved: musculoskeletal, respiratory, and other, and specific information on anatomical location and diagnosis was collected where possible. Standardised definitions were used for musculoskeletal conditions. Conditions were classified as lameness if the horse had an abnormality of gait that prevented it from being exercised, and as a non-lame musculoskeletal injury if there was a detectable abnormality involving a musculoskeletal structure that prevented the horse from being exercised but did not result in gait abnormality. Respiratory events were recorded as upper respiratory tract obstructive disease, cough or nasal discharge, pneumonia, exercise induced pulmonary haemorrhage or other conditions. All trainers participating in the study utilized the services of an attending veterinarian on a regular basis, however not all diagnoses involved a veterinary examination. The decision to request a veterinary examination on any horse was made by the trainer in consultation with the owner of a horse. Results of descriptive statistics regarding voluntary and involuntary events are presented in a companion paper.

Classification of study time

Study time for each horse in a training stable was measured in horse-days, categorized as training-days or spell-days depending on whether the horse was in training or spelling from training. One week of training was counted as seven horse-training-days at risk of an adverse health outcome for a particular horse even though a horse in full training may not perform training activity every single day of the week. A training

preparation was defined as the cumulative sum of training–days starting from the day of enrolment or return to work from a spell, and ending with onset of the next spell or exit of the horse from the study. Interruptions to training were only coded as a spell–period if they exceeded seven consecutive days of no training. Duration of a Spell–period was defined as the cumulative sum of days starting from the first day that a horse did not train, and ending on the last day before the horse resumed training. Training interruptions up to 7–days in duration were counted as part of a training preparation. If a horse was spelled from training for a period ≤ 7 –days in duration during a training preparation, then the number of days spelled were recorded and identified as training days at TAS=1 in that preparation.

Individual horses were able to accumulate more than one training preparation during the study, with each successive training preparation separated by a spell period. Training preparations and spell periods were classified as complete or incomplete. Incomplete training preparations or spell periods involved horses that were in a training preparation or a spell period at the time data collection ended for that horse, either because the study ended, or the horse was moved to a different trainer not participating in the study. In these situations a valid end date was not recorded for the training preparation or spell period because the horse was lost to follow–up while still in either a training preparation or a spell. Complete training preparations and spell periods were those for which a valid start date and end date were known. All complete training periods had an event recorded as the reason for ending the preparation.

Statistical analysis

Continuous data that were non–normally distributed were summarised using median and percentiles, while normally distributed data were summarised using mean and standard deviation. Nominal data were presented as counts or percentages, with 95% confidence intervals where appropriate (Rothman 2002). Incidence rate and annual cumulative incidence estimates were generated for starts per 100 horse–training–days, and the proportion of horses in each age group in training in one season that returned to train in the following season.

Age and gender specific total study–, training–, and spell–days were estimated by aggregating data collected throughout the 34–month study period. The number of days

spent training by each age–class and gender was reported as a percentage of total study days recorded for that age and gender combination.

Minimum, maximum, median, 25th and 75th percentiles were reported for the duration of training preparations in days, with separate summaries for those training preparations ending in either voluntary–spells, musculoskeletal injury, conditions involving the respiratory system, miscellaneous events, retirement without any disorder, and incomplete training preparations. Similar summary data were reported for the duration in days of complete spell–periods associated with voluntary–spells, musculoskeletal injury or conditions associated with the respiratory system, and for incomplete spell periods.

Annual, age–specific, cumulative incidence estimates of retention within the racing industry were calculated as follows. The number of horses in each age class that had complete training preparations with start dates in either the 1997–1998 or 1998–1999 seasons, and that were not lost to follow–up for any reason, was used as a denominator. The number of horses from the denominator that appeared in a training preparation in the following 12–month racing season was used as the numerator. For example, the denominator for the annual, 2–year–old cumulative incidence of retention was the number of 2–year–old racehorses that started a complete training preparation in either the 1997–1998 or 1998–1999 racing seasons, and that were not lost to follow–up. The numerator was the number of horses from the denominator that had either incomplete or complete training preparations recorded in the 12–month period of the following season as 3–year–old racehorses.

Training activity scores at different days from the start of a training preparation were used to describe the pattern of increasing exercise intensity as the number of days increased from the start of a training preparation. The number of days from a start of a training preparation to the time of each visit was arbitrarily split into 7–day intervals for the first 14 days, and then 14–day intervals until 98–days after the start of a training preparation. The number of horses recorded at each TAS between 2–5 was recorded as a percentage of the total number of horses with TAS values recorded in each interval.

The sum of all training–days was used as time–at–risk to estimate incidence rates for starts in trials or races, reported as incidence of starts per 100–horse–training–days. Training–days were recorded by the month of year in which they occurred and by age of

the horse, to allow incidence rate estimates to be generated for each month of the year and for different age groups of horses.

The number of days from the beginning of a training preparation to the first start was summarised for the 2,295 training preparations in which at least one start occurred. These data appeared to be normally distributed on initial examination and estimated summary statistics therefore included the mean, standard deviation and range. Data from a more restricted subset of 1,871 training preparations that involved more than one start in a trial or race were then used to estimate minimum, maximum, median, 25th and 75th percentiles for the number of days between successive starts within the same preparation.

One-way analysis of variance or Kruskal–Wallis tests were used to compare continuous summary measures for different age groups if the data were normally or non-normally distributed, respectively, with t-tests or Mann–Whitney tests used to compare different groups in follow-up tests. Summary measures for continuous outcomes for male and female horses were compared using t-tests or Mann–Whitney tests for normally or non-normally distributed, respectively. Chi-squared tests were used to assess the effect of age or gender on outcomes derived from count data. All statistical tests employed SPSS version 12 for Windows (SPSS[®], Chicago, Illinois, USA) and an alpha level of 5%. If there was no significant effect of gender then data were aggregated for summary purposes, otherwise data were reported as age and gender specific summary measures.

Results

Twenty trainers provided data to the study until they either retired from training (n=1), moved overseas (n=2), or the study concluded (n=17). The 20 trainers represented 5.5% of a total of 363 licensed trainers recorded in NZTR records as of October 1999 (Anonymous 1999).

A total of 1,571 horses were enrolled in the study, comprising 783 females and 788 (50.2%) males. A total of 46 horses were enrolled twice and one horse three times as a result of moving to the stable of another trainer participating in the study. These records were treated as independent for the purposes of analysis and reporting. The 1,571 horses enrolled in the study completed a total of 3,333 training preparations, and 980, 503, 191, 66, 16, five and one animals completed a second, third, fourth, fifth, sixth, seventh, and eight training preparation, respectively. Successive training preparations within the

same horse were separated by a spell period. The number of complete and incomplete training preparations was 2,640 and 693 respectively. Data were collected on a total of 2,097 spell periods, and 323 of these represented incomplete spell periods.

Table 5.1. Number of horses contributing study days in each age group by gender, and numbers of spell, training and study days contributed. Data drawn from a total of 1,571 horses over 34 months (1997 to 2000). Individual horses could contribute days to more than one age group.

Age (yrs)	Female				Male				Total study days
	n	Spell days	Training days	Study days	n	Spell days	Training days	Study days	
2	349	33,085	56,768	89,853	326	29,124	52,624	81,748	171,601
3	375	26,588	65,635	92,223	327	23,069	60,785	83,854	176,077
4	234	13,911	43,046	56,957	206	13,576	39,536	53,112	110,069
5	88	3,772	14,923	18,695	120	7,025	24,385	31,410	50,105
6	26	848	4,653	5,501	67	4,062	12,720	16,782	22,283
7	11	282	1,825	2,107	33	2,378	6,485	8,863	10,970
8	5	102	429	531	13	1,430	3,138	4,568	5,099
9	1	15	116	131	14	1,252	2,015	3,267	3,398
10	0			0	4	627	668	1,295	1,295
11	0			0	2	223	248	471	471
12	0			0	2	424	88	512	512
Unknown	8	146	922	1,068	9	516	1,281	1,797	2,865
Total	1,097	78,749	188,317	267,066	1,123	83,706	203,973	287,679	554,745

Summary information on study days, training days and spell days contributed by horse gender and age group are shown in Table 5.1. Although the total number of horses enrolled in the study was 1,571, individual horses contributed days to more than one age group if they remained enrolled in the study during more than one racing season. Two-year-olds accounted for 28% and 31% of total training days and study days, respectively, whereas 3-year-olds accounted for 32% and 32%, respectively. Females provided a significantly higher proportion of total study days than males in 2-, 3- and 4-year-olds, and males provided more study days than females in horses aged 5 years

or older ($p < 0.001$). Within females the proportion of study days spent in training was significantly different between each age group ($p < 0.001$), with horses aged 5 years and older spending the highest proportion of study time in training. Within males there was a similar progressive increase in the proportion of study days spent in training as age increased from 2- to 4-years with each age group different to the other two groups ($p < 0.001$). However, there was no difference in the proportion of study days spent training between 4-year old males and those aged 5-years and older (Table 5.2; $p = 0.14$). Within each age group there was also a significant effect of gender on proportion of study days spent training, and 2- and 3-year-old males spent proportionally more time training and less time spelling compared with females ($p < 0.001$), while males aged 4- or 5-years and older spent proportionally less time training and more time spelling compared with females of the same age ($p < 0.001$).

There were 314, 132, and 79 horses in the 2-, 3-, and 4-year olds, respectively, that had complete training preparations in either the 1997–1998 or 1998–1999 racing seasons, and that were not lost to follow-up. Age-specific cumulative incidence of retention in training for these horses in the following season when they were one year older, was 68.8% ($n = 216$), 55.3% ($n = 73$), and 46% ($n = 36$), respectively for horses entering their 3-, 4- and 5-years and older age groups.

Table 5.2. Percentage of study days spent training by gender and age, with 95% confidence intervals (95% CI). Totals represent data aggregated over all ages within each gender, and include data from horses of unknown age. Data based on 1,571 horses over 34 months of study as presented in Table 5.1.

Age (yrs)	Training days			
	Female		Male	
	(% of study)	95% CI	(% of study)	95% CI
2	63.2	62.9 – 63.5	64.4	64.0 – 64.7
3	71.2	70.9 – 71.5	72.5	72.2 – 72.8
4	75.6	75.2 – 75.9	74.4	74.1 – 74.8
≥5	81.4	80.1 – 81.8	74.1	73.7 – 74.4
Total	70.5	70.3 – 70.7	70.9	70.7 – 71.1

Summary measures for the 3,333 training preparations are reported in Table 5.3, categorised by the event type marking the end of a training preparation. The median, 25th and 75th percentiles for the 2,640 complete training preparations were 107, 68, and 161 days, respectively. A total of 21 training preparations involved horses of unknown age. The median duration of training preparation in days was not different in males compared with females for those training preparations that ended in a voluntary spell ($p=0.2$), MSI ($p=0.7$), respiratory ($p=0.9$), or miscellaneous events ($p=0.9$), or horses that retired without any disorder ($p=0.7$).

Training preparations ending in voluntary spells were longer in duration than those ending in MSI for 3-, 4- and 5-years and older age groups ($p<0.001$), longer than preparations ending in respiratory system disorders in all age groups ($p<0.05$), and longer than preparations ending in miscellaneous events in 2- and 4-year-olds ($p<0.05$).

Table 5.3. Minimum, maximum and quartiles for duration in days of complete training preparations classified by reason for ending the preparation.

Preparation ending in	Age (yrs)	n	Percentiles of duration (days)				
			minimum	25	50	75	maximum
Voluntary spells	2	537	1	51.5	81	112	305
	3	363	7	95	135	182	444
	4	185	16	128	181	236	365
	≥5	147	17	128	186	251	362
	Unknown	2					
Musculoskeletal system injury	2	288	1	51	77	105	263
	3	256	1	55	92	137	303
	4	139	1	70	127	172	270
	≥5	136	2	65	123	183	460
	Unknown	5					
Respiratory system disorder	2	51	10	23	59	91	192
	3	52	12	64	84	156	265
	4	28	14	89	154	200	278
	≥5	34	14	81	147	193	258
Miscellaneous disorder	2	12	7	43	58	71	106
	3	22	35	71	146	194	357
	4	14	8	85	116	138	273
	≥5	9	17	109	172	276	457
Retirement without any disorder	2	17	7	66	88	105	148
	3	131	11	75	116	155	349
	4	114	15	103	134	190	457
	≥5	88	45	101	146	204	347
	Unknown	10					
Incomplete: lost to follow-up while in a training preparation	2	236	1	31	61	89	274
	3	215	1	61	107	164	425
	4	122	1	43	101	173	427
	≥5	116	1	71	142	190	415
	Unknown	4					
Total		3,333	1	63	104	160	460

Preparations ending in voluntary spells were not different to those ending in MSI in 2-year-olds ($p=0.007$), or to those ending in miscellaneous events in horses aged 3-years ($p=0.7$) or 5-years and older ($p=0.8$). Preparations ending in MSI were longer in duration than those ending with either a respiratory system ($p=0.007$) or miscellaneous event ($p=0.03$) in 2-year-olds, and shorter than preparations ending in a miscellaneous event in 3-year-olds ($p=0.01$). There was no difference in preparation duration for those preparations ending in retirement without any disorder compared with those ending in MSI in 2-year-olds ($p=0.6$), respiratory events in any age group ($p>0.05$) and miscellaneous events in 3-, 4- and 5-years and older age groups ($p>0.05$). Preparations ending in retirement without any disorder were shorter than those ending in voluntary spells, and longer than those ending in MSI, for 3-, 4- and 5-years and older age groups ($p<0.01$), and longer than those ending in a miscellaneous event in 2-year-olds ($p=0.01$).

Summary measures for duration in days of spell periods, are presented in Table 5.4, categorised by type of event marking the end of the previous training preparation. Spells resulting from conditions involving the musculoskeletal, respiratory or other body systems (miscellaneous category) accounted for 58,029, 7,984 and 1,840 horse days, respectively, while voluntary spells accounted for 94,602 days. There was no effect of gender on duration of voluntary spells ($p=0.1$), spells associated with musculoskeletal injury ($p=0.78$), respiratory system ($p=0.6$), or those associated with miscellaneous conditions ($p=0.9$), so estimates were re-calculated over all horses regardless of gender.

Table 5.4. Minimum, maximum and quartiles for duration of spell periods in Thoroughbred horses, in days for voluntary spells and spells associated with musculoskeletal injury, respiratory system disorder or miscellaneous disorders. Data restricted to complete spell periods only and arranged by age of horse in years.

Category of spell	Age (yrs)	n	Percentiles of duration (days)				
			Minimum	25	50	75	Maximum
Voluntary	2	406	10	38	64	98	320
	3	294	8	30	55	97	282
	4	193	8	27	58	105	306
	≥5	150	8	27	60	97	294
	Unknown	2					
Associated with musculoskeletal injury	2	200	8	28	50	89	245
	3	204	9	28	61	104	417
	4	101	9	28	71	130	470
	≥5	74	9	35	74	148	379
	Unknown	2					
Associated with respiratory system disorder	2	40	8	27	44	88	175
	3	41	8	21	36	84	168
	4	17	10	35	65	81	181
	≥5	20	9	16	31	132	276
Miscellaneous disorders	2	8	16	20	21	85	139
	3	9	11	18	29	42	119
	4	11	9	17	52	78	109
	≥5	2	14	16	18	20	22
Incomplete: lost to follow-up while in a spell	2	120	8	41	73	128	329
	3	102	10	51	94	152	484
	4	60	16	41	79	128	455
	≥5	39	8	50	61	144	538
	Unknown	2					
Total		2097	8	31	62	105	538

Age group had no association with duration of voluntary spells ($p=0.2$), or with spells associated with respiratory system ($p=0.47$), or miscellaneous disorders ($p=0.7$), and the median duration of spell estimated without regard for age was 61, 39 and 26 days, respectively for voluntary, respiratory system-associated, and miscellaneous spells. There was a significant difference between age groups in the median duration of a spell associated with musculoskeletal injuries ($p=0.004$). Spells associated with musculoskeletal injury in 2-year-olds were shorter than those in 3-year ($p=0.03$), and 4-year-olds ($p=0.025$), and horses aged 5 years or older ($p=0.001$). There was no difference between genders ($p=0.1$) or age groups ($p=0.5$) with respect to the duration of incomplete spell periods, though the overall median duration of incomplete spell periods was significantly longer ($0<0.001$), than all other categories of spell period.

Table 5.5 shows the TAS scores for horses at different intervals of time from the start of a training preparation. The proportion of horses at lower TAS scores was higher in the earlier period of a training preparation and declined as the duration in days from the start of the training preparation increased. The proportion of 2-year-olds training at TAS=4 or 5 was significantly lower than all other age groups at 15–28, 29–42, and 43–56 days after the beginning of a training preparation ($p<0.05$), and was lower than 4-year and ≥ 5 -year-olds at 1–14 days ($p<0.05$), and than 3-year and 4-year-olds at 71–84 days ($p<0.05$).

Of the 1,571 horses contributing data to the study, a total of 1,309 horses started at least once in a trial or race, for a cumulative total of 9,963 starts. Race starts accounted for 7,261 (73%) of the total starts and the remaining 2,702 starts occurred in official trials under the jurisdiction of the NZTR. The number of starts associated with first, second, third, fourth, and fifth or worse placing were 1,347 (13.5%), 1,304 (13.1%), 1,211 (12.2%), 893 (9%), and 3,935 (39.5%), respectively. A total of 1,008 horses finished in the first three places in at least one of their starts during the study period, and these animals represented 77% of all horses that started at least once. The minimum number of starts recorded for an individual horse over the entire study period was 1, and the median and maximum were six and 38, respectively.

Figure 5.1 shows the total number of training days accumulated by each age group categorised by month of year. In May, June and July, the proportion of 2-year training

days contributed by horses that were officially one year of age and due to turn 2-years on 01 August, was 6%, 21% and 24%, respectively, while for all other months of the year it was less than 3%.

Table 5.6 shows the incidence rates for starts per 100 horse-training-days by month of year and age group. Peak monthly start rates occurred in March (2-year-olds), April (3-year-olds), May (4-year-olds), and November (5-years and older).

Male horses aged 3-years were more likely to win ($p= 0.002$), or place ($p= 0.006$) compared with females in the same age group, while males aged 5 years or older were more likely to win than females in the same age group ($p= 0.002$). There were no differences between males and females in any other age groups with respect to race results.

The number of training-days from the beginning of a preparation to the first start in a race or trial was not different between any age groups (Table 5.7, $p=0.7$). For those training preparations that were associated with more than start there was a progressive reduction in the median number of days between successive starts as age increased and each age group was significantly different to all other age groups (Table 8, $p<0.01$).

Table 5.5. Percentage of horses observed at each level of training activity score (TAS) within different intervals of time in days from the start of a training preparation. The count of horses contributing data in each interval is given in the last row.

TAS score	Days from start of preparation to observation of TAS score								
	1 – 7	8 – 14	15 – 28	29 – 42	43 – 56	57 – 70	71 – 84	85 – 98	>98
2	83.1	77.6	52.2	31.9	24.1	12.0	12.4	2.4	5.1
3	9.2	12.9	23.5	24.2	17.3	10.2	14.3	1.2	1.7
4	7.1	8.0	19.0	32.3	34.1	42.6	20.9	38.8	6.9
5	0.6	1.5	5.3	11.6	24.5	35.2	52.4	57.6	86.3
Count of horses (n)	326	714	664	545	220	176	105	85	117

Table 5.6. Incidence rate (IR), and 95% confidence intervals (95% CI), for starts per 100 horse–training days by month of the year, and horse age in years as determined on the day of a start.

Month	Horse age								Total	
	2 yrs		3 yrs		4 yrs		≥5 yrs			
	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI
January	1.15	0.94 – 1.4	2.94	2.62 – 3.29	3.54	3.11 – 4.02	3.81	3.31 – 4.36	2.71	2.36 – 2.71
February	1.18	0.96 – 1.43	2.06	1.78 – 2.36	2.60	2.22 – 3.04	2.40	2.01 – 2.84	1.97	1.81 – 2.13
March	2.11	1.83 – 2.42	2.71	2.41 – 3.04	2.96	2.57 – 3.38	2.68	2.30 – 3.11	2.57	2.16 – 2.57
April	2.10	1.8 – 2.44	3.42	3.06 – 3.81	3.74	3.29 – 4.24	4.10	3.61 – 4.65	3.25	2.45 – 3.25
May	1.88	1.6 – 2.21	3.38	2.99 – 3.81	4.89	4.34 – 5.49	4.52	3.97 – 5.12	3.47	2.72 – 3.47
June	0.91	0.75 – 1.1	2.97	2.59 – 3.38	3.90	3.37 – 4.50	4.44	3.88 – 5.07	2.50	2.32 – 2.50
July	0.62	0.51 – 0.74	1.69	1.43 – 1.97	2.17	1.79 – 2.60	3.23	2.75 – 3.77	1.41	1.30 – 1.53
August	0.35	0.22 – 0.53	1.17	0.99 – 1.38	1.48	1.23 – 1.76	2.35	2.02 – 2.72	1.34	1.23 to 1.47
September	1.04	0.8 – 1.32	2.47	2.21 – 2.76	2.97	2.62 – 3.36	3.59	3.16 – 4.06	2.54	2.13 – 2.54
October	1.37	1.1 – 1.68	2.87	2.58 – 3.18	3.72	3.32 – 4.17	4.27	3.79 – 4.80	3.04	2.18 – 3.04
November	1.32	1.06 – 1.62	3.09	2.78 – 3.43	3.90	3.46 – 4.38	4.57	4.03 – 5.16	3.15	2.37 – 3.15
December	1.32	1.08 – 1.6	3.09	2.77 – 3.43	4.09	3.64 – 4.59	4.28	3.75 – 4.87	3.06	2.33 – 3.06
Total	1.22	1.16 – 1.29	2.62	2.53 – 2.71	3.29	3.16 – 3.41	3.63	3.50 – 3.78	2.54	2.49 – 2.59

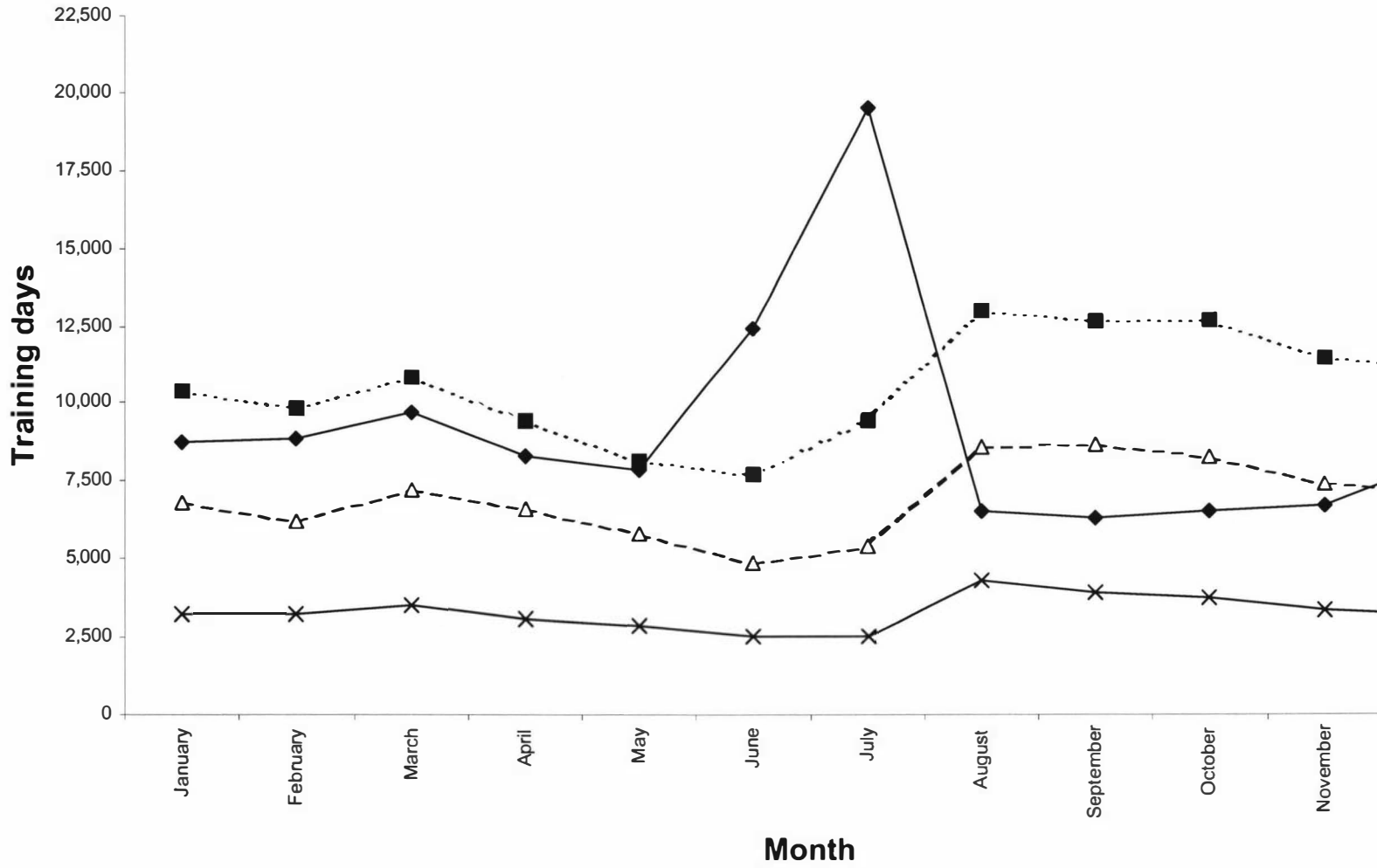


Figure 5.1: Total training days accumulated by month of the year in Thoroughbred horses aged 2 (◆), 3 (■), 4 (△), and ≥5 (×) years.

Table 5.7. Summary information for days to first start in a trial or race for 2,465 training preparations in which at least one start took place. SD= standard deviation.

Age (yrs)	n	Mean	95% CI		SD	Minimum	Maximum
			Lower	Upper			
2	555	70.0	67.6	72.4	29.0	3	186
3	791	67.8	65.3	70.1	32.2	0	243
4	504	66.9	64.2	69.7	31.5	0	174
≥5	445	68.4	64.9	71.9	37.6	0	218
Total	2,295	68.3	66.9	69.6	32.5	0	243

Table 5.8. Minimum, maximum and percentiles for the number of days between starts in the same training preparation for horses of different ages. Age was determined on the day of each start for any horse. Data limited to 1,871 training preparations associated with more than one start during the preparation, for a total of 9,539 starts.

Age (yrs)	Starts (n)	Percentiles of days between starts				
		Minimum	25th	Median	75th	Maximum
2	1,011	2	14	20	26	127
3	3,075	2	14	19	24	154
4	2,649	2	12	16	22	124
≥5	2,804	2	10	14	21	161
Total	9,539	2	13	17	23	161

Discussion

This paper has presented results from a large scale, epidemiological study of the horse racing industry in New Zealand and describes patterns of health and performance. Trainers that participated in the study were not randomly selected, and therefore may not have been a representative sample of the population of professional trainers in New Zealand. The trainers were selected as a convenience sample from five regional training venues in the North Island of New Zealand. Important considerations in selection of trainers included the enthusiasm of the trainer for the project given the demands

imposed by the prolonged duration of the study period, and proximity of trainers to the study personnel.

Information collected during the course of the longitudinal study was contributed by trainers and not by veterinarians. While this practice ensured that information was collected from the persons responsible for managing training activity and making decisions regarding training or spelling of horses, it also increased the potential for misclassification bias particularly regarding events that resulted in the end of a training preparation. This is discussed in more detail in the companion paper. A number of steps were implemented in an attempt to ensure that data collected had good internal validity. The questionnaire was designed with standardised definitions and predominantly closed questions, and contained summary information about the horse from previous visits. The design of the questionnaire remained the same and every visit was conducted in the same way throughout the study. An explanatory guide to the study was discussed in person with every trainer at the beginning of the study and periodic reports were provided to trainers through the study period. The definitions for training activity score were developed in consultation with trainers by adapting definitions of training speed that were in common use by trainers in New Zealand. All veterinary practices that provided veterinary services to the trainers participating in the study were also visited to discuss the study and copies of all reports were sent to veterinarians. Telephone calls and additional visits were made on occasion to trainers and to veterinarians to discuss aspects of the study and collect additional information.

The longitudinal study design was well suited to the horse racing industry and there was constant movement of horses into training stables to begin training, and out of stables to spell or exit from the racing industry during the study period. More (1999) has reported that 71% and 46% of horses were still racing 12- and 24- months after their first start, indicating that there was a high rate of turnover of horses in the Australian racing industry. We expected similar rates of turnover of horses in the New Zealand racing industry and adopted a study design that allowed continued enrolment of new horses throughout the study period in order to offset these losses. A relatively long study period was chosen to allow data to be collected from horses with injuries or conditions requiring prolonged spell periods to complete recovery and return to training. The dynamic nature of training and an open study design meant that individual horses contributed varying amounts of time to the study. Time-at-risk was therefore best

represented by the number of days contributed by each horse to training preparations or spell periods, and outcome measures such as incidence rates and cumulative incidences were adopted. The longitudinal design was considered preferable to case-control or cross section studies in describing patterns in the industry and arriving at valid causal inferences regarding putative risk factors.

This paper contains descriptive results and bivariate statistical comparisons. A companion paper reports results for voluntary and involuntary events associated with spell periods or that resulted in horses either dying or retiring from racing. Additional analyses are being completed to apply multivariate statistical procedures to these data in order to examine risk factors for musculoskeletal injuries in racehorses.

This study demonstrated that the training population was dominated by young horses aged 2- and 3-years, and females contributed more study days than males until 5-years of age, when males began to dominate. Asian countries have demonstrated an increasing demand for New Zealand-bred racehorses over the past decade and the majority of horses exported to Asia in recent years have been younger than 5-years of age, and male. In addition, there may be associations between gender and factors influencing the likelihood of horses entering training in New Zealand, or risk of occurrence of conditions that may interfere with training. The dominance of males in the population of training horses aged 5-years or older was considered due in part to females exiting the training population to begin a breeding career. Fewer male than female horses have breeding potential and there was likely to be increased interest in training and racing a gelding for longer periods of time compared with mares.

In addition, 2- and 3-year-old males appeared to spend a higher proportion of study time in training than females while females aged 4-years or older spent a higher proportion of study time in training than males. The discrepancy in younger horses may have represented an association between gender and conditions interfering with training (Estberg et al 1996; Cohen et al 1999), or with a trainer's decisions to spell horses. The observed difference in older horses was consistent with the hypothesis that older females were more likely to be retired for breeding than spelled and brought back into work.

Examination of race-day records obtained from NZTR over three consecutive seasons (1997-1998, 1998-1999, 1999-2000) for all starts in New Zealand indicated that 2-

year-olds accounted for 10% of all horse starts and 3-year-olds for 25%. These results highlight a discrepancy of interest between NZTR records of horses that have started in one or more trials or races, and data collected from trainers during the longitudinal study described in this paper. Our longitudinal study results indicated that 2- and 3-year-olds were responsible for 31% and 32% of total study days, and 28% and 33% of training days, respectively. The discrepancy was consistent with the hypothesis that a number of 2-year-old horses train but do not start in a trial or race. A study performed in New Zealand and limited to the use of NZTR records of trial and race results would therefore potentially under represent the study contribution from 2-year-olds and presumably over represent the contribution from older horses. More research is required to explain the reasons for this apparent discrepancy. There may be fewer racing opportunities for 2-year-old horses, or trainers may purposefully train 2-year-olds in a different manner to older horses. These findings also suggest that studies aiming to extrapolate results to the population of racehorses that are in training, may be subject to selection bias if they only source data from racing industry records of horses that have started in trials or races. It is also possible that the discrepancy was due to inadvertent biases in selection of the convenience sample of trainers enrolled in this study.

Age of horse appeared to play an important role in explaining some of the variability for a number of outcomes measured in the study, and most notable differences were apparent between 2-year-olds and horses older than 2-years. Two-year-olds spent fewer days and a lower proportion of study time in training preparations than older horses. They took longer to advance from TAS scores of 2 on entry into training to 5 when compared with older horses, had a longer interval from the beginning of a preparation to their first start in a trial or race, longer interval between starts than older horses, and had the lowest incidence rate of starts per 100 horse-training-days of all age groups. There was an age-associated increase in training preparation duration from 2- to 4-years of age that occurred regardless of the reason for ending a training preparation. These characteristics supported the hypothesis that trainers manage younger horses and in particular 2-year-olds, in a slightly more conservative fashion than older horses. However, they may also have reflected differences in susceptibility to injury or other conditions interfering with training, tolerance of horses to the stresses of stabling and training, and variation in racing opportunities according to horse age. The combination of shorter-duration spell periods associated with musculoskeletal injuries

(Table 4), and lower TAS during training preparations, may also reflect a trainer's decision to spell 2-year-olds in response to any indication of injury and then return them to work relatively quickly. It is also likely to reflect age-associated variation in training objectives, as 2-year-olds appeared to spend more time than older horses working at low exercise intensity simply to become accustomed to stable routines and to track work, without any specific athletic achievement goals.

While there appeared to be an age-associated increase in training preparation duration between the ages of 2- to 4-years that then levelled off for older horses, there was little association between age and spell-duration other than a decline in length of spells due to MSI in older horses relative to 2-year-olds. The median voluntary spell duration of 61 days for all ages was consistent with a two-calendar month spell period being the basis for trainer preferences on spell duration. Differences in spell duration for different categories of event were likely to reflect trainer perceptions regarding the time required for horses to recover from respiratory conditions as opposed to MSI or conditions involving other body systems such as colic or skin disorders for example. Further information is required to understand the factors that may influence spell period duration including whether decisions regarding spell duration are made at the beginning of a spell or depend on monitoring of horse-related variables during the spell.

Duration of training preparations and spell periods were important outcomes in the present study, and were based on identifying start and end dates for each type of activity. Start and end dates for complete training preparations were considered to have high validity because trainers were accustomed to recording when horses entered and left their stables for invoicing owners and for monitoring activity of horses under their care. Incomplete training periods were the result of horses that were in a training preparation at the time the study ended, and a small number of horses that were moved by their owner to a different trainer while in full training. Since events such as MSI and disorders of the respiratory or other body systems were only recorded if they marked the end of a training preparation, then all preparations associated with events were complete. There was more potential for bias in recording duration of spell preparations and in assigning the duration recorded to the event that marked the end of the preceding training preparation and the beginning of the spell period. During a spell horses were typically under the care of the owner and not the trainer and decisions may have been made regarding a horse's status without the trainer being aware. For example a horse

may have started a spell as a result of a MSI and the owner may have continued to spell the horse after recovery from the MSI for other reasons including seasonal, climatic, racing opportunities, personal reasons, or a decision to retire the horse from racing. Although every attempt was made to closely monitor spell periods by asking trainers at every visit about those horses recorded as spelling from that stable, it was possible that trainers were not aware of a change in the status of a particular horse.

TAS levels were used as a measure of increasing exercise intensity. Definitions created for this study were kept simple and incorporated clear gait changes (trot versus canter or gallop for example), or a dichotomous distinction based on whether a horse had started in a trial or race. Definitions were partly based on discussions with trainers in order to use terms that trainers were familiar with during the data collection phase. TASs on horses at different intervals after the beginning of a training preparation showed that almost all horses entered each training preparation doing slow work, and gradually progressed over time through more intensive exercise until animals were ready to start in a trial or race. It was common for horses to receive pre-training exercise at a facility other than the trainer's stable, prior to a horse returning to the trainer's stable to commence a preparation. Data were not collected on pre-training because these activities took place at different locations from the training stables and were under the supervision of different individuals. Horses that began a training preparation at higher TAS included horses that had been pre-trained up to TAS of 3 or 4 prior to resuming work in the trainer's stable, and horses that changed trainers while at TAS of 3, 4 or even 5. The proportion of horses working at TAS of 4 or 5 increased in a linear fashion for the first 8 weeks of a training preparation, particularly for 2- and 3-year-olds, and older horses showed a period of more rapid progression between 4 and 8 weeks into a preparation. The rate of increase in the proportion of horses working at TAS 4 or 5 appeared to plateau after Week 8, a time that was temporally related to the first start in a trial or race. These patterns appeared to reflect age-specific variation in the way trainers managed horses and a general desire to have a horse start in a trial or race within 2- to 3-months after beginning training.

The number of horse-training-days per month of the year reached a nadir in winter with minimum values around June for all age groups other than 2-year-olds. The dramatic rise in 2-year-old training days in winter was partially explained by the entry into training for the first time of a number of horses that were not officially 2-years-old

until 01 August of that year. The remainder of this rise was associated with other 2-year-olds that either returned to training or entered training for the first time in the last three months before they officially turned 3-years of age. The progression of horses from one age group to the next at 01 August appeared to be an important contributor to the rise in age group training days observed across all age groups between July and August.

The variation in monthly incidence rates for starts per 100 training-days was attributed in part to constraints imposed on availability of starting opportunities, dictated by race dates that are in turn determined by committee and not necessarily by horse associated factors. It is noteworthy that 2-year-olds accounted for 28% of training days, and 13% of starts compared with 3-year-olds (32% and 33%), 4-year-olds (21% and 27%), and horse aged 5-years and older (18% and 26%), respectively. Starts per 100 training days may be considered as a measure of work efficiency or return on trainer investment, and 2-year-olds represented the most inefficient group of horses by this measure. Starts per 100 training days rose as horses aged, and peak rates were attained in the oldest age group. This was not necessarily related to stakes earning potential or exposure to group or listed races because many of the high prestige and high stakes value races held each year have been purposefully focussed towards younger age groups of horses.

The mean number of days to the first start in an official trial or race was remarkably consistent across all age groups and appeared to identify a common desired goal amongst trainers of having a horse start in a trial or race by the end of the 10th week of a training preparation. Horses that started on the first day of a training preparation represented those animals that had been transferred from one trainer to another while in full training, and occasionally horses that had been pre-trained by a non-licensed trainer right up to race fitness. The increase in start incidence as horses age was reflected in the observed decline in median days between starts from 20 days in 2-year-olds to 14 days in horse aged 5 years or older.

In conclusion, this study has provided summary information on training, racing and general health patterns in Thoroughbred racehorses in the North Island of New Zealand. Although limited to simple comparisons and descriptive statistics, the paper has contributed to the identification and prioritisation of issues facing the racing industry in New Zealand.

Acknowledgements

The authors gratefully acknowledge funding support from the New Zealand Equine Research Foundation, and NZTR for provision of data. The assistance of Ms Dagmar Fikken in collection of data is also acknowledged, as is the commitment and assistance of veterinarians, track managers, trainers and their staff.

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Chapter 6

Profiling the New Zealand Thoroughbred racing industry. II. Conditions interfering with training and racing *

* Published as: NR Perkins, SWJ Reid, RS Morris. *New Zealand Veterinary Journal*, 53(1), 69-76, 2005.

Abstract

AIM: To describe and enumerate conditions that interrupted training and racing in a population of Thoroughbred racehorses in New Zealand.

METHODS: A longitudinal study design was used to collect data on horses training under the care of 20 participating trainers from venues in the mid to lower regions of the North Island between October 1997 and July 2000. Incidence rates were reported for first and second occurrences for different categories of musculoskeletal injury (MSI), and first occurrences of upper and lower respiratory tract disease, using training–days as time–at–risk. The proportion of horses that retired or died due to MSI, respiratory tract or miscellaneous conditions was used to estimate risk of exit for each type of event. Duration of training preparation, starts per 100 training–days and proportion of starts that ended in first, second or third place, were calculated for horses at risk for first MSI, and all subsequent MSIs. In training preparations that had at least one start and that ended in MSI the cumulative percentage of MSIs by day of diagnosis was reported for 0–21 days after the last start in the preparation.

RESULTS: 1,571 horses were followed during 3,333 training preparations and 392,290 training days. Events associated with the end of a training preparation or spell period included musculoskeletal injury (MSI, n=834), respiratory event (RE, n=165), miscellaneous event (ME, n=58), and voluntary retirements (n=360). Causes of MSI included lameness (n=400), shin soreness (n=207), tendon and ligament conditions (n=98), injury or laceration (n=56), fractures (n=55), and back disorders (n=18). MSIs involved the limbs in 97% of cases, and the lower limbs up to the carpus or hock in the fore– and hindlimbs, respectively, in 81% of cases. Most (93%) lower limb conditions involved a forelimb while 70% of MSIs that involved structures above the carpus or hock, involved a hindlimb. Incidence rates are reported for each age group for first and second occurrences of MSI, and first occurrence of upper and lower respiratory tract disease. The risk of MSI in horses was higher in horses that had incurred one previous MSI (RR 1.4, 95% CI 1.2–1.7, $p < 0.001$) than in horses without any previous MSI. The proportion of horses that exited due to death or retirement varied with the type of injury, and the highest proportion was associated with recurrent fractures, and tendon and ligament injuries (46.2 and 44.4%, respectively). The overall incidence rate of horses exiting the study due to retirement or death increased with increasing age, and was

higher in females than males for horses aged 2-, 3-, 4- years, and ≥ 5 -years-old. A reduction in the number of starts per 100 training-days was observed in horses aged ≥ 5 -years when returning to training after an initial MSI ($p = 0.004$). Male horses of all age groups and females younger than 4-years had shorter median training preparations ($p < 0.05$), when returning to training after an initial MSI compared with preparations at risk for a first occurrence of MSI. Between 27 and 62% of MSI cases that occurred in training preparations after at least one start, were reported on the day of the last start, and the remainder were reported in the days to weeks following the last start of that preparation.

CONCLUSION: Incidence rates, and proportions of affected horses that retired or died as a result of injury or disorder varied with type of injury and age of horse. Horses returning to training after an initial MSI were at higher risk of subsequent MSI, and showed changes in duration of training preparations but little change in starts per 100 training-days or probability of placing in each start. MSIs in racing horses were less likely to be reported on the day of a race than at other times in the training preparation for all ages except 2-year-olds.

Introduction

All forms of intensive athletic endeavour place stresses on the athlete's musculoskeletal system and horse racing is no exception. The musculoskeletal system of the horse has an inherent ability to adapt to the demands of high speed exercise though if a threshold in adaptive capacity is exceeded then some form of damage to the structures of the musculoskeletal system may result (Young et al 1991). Continued or extreme insult may overwhelm the repair and adaptation process and place the horse at risk of more serious and symptomatic musculoskeletal injury (Pool and Meagher 1990; Stover et al 1992). Injuries incurred during training and racing have direct costs associated with medical or surgical care, and time lost from racing, as well as potential for adversely affecting public perception. Improvements in the understanding of risk factors are necessary to facilitate the development of preventive and protective recommendations for track managers, trainers, and riders in the future.

Few studies of the health and injury of racehorses have employed prospective methodologies to collect data on musculoskeletal injuries (Jeffcott et al 1982; Rosedale et al 1985; Bailey et al 1999; Cohen et al 1999; Williams et al 2001). Studies performed

in a variety of countries have indicated that broad patterns of injuries in racing Thoroughbreds are similar, and the most common type of condition interfering with training and racing is MSI involving the lower forelimb (Ueda et al 1993; Peloso et al 1994; Cohen et al 1997, 1999; Williams et al 2001). There also are regional differences in risk for specific types of injury for example the most common MSI in racehorses in Britain involved tendons and ligaments of the lower forelimb (Williams et al 2001), while in the United States of America (USA) the most common injury involved the proximal sesamoid bones of the lower forelimb (Peloso et al 1994). Differences between studies may reflect regional differences in racetrack composition, race characteristics, training methods, horse populations and variation in study design and case definition.

No previous investigation of the health and performance of racehorses in New Zealand has been reported. Measures of frequency of occurrence of different types of injuries or other disorders and their impact on health and performance are considered vital to the understanding of issues facing the racing Thoroughbred industry, and in the prioritisation and subsequent development of approaches aimed at reducing or eliminating risk factors contributing to such conditions. Therefore the objective of this study was to describe injuries or other disorders that interfere with racing and training in a population of training Thoroughbreds in New Zealand.

Materials and methods

Selection of trainers

Details of the study design have been presented in a companion paper (Perkins et al 2005). Data on horse health and training activity were collected at approximately monthly intervals over a 34-month period from 20 participating trainers at five regional training venues in the mid to lower regions of the North Island of New Zealand. Trainers represented a convenience sample of licensed professional Thoroughbred trainers in New Zealand and were selected based on their willingness to collaborate over a prolonged time period, and proximity to study personnel.

Data collection

A custom designed questionnaire was used to collect data from trainers on training activity and injuries or disorders that interfered with training and racing.

A training preparation was defined as the time period beginning when a horse entered a participating stable to begin training, and ended with an event marked by the beginning of a spell >7-days in duration, retirement from racing, death of the horse, or removal of the horse from that stable to be trained by a different trainer not participating in the study. Events marking the end of a training preparation were classified as voluntary if the horse had no injury or disorder that interfered with training, and involuntary if the event involved an injury or disorder that forced the trainer to spell or retire the horse, or resulted in death of the horse. Voluntary events (VE) included voluntary spells and retirements where the horse had no injury or disorder that interfered with training. Involuntary events were classified according to the body system involved: musculoskeletal, respiratory and miscellaneous (all other systems), and specific information on anatomical location and diagnosis was collected. Standardised definitions were used for MSI with lameness defined as an abnormality of gait that prevented a horse from being exercised, and a MSI not associated with lameness as a detectable abnormality involving a musculoskeletal structure that prevented the horse from being exercised but did not result in gait abnormality. Respiratory events were classified as upper (obstructive airway disease, cough or nasal discharge), or lower (pneumonia, exercise induced pulmonary haemorrhage), respiratory tract disease. Involuntary events that occurred while a horse was spelling for another reason were recorded also and identified as occurring during a spell and not during a training preparation. The outcome for every event was recorded as exit from the study associated with retirement or death, or spell.

All trainers regularly used the services of veterinarians experienced in racetrack veterinary practice, however not all diagnostic information recorded during the study involved a veterinary examination of the horse involved. The decision to request a veterinary examination on any horse was made by the trainer in consultation with the owner of the horse. Detailed information on veterinary involvement in examination and diagnosis of racehorses was obtained from nine of the trainers over a 12-month period during the longitudinal study period.

Classification of study time

Study time was measured in horse-days, categorized as training-days or spell-days depending on whether the horse was in training or spelling from training. Interruptions to training were only coded as a spell period if they exceeded seven consecutive days in

duration. Horses were identified as lost to follow-up if they were in a training preparation or spell period at the time the study ended, or if they were transferred to another trainer not participating in the study during a training preparation or spell period.

Statistical analysis

MSIs were aggregated into categories for summary purposes and counts and proportions of MSIs presented by anatomical location and category. Information on veterinary involvement in MSIs was obtained for 165 cases from nine trainers and was summarised as the proportion of cases in each MSI category where a veterinarian made the diagnosis.

Age and gender-specific summary statistics were calculated for most variables. Incidence rates (IR) and 95% confidence intervals (CI) for first occurrence MSI and RE that occurred during training and racing were calculated using horse-training days as a measure of time-at-risk (Rothman 2002). First occurrence incidence rates were estimated by dividing the number of individual horses affected by the sum of horse-training-days at risk. Affected animals only contributed training-days to time-at-risk until the date of first occurrence of each event type. Unaffected horses contributed training-days to time-at-risk until they either exited the study or the study period ended. Relative risk (RR) estimates were generated for selected comparisons by dividing one IR by another.

The incidence rate of second MSI in the population of horses that were diagnosed with a first occurrence MSI was calculated by dividing the number of horses diagnosed with a second MSI by the sum of horse-training-days accumulated from the time a horse returned to training after the initial MSI, to the onset of a second MSI or until the horse exited the study or was lost to follow-up. Incidence rate ratios were calculated for each injury type by dividing the IR associated with second occurrence of a MSI by the IR associated with the first occurrence of the same injury type to produce a relative risk (RR) of second injury in those horses that had already incurred an initial injury.

The proportion of events that resulted in exits was calculated by dividing the number of individual horses that exited the study due to each event type by the total number of events of that type. For MSI this was repeated for first occurrence events and all subsequent events to produce cumulative incidence estimates of risk of exit for different

types of event. Exits attributable to different events were represented by the sum of retirements and deaths resulting from each event type.

Age and gender-specific incidence rates for exits from racing were calculated by dividing the number of individual horses that exited the study within each age and gender combination by the total number of training-days at risk for each combination.

Training preparations were divided into those preparations at risk for first occurrence of MSI, and those at risk for all subsequent occurrences of MSI. Preparations at risk for first occurrence of MSI included all preparations for horses never diagnosed with MSI, and training preparations up to and including the preparation that ended in the first occurrence of MSI for affected horses. Training preparations at risk of subsequent MSI included all preparations observed in horses that returned to training after a first occurrence of MSI. Median duration of training preparation in days, incidence rate of starts per 100 training-days, and proportion of starts resulting in a place (first, second or third position at finish of a trial or race), were estimated for the two categories of training preparation for each combination of age group and gender. Statistical comparisons used Kruskal Wallis and Mann Whitney tests for non-normally distributed data, chi-squared tests for count data, and parametric tests (t-test, ANOVA), for normally distributed data. All statistical comparisons employed an alpha level of 5%. Data were entered in a custom designed Access database and analysed using SPSS, version 12 for Windows (SPSS® Chicago, Illinois, USA).

Results

Summary statistics describing the population of training horses and their training and racing patterns were presented in the companion paper (Perkins et al 2005).

There were a total of 2,652 voluntary and involuntary events observed during the study. Voluntary events included 1,234 voluntary spells and 360 cases where horses retired from racing without any injury or disorder. Involuntary events included 834 MSI, 165 respiratory events (RE), and 59 miscellaneous events (ME). The number of events organised by category and outcome is presented in Table 6.1. A total of 555 horses exited the industry during the study, 26 due to death and the remaining 529 due to retirement from racing. Of the 555 exits, 360 (64.9%) were associated with voluntary retirement (no injury or condition that interfered with training), and 137 (24.7%) with MSI. The proportion of MSIs, respiratory and miscellaneous causes of all involuntary

events were 78.8%, 15.6%, and 5.6%, respectively, and indicated that MSIs were the most important reason for involuntary interruptions to training and racing.

Table 6.1. Data from 2,652 events in Thoroughbred horses associated with death or retirement or the onset of a spell period, each event marking the end of a training preparation or spell period. Exit percentage represents the percentage of total events associated with death or retirement.

Event	Spell	Outcome		Total	Exit %
		Exits			
		Death	Retirement		
Voluntary	1,234	0	360	1,594	22.6
Involuntary					
Musculoskeletal	697	19	118	834	16.4
Respiratory	128	0	37	165	22.4
Miscellaneous	38	7	14	59	35.6
Total	2,097	26	529	2,652	20.9

Most events occurred during training preparations. However, there were 12 events recorded as occurring while the horse was already out spelling for another reason. Ten cases involved MSI while the horse was spelling, one a horse lost to follow-up because the lease expired on the animal while it was spelling, and another a horse which died from a systemic infection while spelling for an unrelated reason.

MSIs were classified into six categories for reporting with 400, 207, 98, 56, 55, and 18 animals diagnosed with lameness (non-fracture), shin soreness, tendon and ligament injury, injury or laceration, lameness (fracture) and back disorders, respectively. Of the 834 MSIs, a total of 807 (96.7%) involved the limbs and the remainder involved conditions of the vertebral column (n=26) and skull (n=1). Detailed information on the anatomical location of limb-associated MSIs was available for 728 (87.3%) cases, and 610 (81%) of these involved lower limb structures between the foot and carpus, inclusive, in forelegs, or foot and hock, inclusive, in hindlegs. The remaining 118 MSIs involved structures in the upper limbs, above the carpus or hock.

Data on forelimb vs hindlimb were available for 751/807 cases, of which 612 (81.5%) involved forelimbs. Of the 610 conditions that involved the lower limbs, 563 (92.3%) involved the forelimbs only, 28 (4.6%) involved the hindlimbs only, three (0.5%) involved all four limbs, and 16 (2.6%) where it was not known if they involved the forelimb or hindlimb. In contrast, the 118 upper limb lesions (excluding back, pelvis

and head), included 82 (69.5%) in hindlimbs, 26 (22%) in forelimbs and 10 (8.5%) in which the site of the lesion was unknown.

Veterinarians were responsible for 100% of diagnoses associated with fractures, 69% of non-fracture cases of lameness, 87% of injuries and lacerations, 65% of tendon and ligament injuries, 50% of cases of back disease, and only 8% of cases of shin soreness. When aggregated over all MSI events, veterinarians were responsible for 89/165 (54%) of the diagnoses for injuries and conditions involving the musculoskeletal system.

Table 6.2 shows the estimated IRs for different categories of MSI. Overall, the highest IRs were observed in 2-year-olds, and the lowest in 4-year-olds. Shin soreness was more common in younger than older animals and RR values indicated 2-year-olds were 2.7 (95% CI 1.9–3.9, $p < 0.05$), 7.8 (95% CI 4.1–14.9, $p < 0.05$), and 25.9 (95% CI 8.2–81.8, $p < 0.05$) times more likely to be diagnosed with shin soreness than 3-, 4-, and ≥ 5 -year-olds, respectively. In contrast, tendon and ligament injuries were more common in older animals, and ≥ 5 -year-olds were 6.3 (95% CI 2.8–14.2, $p < 0.05$), 4.5 (95% CI 2.3–8.7, $p < 0.05$), and 2.1 (95% CI 1.2–3.7, $p < 0.05$), times more likely to be diagnosed with tendon and ligament injuries than 2-, 3-, and 4-year-olds, respectively. Gender had an effect on the risk of MSI for tendon and ligament injuries and non-fracture cases of lameness only. Male horses were more likely to incur tendon and ligament injuries (RR 2.5, 95% CI 1.5–4.3, $p < 0.05$), and less likely to incur non-fracture cases of lameness (RR 0.7, 95% CI 0.5–0.8, $p < 0.05$), compared with females.

Incidence rates and CI for second MSI in horses that had returned to training after an initial injury, are reported in Table 6.3. For each MSI category the pattern of change in IR in different age groups of horses was similar to that observed for first occurrence MSI, and lameness (non-fracture) was more common in young animals while tendon and ligament injury was more common in older animals. Comparing the overall IR for first vs second occurrence MSI indicated that the incidence rate of a second MSI in those horses that had already recovered from the first MSI, was higher than that of the first MSI (Table 6.4, RR 1.5, 95% CI 1.2–1.7, $p < 0.05$). The risk of lameness (non-fracture) was significantly elevated for horses entering training after an initial MSI compared with those animals prior to their first MSI ($p = 0.001$), and there was a non-significant tendency for elevation in risk for shin soreness and injury or laceration ($p < 0.1$).

Outcomes for first injury cases of MSI, and all subsequent cases, are presented in Table 6.5. The highest proportion of exits in both the first injury group and re-injury cases occurred in horses diagnosed with fracture injuries (42.9% and 46.2%, respectively), while the proportion of tendon and ligament injury cases that resulted in exits from the study was 41.7% and 44.4% in first occurrence and re-injury cases, respectively.

Of the 165 cases of respiratory tract disease observed during the study, 122 (74%) involved the upper respiratory tract, and included 25 cases of obstructive airway disease, and 97 cases of bacterial or viral infectious conditions. There were 43 cases of lower respiratory tract disease, and these included 38 cases of exercise induced pulmonary haemorrhage, and 5 cases of pneumonia. No fatalities were observed as a result of respiratory disease, and the percentage of cases of disease in the upper and lower respiratory tracts that led to retirement of the horse as a result was 58% and 10%, respectively. Incidence rates and confidence intervals for the first occurrence of upper and lower respiratory tract disease cases are presented in Table 6.6. Upper respiratory tract disease appeared to be more common than lower respiratory tract disease.

The number of horses that exited the study as a result of MSI, respiratory (RE), miscellaneous (ME), and voluntary events (VE) is displayed in Table 6.7. There was an increase in the incidence of exits as age increased that appeared to be more noticeable in females than in males and within each age group, females had a higher incidence of exits than males ($p < 0.01$).

Of the 834 MSI events, 500 (60%) occurred in training preparations after the horse had started in at least one race or trial, and the remaining 334 either in spell periods ($n=10$, 1.2%), or in training preparations where the horse had not yet started in a trial or race ($n=324$, 38.8%). Of the 500 events occurring in training preparations after at least one start, a total of 202 (40.3%) were reported on the same day as the start, an indication that injury had occurred during the race. A further 61 events were reported in the next 3 days, bringing the total to 263 (52.5%) that were reported within 3 days of a start. Figure 6.1 shows the cumulative percentage of 500 cases of MSI relative to the day of reported diagnosis after the last race or trial start. Data indicate variation in time of reporting by age group and 62.2% of cases of MSI reported in 2-year-olds were reported on the day of the last start. This contrasts with 38%, 26.7% and 29.7% in 3-, 4-, and ≥ 5 -year-old horses, respectively.

The 26 deaths reported during the study period included six horses euthanased as a result of injuries incurred during a race or trial, 19 horses that died or were euthanased during a training preparation but not as a result of any event associated directly with a race or trial, and one death that occurred as a result of systemic infection in a horse being spelled for another reason. Nineteen fatalities involved MSI, and these included 15 catastrophic fractures of the lower limb resulting in euthanasia, two had tendon injury or breakdown necessitating euthanasia, and two had chronic injury (navicular disease and carpal arthritis) resulting in euthanasia. All six fatalities that occurred during a race or trial involved fractures of the lower limbs, and the remaining nine fatal fractures were sustained during training. Fatalities that occurred during a training preparation and not associated with the musculoskeletal system included sudden death (n=3), cardiac disease (n=2), and one horse euthanised as a result of abnormal behaviour associated with aggression.

Summary measures of training and racing performance are presented in Table 6.8 for training preparations up to the first MSI (including all preparations that ended for reasons other than MSI), and those training preparations occurring in horses after an initial MSI. Preparations that occurred after the first MSI were shorter in duration than those occurring up to the first MSI, for all except female horses aged ≥ 4 -years. Incidence of starts per 100 training-days was lower in male horses aged ≥ 5 -years after the first MSI compared to preparations up to the first MSI. There was a tendency for the proportion of first, second, or third placings per start to be higher in 3-year-old males after the first MSI compared to preparations up to the first MSI ($p=0.052$).

Table 6.2. Age-specific incidence rate (IR) estimates per 1,000 training-days, and 95% confidence intervals (CI) for categories of musculoskeletal injuries in horses. Estimates were based on first occurrence of each injury, and horses contributed training-days at risk either to the day of first occurrence or until they were lost to followup. Data based on 595 cases of musculoskeletal injury (MSI) during 311,046 training-days.

MSI category	Age (years)								Total	
	2		3		4		≥5			
	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI
Lameness (non-fracture)	1.29	1.06 – 1.57	0.82	0.66 – 1.03	0.75	0.56 – 0.99	0.64	0.46 – 0.87	0.89	0.79 – 1.0
Lameness (fracture)	0.12	0.06 – 0.23	0.16	0.09 – 0.26	0.11	0.04 – 0.22	0.14	0.06 – 0.26	0.14	0.1 – 0.18
Shin soreness	1.19	0.97 – 1.46	0.44	0.32 – 0.59	0.15	0.07 – 0.28	0.05	0.01 – 0.13	0.50	0.42 – 0.58
Tendon and ligament injury	0.09	0.04 – 0.18	0.12	0.06 – 0.21	0.26	0.15 – 0.42	0.55	0.39 – 0.76	0.23	0.18 – 0.29
Back disorder	0.04	0.008 – 0.11	0.02	0.003 – 0.07	0.06	0.02 – 0.16	0.06	0.02 – 0.16	0.04	0.02 – 0.07
Injury or laceration	0.19	0.1 – 0.31	0.14	0.08 – 0.24	0.06	0.02 – 0.16	0.05	0.01 – 0.13	0.12	0.08 – 0.16
Total	2.92	2.56 – 3.22	1.71	1.46 – 1.99	1.39	1.12 – 1.71	1.49	1.21 – 1.81	1.91	1.76 – 2.07

Table 6.3. Age-specific incidence rate (IR) estimates per 1,000 training-days, and 95% confidence intervals (CI) for second occurrence of musculoskeletal injury (MSI) in horses. Data restricted to training preparations observed in horses resuming work after an initial MSI. Horses contributed training days at risk either to the day of second occurrence or until they were lost to followup. Data based on 169 MSI cases during 60,749 training days.

MSI category	Age (years)									
	2		3		4		≥5		Total	
	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI
Lameness (non-fracture)	2.14	1.34 – 3.24	1.46	1.0 – 2.06	1.00	0.56 – 1.66	0.97	0.52 – 1.66	1.35	1.07 – 1.68
Lameness (fracture)	0.19	0.02 – 0.7	0.14	0.03 – 0.4	0.13	0.02 – 0.48	0.22	0.05 – 0.66	0.16	0.08 – 0.30
Shin soreness	2.14	1.34 – 3.24	0.50	0.25 – 0.9	0.33	0.11 – 0.78	0.22	0.05 – 0.66	0.69	0.5 – 0.93
Tendon and ligament injury	0	0 – 0.36	0.23	0.07 – 0.53	0.54	0.23 – 1.05	0.37	0.12 – 0.87	0.30	0.18 – 0.47
Back disorder	0	0 – 0.36	0.05	0.001 – 0.25	0.13	0.02 – 0.48	0.07	0.002 – 0.42	0.07	0.02 – 0.17
Injury or laceration	0.49	0.16 – 1.14	0.18	0.05 – 0.47	0.13	0.02 – 0.48	0.15	0.02 – 0.54	0.21	0.11 – 0.37
Total	4.96	3.7 – 6.53	2.55	1.93 – 3.31	2.27	1.58 – 3.18	2.02	1.33 – 2.94	2.78	2.38 – 3.23

Table 6.4. Relative risk (RR) and 95% confidence intervals (CI) for second musculoskeletal injury (MSI) in those horses that returned to training after any initial MSI.

MSI category	RR	95% CI	P-value
Lameness (non-fracture)	1.52	1.18 – 1.94	0.001
Lameness (fracture)	1.22	0.61 – 2.43	0.7
Shin soreness	1.39	0.99 – 1.95	0.07
Tendon and ligament injury	1.28	0.76 – 2.15	0.42
Back disorder	1.58	0.51 – 4.83	0.64
Injury or laceration	1.85	0.98 – 3.48	0.08
Total	1.45	1.23 – 1.72	< 0.001

Table 6.5. Numbers of musculoskeletal injury (MSI) cases, deaths and retirements, for each category of injury, in 595 cases of first occurrence of MSI, and 239 cases of recurrent MSI, in Thoroughbred horses. Exits were estimated as the number of deaths plus the number of retirements divided by the total number for each MSI category.

MSI category	First MSI occurrence				All subsequent MSI occurrences			
	Number	Death	Retirement	% Exit	Number	Death	Retirement	% Exit
Lameness (non-fracture)	277	0	38	13.7	122	2	20	18.0
Lameness (fracture)	42	12	6	42.9	13	3	3	46.2
Shin soreness	155		4	2.6	52	0	0	0.0
Tendon and ligament injury	72	1	29	41.7	27	0	12	44.4
Back disorder	13		2	15.4	5	0	1	20.0
Injury or laceration	36	1	1	5.6	20	0	2	10.0
Total	595	14	80	15.8	239	5	38	18.0

Table 6.6. Age-specific incidence rate (IR) per 1,000 training-days, and 95% confidence intervals (CI) for first occurrence of disease in the upper and lower respiratory tracts that resulted in spells in Thoroughbred horses. Data based on a total of 142 cases of respiratory disease reported during 282,232 training-days at risk.

Respiratory tract category	Age (years)								Total	
	2		3		4		≥5			
	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI	IR	95% CI
Upper	0.62	0.46 – 0.83	0.42	0.29 – 0.58	0.25	0.14 – 0.42	0.15	0.07 – 0.29	0.38	0.31 – 0.46
Lower	0.01	0.0003 – 0.07	0.07	0.02 – 0.15	0.15	0.07 – 0.29	0.32	0.19 – 0.51	0.12	0.09 – 0.17
Total	0.64	0.47 – 0.84	0.49	0.35 – 0.66	0.41	0.26 – 0.60	0.48	0.32 – 0.69	0.5	0.42 – 0.59

Table 6.7. Numbers of horses exiting the study by gender and age group due to musculoskeletal injury (MSI), miscellaneous (ME), respiratory (RE), and voluntary events (VE). Incidence rate (IR) and 95% confidence interval (CI) estimates for all exits combined within each gender by age group used total training–days for that gender by age group as the denominator. Data from 544 horses of known age that exited the study prior to its completion.

Gender	Age (yrs)	Reasons for exit from the study				Total	IR	95% CI
		MSI	RE	ME	VE			
Female	2	9	1	1	14	25	0.44	0.29 - 0.65
	3	23	9	4	91	127	1.93	1.61 - 2.30
	4	20	4	4	76	104	2.42	1.97 - 2.93
	5+	21	2	4	51	78	3.55	2.81 - 4.44
Male	2	5	0	2	3	10	0.19	0.09 - 0.35
	3	10	3	2	40	55	0.90	0.68 - 1.18
	4	17	4	1	38	60	1.52	1.16 - 1.95
	5+	31	14	3	37	85	1.71	1.37 - 2.11
Total		136	37	21	350	544	1.39	1.27 - 1.51

Table 6.8. Number of observations, median duration of training preparation, starts per 100 training–days, and places (first, second or third) per start, for male and female horses of different ages. Data derived from 2,578 training preparations ending in either first musculoskeletal injury (MSI) or any reason unrelated to MSI, and 753 training preparations observed in horses returning to work after an initial MSI. P-values were derived from statistical tests comparing each variable between the two categories of training preparations within each age group and gender combination.

	Males				Females			
	Age (years)				Age (years)			
	2	3	4	5+	2	3	4	5+
Training preparations up to first MSI								
Number of observations	474	374	203	268	495	382	228	135
Median preparation duration (days)	75.5	124	149	164	77	119	134	149
Starts per 100 training-days	1.22	2.53	3.24	3.61	1.38	2.44	3.01	3.45
Places per start	0.46	0.43	0.41	0.37	0.47	0.34	0.37	0.29
Training preparations after first MSI								
Number of observations	80	119	75	92	92	164	96	35
Median preparation duration (days)	61.5	108	132	134	66	91.5	132	139
Starts per 100 training-days	1.59	2.46	2.99	3.11	1.57	2.55	2.92	2.96
Places per start	0.50	0.47	0.40	0.35	0.51	0.40	0.37	0.27
P-values								
Median preparation duration	0.05	0.017	0.06	0.001	0.002	0.0001	0.1	0.2
Starts per 100 training-days	0.1	0.1	0.2	0.004	0.6	0.7	0.96	0.2
Places per start	0.6	0.052	0.9	0.8	0.3	0.1	0.7	0.7

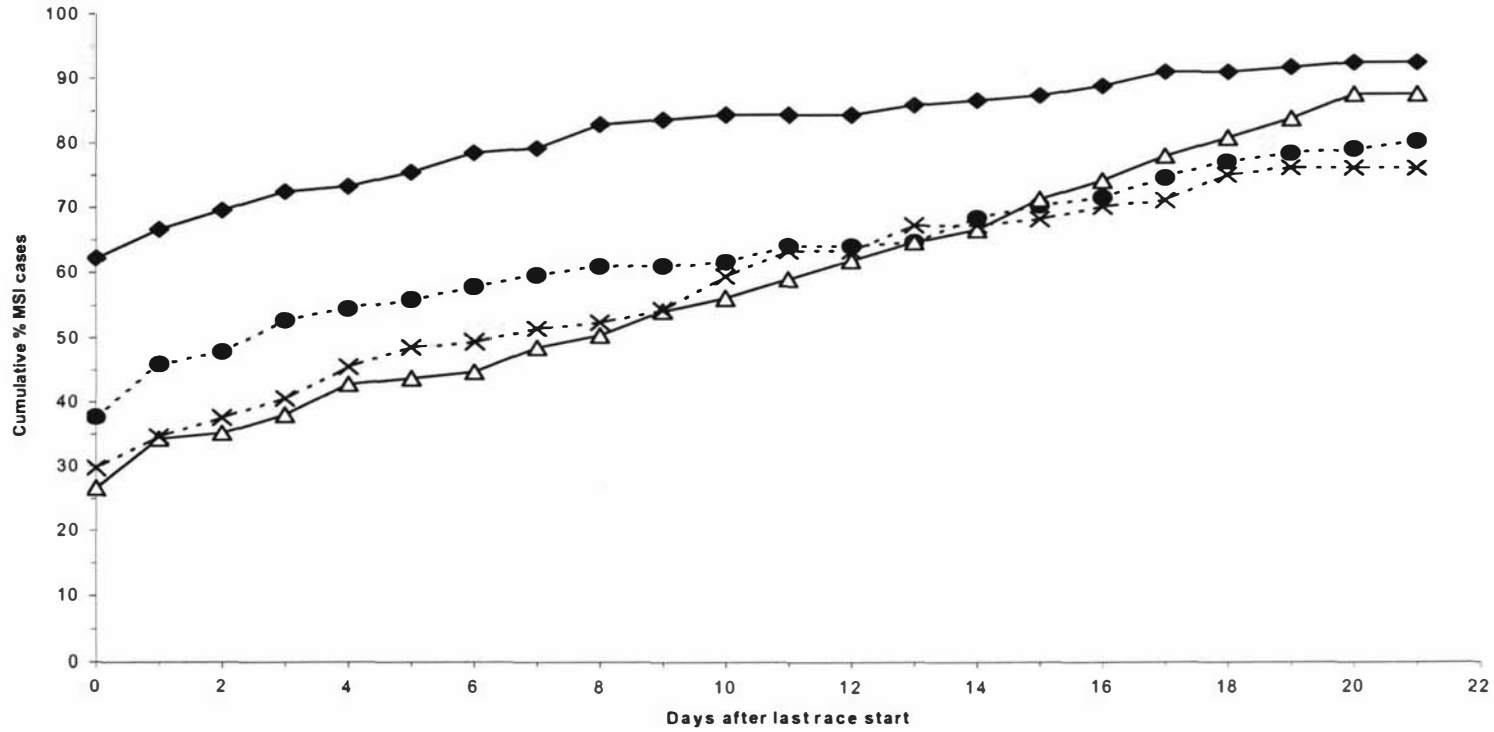


Figure 6.1. Cumulative percentage of musculoskeletal injury (MSI) cases vs day of reported diagnosis represented as days after the last start in a trial or race. Data restricted to 500 cases of MSI reported in training preparations in 2- (♦), 3- (●), 4- (Δ), and ≥5-year-old (×) horses, associated with at least one start, and limited to the period ending 21 days after the last start in a training preparation.

Discussion

This study reported statistics concerning injuries and disorders in Thoroughbred racehorses that interfered with training and racing. Summary statistical measures were stratified where appropriate by major confounders including age and gender. Simple statistical comparisons were performed to provide insight into possible associations between explanatory factors and outcomes of health and performance, but results should be interpreted with caution since comparisons were not adjusted for other potential confounders. Multivariate studies are currently being undertaken to investigate potential risk factors for injuries and other conditions in New Zealand racehorses and will be the subject of future papers.

The study population may not have been representative of the population of racehorses in New Zealand because the trainers enrolled in this study were a convenience sample and not a random sample drawn from the population of trainers. The relatively large size of the study population, the prolonged study period, and the longitudinal design were strengths of the study since they allowed information to be collected on horses over a period of time sufficiently long enough to monitor horses returning to training after long spell periods, and allowed generation of time-at-risk in order to calculate incidence rates and cumulative incidence estimates for various measures of performance and health.

All information concerning injuries and disorders in racehorses collected during this study was obtained directly from trainers. All trainers were experienced at handling and managing horses and were considered able to respond well to the definitions used in the questionnaire during data collection. It was not possible to collect information on the same horses concurrently from veterinarians because trainers did not request veterinary examinations for all injuries or disorders in horses under their care, and retrospective analysis of veterinary records from selected clinics did not allow identification of horses or conditions to sufficient detail to warrant inclusion in the study. Veterinary involvement in diagnosis of injuries and disorders affecting racehorses ranged from 8% of cases of shin soreness to 100% of cases that involved limb fractures, and when data were aggregated over all types of MSI, a veterinarian was responsible for the diagnosis in 54% of cases. Trainers appeared to be less likely to request veterinary assistance for more common conditions that they were familiar with, and that were less likely to require detailed treatment, and more likely to request veterinary assistance for more

serious injuries requiring medical or surgical treatment. Professional trainers were very familiar with shin soreness and generally accustomed to palpating the dorsal metacarpal region of all horses in training on a daily basis and it was felt that the risk of misclassification for shin soreness was relatively low. While there may have been misclassification for specific diagnoses involving conditions other than shin soreness it was felt that trainers were capable of detecting musculoskeletal abnormalities according to the definitions used in the study. Broad categories of MSI were used in an attempt to offset the potential for misdiagnosis of specific types of injury. If cases of shin soreness were excluded from the calculations, veterinarians were responsible for diagnosis of 73% of cases. Higher proportional involvement of veterinarians in more severe conditions was not surprising given that the trainers participating in the study were all professional and had an obligation to provide excellent care for horses under their management, and accurate information to horse owners. The wide variation in veterinary involvement according to type of MSI also indicated that estimates of prevalence or incidence for various types of injury obtained from veterinarians would be likely to underestimate the true values, alarmingly so for some conditions such as shin soreness. Although this study did not assess the impact of veterinary involvement on outcomes following injury, it is suggested that increased veterinary involvement in the diagnosis and management of conditions affecting racehorses may be beneficial for the industry by allowing early detection and implementation of effective treatment or management of conditions.

MSIs in racehorses ranged from mild conditions associated with little or no lameness and little impact on training activity, to severe lameness or breakdown resulting in retirement or death of the animal (Hill et al 2001). The present study focussed on events that resulted in retirement, death, or spell periods >7-days, therefore removing distraction created by events of little consequence.

The proportions of involuntary events associated with MSI, respiratory and miscellaneous events reported in this study were consistent with those reported elsewhere, such as the United Kingdom (UK) where the proportion of training days lost due to musculoskeletal and respiratory conditions was 68% and 22%, respectively (Rosdale et al 1985). The higher relative contribution of respiratory conditions in that study may reflect either an increased incidence and/or impact of respiratory conditions in the UK compared with New Zealand as a result of variation in climate, management

or disease risk, or simply random variation in reporting. A more recent prospective study of clinical events reported by veterinarians at racecourses around Britain, reported 82% of 2,358 events involved the musculoskeletal system and the remainder were either undiagnosed or involved other systems (Williams et al 2001).

The finding in our study that MSIs primarily involved structures of the lower forelimb was also consistent with similar findings from the UK (Williams et al 2001), and USA (Peloso et al 1994; Cohen et al 1997), as would be expected given the likelihood of a common pathogenesis for MSI in racehorses around the world.

Shin soreness was the most commonly reported individual MSI in the present study, affecting mainly 2- and 3-year-olds as has previously been reported (Bailey et al 1999). However, only 16% and 7.5% of all horses contributing training days to 2- and 3-year-old populations, respectively, suffered interruptions to training as a result of shin soreness in the current study. Additional horses were diagnosed with shin soreness without being spelled and therefore were not counted as musculoskeletal events under the definitions used in this study. Previous studies reported cumulative incidence estimates as high as 42% (Bailey et al 1999) and 70% (Norwood 1978), in 2-year-olds in Australia and the USA, respectively, though these studies included cases that did not result in interruption to training programmes. Studies in the UK reported shin soreness in 9% of cases of lameness where training was interrupted (Jeffcott et al 1982; Rosedale et al 1985). Differences in case definition or eligibility criteria offer partial explanations for the variation in cumulative incidence estimates between the different studies. Other possible explanations include regional variation in track composition and design, and training methods. In addition, advances in understanding of factors contributing to shin soreness and promotion of more effective training methods and track management (Moyer et al 1991), may have reduced its impact on time lost from training in the horses in our study.

IRs for MSI categories showed variation by age and gender. Shin soreness was more common in young horses of both genders, while tendon and ligament injuries were more common in older horses, and particularly in males relative to females. There is a paucity of comparative data in the veterinary literature reporting IRs for injuries in training horses. The use of pre-existing records sourced from racing clubs or centralised racing administrators has limited authors to estimating IRs for injuries per unit of horse starts rather than per horse-training-day. MSI rates in starting horses have been

reported as 3.3 per 1,000 starts in the USA (Peloso et al 1994), and 3.1 per 1,000 starts in the UK (Williams et al 2001). Bailey et al (1999) followed 169 Thoroughbreds for two seasons, and reported IRs for MSIs per 100 horse-weeks of training time. MSIs were included in that study if they resulted in any form of modification or interruption to training, and each training week was estimated to have contributed 6 days to time-at-risk because most horses had one day without training each calendar week. As a result IR estimates from work by Bailey for shin soreness of 1.63 per 100 horse-weeks, injury or laceration of 0.75 per 100 horse-weeks, and upper respiratory tract disease of 0.75 per 100 horse-weeks, were not directly comparable to IRs derived in our study.

Fatalities in racehorses in our study were mainly the result of limb fractures and a small number of deaths associated with soft tissue injury, chronic musculoskeletal disease, cardiovascular accidents or disorders, undiagnosed sudden death, and behavioural abnormalities. These findings were consistent with other reports that identified limb fractures as the major cause of death in racehorses (Johnson et al 1994), and reported other less common causes including tendon or ligament injury, laminitis, septic arthritis, and rhabdomyolysis. A similar study reported 6% of fatalities in training horses to be associated with accidents or mishaps, and 13% associated with conditions unrelated to exercise (Johnson 1993).

Exits recorded in our study were a measure of losses to the racing industry and were attributed to deaths and retirement either in the absence of (voluntary retirement), or directly resulting from, an injury or disorder that affected performance. Almost three times as many horses exited under voluntary retirement than the next most common cause of exits which was MSI. The most likely explanation for voluntary exits was considered to be a lack of competitive ability (Jeffcott et al 1982, More 1999), though a variety of other factors may influence a decision to retire a horse from training and racing in the absence of any condition interfering with training. For example, loss of interest in the industry, financial reasons, and other uses for the horse such as breeding or pleasure riding.

Involuntary events that interrupt training programmes resulted in economic losses through a variety of pathways including horses failing to start in a trial or race, premature retirement, reduced competitive ability, and medical or surgical costs associated with some conditions. Results presented in this paper indicated that horses in training after an initial MSI generally had shorter median training preparations than

those preparations where a MSI did not occur or that ended in the initial occurrence of a MSI. However, there was little difference in the incidence of starts per 100 training-days, or the proportion of starts that ended with first, second or third place, between training preparations after an initial MSI and other training preparations. Involuntary exits accounted for 195/555 (35%) all exits observed during the study and MSI was responsible for 137 of these. The risk of exit due to MSI was dependent on the type of injury, and the worst prognosis associated with fractures, and tendon and ligament injuries. This was expected given the effect such conditions have on long-term athletic function, risk of recurrence, costs associated with medical or surgical therapy and the need for long-term recuperation.

Many MSIs were reported in training preparations where the horse did not start in a trial or race. This finding in combination with the pattern of reported diagnosis of MSIs relative to the last race or trial start (as shown in Figure 1), confirmed the importance of training associated-exercise as a contributor to MSI. The timing of reporting of a MSI does not necessarily correspond to the time of occurrence of the injury and cases that were reported several days after the last race may have involved an original injury that was incurred during the race and either became apparent or was exacerbated at a later date. A major implication of this finding was in relation to the design of studies that sourced injury data from a centralised or racing club database of injuries that occurred during a race and were reported to the attending veterinary surgeon while the horse was still at the racetrack. Our results indicate that use of such records for injuries other than catastrophic or fatal injuries may seriously underestimate MSIs and could misrepresent the type of injuries reported as occurring during a race. Additional research is required to investigate the validity of raceday injury records maintained by the racing industry.

In conclusion, this paper reported IRs for injuries and disorders that interfered with training and racing in a population of New Zealand Thoroughbreds between 1997–2000, and has used simple descriptive statistics to explore the impact of such events on subsequent health and performance. These results represent a valuable contribution to our ability to identify and prioritise issues facing the Thoroughbred racing industry in New Zealand.

Acknowledgements

The authors gratefully acknowledge funding support from the New Zealand Equine Research Foundation, and NZTR for provision of data. The assistance of Ms Dagmar Fikken in data collection is also acknowledged as is the commitment and assistance of veterinarians, track managers, trainers and their staff.

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Chapter 7

Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses *

* Published as: NR Perkins, SWJ Reid, RS Morris. *New Zealand Veterinary Journal*, 53(3), 171-183, 2005.

Abstract

AIM: To investigate risk factors for injury to musculoskeletal structures of the lower fore- and hindlimbs of Thoroughbreds training and racing in New Zealand.

METHODS: A case-control study analysed by logistic regression was used to compare explanatory variables for musculoskeletal injuries (MSI) in racehorses. The first dataset (termed the training dataset), involved 459 first-occurrence cases of lower-limb MSI in horses in training, and the second (starting dataset) a subset of these horses that had started in at least one trial or race in the preparation that ended with MSI (n=294). All non-case training preparations for which complete data were available were used in the analyses as controls, and provided 2,181 and 1,639 training preparations for the training and starting datasets, respectively. Multivariate logistic regression was used to evaluate risk factors and results reported as odds ratios (OR) and 95% confidence intervals (CI).

RESULTS: Horses aged 5-years or older were at higher risk of injury than 2-year olds. Elevated odds of MSI occurred in starting horses that were training in the 1997-1998 year compared with the 1999-2000 year, and in those horses where trials comprised more than 20% of all starts in a preparation. Training preparations that ended in winter, and horses in their third or later training preparation had lower odds of MSI compared with those ending in other seasons or the first preparation, respectively. Reduced odds of MSI were observed in preparations with any starts compared with those that had no starts, and in the starting dataset, those preparations with more than one start has reduced likelihood of MSI compared with preparations with only one start. Preparations longer than 20 weeks were associated with reduced odds of MSI compared with those shorter than 20 weeks in the training dataset.

Cumulative racing distance in the last 30 days of a training preparation, was best modelled with linear and quadratic terms. Results indicated that increasing values of cumulative racing distance was associated with an initial reduction in the odds of MSI that then levelled out and finally appeared to increase again as the explanatory variable continued to increase. There was significant between trainer variation in risk of MSI.

CONCLUSION: This study identified a number of risk factors for MSI in training and racing Thoroughbreds in New Zealand, including intrinsic (age) and extrinsic factors. Measures of cumulative exercise intensity appeared to have an initial protective effect that levelled out and finally increased as exposure increased. There was significant

variation between trainers indicating a role of management and training methods in the risk of MSI.

Introduction

Musculoskeletal injuries are the most common conditions interfering with athletic performance in racehorses (Rossdale et al 1985; Williams et al 2001). Injuries range from inconsequential to life threatening and the impact of injury on a horse's athletic career may vary from modification to a training programme through various levels of interruption to training while treatment and recovery occur, loss of athletic performance, retirement, and death or euthanasia.

Of musculoskeletal injuries reported in a recent longitudinal study of British racecourse injuries, >90% involved the limbs, and >80% of limb injuries involved the forelimbs (Williams et al 2001), while studies on racehorses in Kentucky reported >90% of musculoskeletal injuries that occurred during racing involved the forelimbs (Peloso et al 1994; Cohen et al 1997). In addition, only 4% of limb injuries in those studies from Kentucky (Peloso et al 1994; Cohen et al 1997), and 16% in the British study (Williams et al 2001), involved structures proximal to the carpus or hock. Differences in proportions of injuries involving these structures may reflect regional variation in horse populations, as well as other factors that may vary between the UK and the USA including track surface, race type and training methods.

A large number of putative risk factors for musculoskeletal injury have been identified in previous studies, and examples included horse age (Bailey et al 1997; Williams et al 2001); gender (Estberg et al 1996b); race type (Bailey et al 1998); race distance (Bailey et al 1997); race track (Bailey et al 1998); season (Mohammed et al 1991); measures of exercise intensity (Estberg et al 1995, 1998a); pre-existing pathology involving the musculoskeletal system (Stover et al 1992; Cohen et al 1997); horseshoe characteristics (Kane et al 1996); and various activities that have been observed to occur during a race such as interaction with other horses, stumbling, lead changes, and use of the whip (Cohen et al 1997).

Many studies have utilised information from data recording systems maintained at different levels within the racing industry regarding injuries incurred in horses during training or racing, and records relating to performance in official trials (timed workouts) or races. For example, the California Horse Racing Board and the California Veterinary

Diagnostic Laboratory System established a necropsy programme in 1990 for all racehorses that died or were euthanised at any racetrack under the jurisdiction of the California Horse Racing Board. Several studies have utilised these data to retrospectively examine factors associated with fatalities in California racehorses that occurred during either training or racing (Johnson et al 1994; Estberg et al 1995, 1996a, 1996b, 1998a; Carrier et al 1998). Data derived from pre- (Cohen et al 1999) and post-race, veterinary reports (Peloso et al 1994; Cohen et al 1997, 1999, 2000; Williams et al 2001) have also been used to examine factors associated with fatal and non-fatal injuries that occurred during a race. All of these studies have combined injury data with information on starts in trials or races, either derived from the racetrack veterinarian (Johnson et al 1994) or from a centralised recording system containing information on all starts for racehorses in a particular region or country (Peloso et al 1994; Estberg et al 1995, 1996a, 1996b, 1998a; Carrier et al 1998; Cohen et al 1997, 1999, 2000; Williams et al 2001). A smaller number of studies have obtained information on racehorse injuries in a prospective manner directly from trainers in the UK (Jeffcott et al 1982; Rosedale et al 1985) and Australia (Bailey 1998). There is no centralised recording or reporting system in New Zealand for injuries incurred by racehorses during training or racing.

This paper utilised data collected in a longitudinal study from trainers in New Zealand to investigate injuries incurred by racehorses during training and racing. The aims of this paper were to investigate possible risk factors for musculoskeletal injury in a population of racehorses in training in New Zealand.

Materials and methods

Selection of trainers and horses

Details of the study design have been published previously (Perkins et al 2005a, b) and will be described briefly here. The study involved a longitudinal design that incorporated monthly collection of data from 20 Thoroughbred trainers in New Zealand over a 34-month period starting in October 1997 and ending in July, 2000. Trainers in New Zealand have fixed establishments and do not move between training venues during the year. All trainers participating in the study had separate premises and all horses trained by a single trainer were housed at one location while in training. Trainers were based at one of five regional training venues and a regional racing club was

responsible for maintaining training track surfaces at each venue for use by trainers. A variable coding for track was created to represent the training venue used by a trainer for high-speed exercise training.

Selected trainers represented a convenience sample of licensed, professional trainers that were enthusiastic about the project and likely to participate actively over a prolonged period of time. All horses trained at participating stables were enrolled in the study, with data collection for each horse commencing on the day the horse entered the stable to begin training and continuing until the study ended or the horse retired, died, or changed trainers to a trainer not participating in the study. New horses were enrolled in the study throughout the study period.

Data Collection and processing

Custom designed questionnaires were used to collect information on training activity and on injuries or other conditions that had interfered with training. A questionnaire was printed for every horse in a stable to facilitate data collection at each visit and contained information to identify the horse, information from the previous visits regarding activity and presence or absence of any illness or injury, and a series of questions to be answered about activity and health in the period since the previous visit. Trainers were queried by telephone between visits to answer queries regarding questionnaires. Electronic data on official race and trial results for all horses starting in trials and races in New Zealand during the study period, were obtained from New Zealand Thoroughbred Racing (NZTR). Approximately 94% of all Thoroughbred races held in New Zealand are flat races and the remaining 6% are comprised of hurdle and steeplechase events. Information from hurdle and steeplechase events were retained in the datasets and a binary variable generated to indicate whether a horse had no or any starts in hurdle or steeplechase events.

A training activity score (TAS) was used to record the level of training activity achieved by each horse in the period between visits. TASs were defined as spell (TAS=1), walk or trot (TAS=2), activity up to but not exceeding a canter (TAS=3), fast work but not yet starting in a trial or race (TAS=4), and horses that had started in at least one trial or race since the last visit (TAS=5).

Horse age was determined in years based on the official 01 August birthdate for Thoroughbreds in New Zealand. Age data were aggregated in older categories because

of the paucity of horses older than 5-years of age. Data on gender were aggregated to male and female.

A training preparation began on the date that a horse entered a training stable to begin training. Training preparations ended with an event marked by the onset of a spell longer than 7-days in duration, retirement from racing, or death of the horse.

Data were collected on any condition or disease resulting in a decision by the trainer to end the training preparation for any horse, or that resulted in death of the horse. Conditions were classified according to body system affected (musculoskeletal, respiratory, and other), and specific information on anatomical location and diagnosis was collected where possible. Standardised definitions were used for musculoskeletal conditions. Conditions were classified as lameness if the horse had an abnormality of gait that prevented it from being exercised, and as a non-lame musculoskeletal injury if there was a detectable abnormality involving a musculoskeletal structure that prevented the horse from being exercised but did not result in gait abnormality. All trainers participating in the study utilized the services of an attending veterinarian on a regular basis, however not all diagnoses involved a veterinary examination. The decision to request a veterinary examination on any horse was made by the trainer in consultation with the owner of a horse.

Classification of study time

Data were aggregated to the level of a training preparation for each horse and each training preparation constituted a single row of data covariates to identify horse, preparation number and other variables in the dataset. A training preparation was defined as the cumulative sum of training-days starting from the day of enrolment or return to work from a spell, and ending with onset of the next spell or exit of the horse from the study. Interruptions to training were only coded as a spell-period if they exceeded seven consecutive days of no training and interruptions to training that were up to 7-days in duration were counted as part of a training preparation, and recorded as training-days at TAS=1.

Individual horses were able to accumulate more than one training preparation during the study, with each successive training preparation separated by a spell period. Training preparations and spell periods were classified as complete or incomplete. Incomplete training preparations or spell periods involved horses that were in a training preparation

or a spell period at the time data collection ended for that horse, either because the study ended, or the horse was moved to a different trainer not participating in the study. In these situations a valid end date was not recorded for the training preparation or spell period because the horse was lost to follow-up while still in either a training preparation or a spell, and the end date recorded was the last day the horse was still in the stable or the date the study ended. Complete training preparations and spell periods were those for which a valid start date and end date were known and all complete training periods had an event recorded as the reason for ending the preparation. Only training preparation days were deemed to represent time-at-risk for musculoskeletal injury (MSI).

Case definition

A case was defined as any training preparation that ended with a Thoroughbred racehorse diagnosed with a MSI that involved the lower limbs (foot to hock or carpus in hind- and forelimbs, respectively). Only the first lower-limb MSI for any horse was identified as a case and any training preparations recorded from cases that occurred after the first occurrence of a lower-limb MSI were excluded from the analyses. Additional exclusions included lower limb MSI that were the result of accidental injury not associated with training activity, lower limb MSI that resulted in interruptions to a training preparation that were less than 7-days in duration, and any MSI involving anatomic structures limited to the upper limbs, body, neck or head.

Two separate case populations were produced. The first population was comprised of case-horses derived from all horses in training including horses that had started in a trial or race in that preparation as well as horses that had not started in a trial or race during the preparation. This population was called the training dataset. The second population of cases was a subset of the first, restricted to those cases that had started in at least one trial or race during the preparation that ended with a MSI meeting the description above, and was called the starting dataset.

Control selection

All training-preparations that were complete and that did not end with a MSI meeting the case definition above, were classified as controls for analysis. Data from incomplete training preparations were excluded from the analysis because of interest in considering the effect of duration of training-preparation in the analytical models, and incomplete

training preparations had no known end date. Case horses could contribute training preparations to the eligible control population if those preparations occurred during the study period prior to the preparation that ended with an incident, lower-limb MSI but they could not contribute any training preparations to either cases or controls after the first occurrence of a MSI.

Training and starting datasets of controls were generated using similar rules as for cases. The first involved all complete training preparations that did not end in a first occurrence, lower-limb MSI including preparations that were not associated with any starts in trials or races. The second was restricted to those complete, non-case training preparations associated with at least one start in either a trial or a race.

Statistical analysis

A binary outcome variable was generated for each training preparation to code for the presence or absence of a MSI at the end of the preparation. Separate, unmatched, multivariate logistic regression procedures were then used to analyse the two datasets. All explanatory variables were aggregated to the level of the training preparation. Potential explanatory variables were screened using univariate logistic regression, and a critical probability of $p < 0.25$ was used to select variables for inclusion in subsequent multivariate models. A forward stepwise model building process was then used to develop a multivariate model, and variables were retained in the model if they were associated with a likelihood ratio $p < 0.06$, with those variables associated with p -values between 0.05 and 0.06 identified as possible risk factors with a tendency towards statistical significance. Biologically plausible interaction terms between main-effect variables were then considered for inclusion in the multivariate model. Summary measures of model goodness-of-fit included comparison of deviance to the degrees of freedom, and estimation of the Hosmer-Lemeshow goodness-of-fit statistic (Hosmer and Lemeshow 2000, pp 143–156). Regression diagnostics included evaluation of standardized Pearson residuals, the change in the Pearson chi-square statistic following deletion from the model of individuals within each covariate pattern ($\Delta\chi^2$), and the change in the value of the estimated coefficients following deletion of individuals within each covariate pattern ($\Delta\beta$), as described in Hosmer and Lemeshow (2000, pp167–183). Linearity of the logit for continuous variables was checked by plotting regression coefficients against the mid-points of the four quantiles for each continuous variable in the final model, and by the method of fractional polynomials (Hosmer and

Lemeshow 2000, pp97–116). Evidence of a non–linear relationship was then followed by either consideration of the addition of a quadratic term to the final model, or replacing the continuous variable with a nominal variable split into two or more categories. Continuous variables in the model were centered by subtracting the mean value from every data point to produce a variable where zero represented the average, and non–zero values represented deviations from the average (Dohoo et al 2003, pp 291).

Predicted probabilities were generated from final logistic regression models to illustrate non–linear relationships between the probability of being diagnosed as a case, and those continuous variables in the final models that were represented by both linear and quadratic terms. This was done by holding other predictor variables constant and allowing a single continuous predictor (both linear and quadratic terms) to vary across the range of values observed in the dataset. Other explanatory variables in the model were set at zero values (representing the reference level for categorical variables, and the average value for continuous, centered variables), and the level of trainer was chosen to represent the trainer with the most horse–preparations in the dataset. Plots were then generated of the predicted probability and 95% confidence interval for the outcome being a case ($\text{Pr}(y=1)$), against the values of the cumulative distance raced in the last 30–days.

There was potential for clustering of training preparations within horses, and of horses within training stables. A variable coding for trainer identity was forced into the final models as a fixed effect to account for expected clustering at the trainer level. The occurrence of multiple training preparations from some horses was assumed to result in the potential for correlations between training preparations from the same horse, while assuming no correlation between training preparations from different horses. A variable coding for horse identity was entered into multivariate models to identify cluster levels for generation of robust standard error terms for model coefficients as described in Hosmer and Lemeshow (2000, pp308–316).

All analyses were performed in Stata version 8.2 (Stata Corporation, College Station, Texas, USA), using logit and logistic analyses, and horse entered using the cluster() option. Results were presented as odds ratios and 95% confidence intervals.

Results

The complete dataset from the longitudinal study contained information from 1,571 horses and 3,333 training preparations collected during the 34-month study period. Exclusion of incomplete training preparations left 2,640 complete training preparations that involved 1,385 horses.

A total of 473 incident cases of lower limb, musculoskeletal injury (MSI) were reported, and 14 of these involved accidental injuries or lacerations that were unrelated to any form of training endeavour. A breakdown by injury of the remaining 459 MSI that met the criteria for incident cases of lower limb, MSI in the population of training horses, is presented in Table 7.1. Table 7.1 also shows the injury type for the 294 incident cases of lower limb, MSI that occurred in training preparations where the horse involved had started in at least one trial or race during the preparation that ended in injury. Undefined cases included horses with lameness that could not be isolated to a specific anatomic location (n=4 and 1 from the training and starting groups, respectively), and horses diagnosed with a condition called "jarring up" (n=70 and 55 from the training and starting groups, respectively). Jarring up was a term used by trainers and equine veterinarians in New Zealand to refer to a syndrome where horses showed variable clinical signs of lower limb MSI including short striding and other gait changes without overt lameness, and fetlock swelling in most but not all cases.

Table 7.1. Classification of injury for 459 lower limb, musculoskeletal injuries in racehorses, of which 294 occurred in horses that had started in at least one trial or race during the preparation in which they were injured.

Injury	Source population	
	All training horses	Horses that had started in 1 trial or race
Shin soreness	159	101
Tendon or ligament	79	52
Undefined	74	56
Fetlock	45	26
Carpus	37	23
Metacarpus	28	17
Foot	15	8
Proximal sesamoid	15	6
Hock	5	3
Pastern	2	2
Total	459	294

The training dataset contained 2,640 rows of data comprised of 459 case-preparations and 2,181 preparations from controls. One horse contributed a total of eight training preparations and seven, six, five, four, three, two and one training preparations were contributed by one, seven, 24, 86, 218, 417, and 631 horses, respectively. The average number of training preparations contributed by an individual horse was 1.9. Any one horse could only contribute at most a single case preparation, so multiple preparations represented control preparations either with or without a single case preparation in the same horse. A total of 112 case-horses contributed only the preparation that ended with their being diagnosed as a case, and the other 347 case-horses contributed between one and seven training preparations to the control population, all being completed prior to the preparation in which they sustained the MSI that resulted in a case classification.

The starting dataset contained 1,933 rows of data relating to preparations that included at least one start in a trial or race, with 294 cases and 1,639 control training preparations. One horse contributed a total of seven training preparations and six, five, four, three, two and one training preparations were contributed by one, eight, 41, 134, 351, and 612 horses, respectively. The average number of training preparations contributed by an individual horse was 1.7.

There were 20 trainers in the datasets with each trainer contributing between 24–280 (average = 132), and 10–200 (average=96) training preparations to the training and starting datasets, respectively.

Results of univariate screening of risk factors for lower limb musculoskeletal injury are shown in Tables 7.2 and 7.3.

Table 7.2. Results of univariate logistic regression screening of potential risk factors for lower limb musculoskeletal injury in racehorses with odds ratio (OR), 95% confidence interval of odds ratio (95% CI), and p-values. Data drawn from 2,640 training preparations involving 1,384 horses and included 459 cases of musculoskeletal injury. Data include training preparations with and without starts in trials or races.

Variable	Category	Control n	Case n	OR	95% CI		p-value	
					Lower	Upper		
Trainer	1	108	27				<0.001	
	2	81	13	0.64	0.31	1.32	0.23	
	3	39	11	1.13	0.51	2.49	0.77	
	4	21	3	0.57	0.16	2.06	0.39	
	5	147	34	0.93	0.53	1.62	0.79	
	6	166	36	0.87	0.5	1.51	0.62	
	7	118	17	0.58	0.3	1.12	0.1	
	8	91	15	0.66	0.33	1.31	0.24	
	9	37	11	1.19	0.54	2.63	0.67	
	10	105	26	0.99	0.54	1.81	0.98	
	11	63	12	0.76	0.36	1.61	0.48	
	12	144	35	0.97	0.56	1.7	0.92	
	13	184	34	0.74	0.42	1.29	0.29	
	14	186	38	0.82	0.47	1.41	0.47	
	15 ^a	24	0	0				
	16	219	19	0.35	0.18	0.65	0.001	
	17	107	31	1.16	0.65	2.07	0.62	
	18	55	17	1.24	0.62	2.46	0.55	
	19	218	62	1.14	0.68	1.89	0.62	
	20	68	18	1.06	0.54	2.07	0.87	
Track	1	613	130	Ref			0.5	
	2	55	17	1.46	0.82	2.59	0.2	
	3	108	27	1.18	0.74	1.87	0.49	
	4	292	65	1.05	0.76	1.46	0.77	
	5	1113	220	0.93	0.73	1.18	0.56	
Gender	Female	1133	220	Ref				
	Male	1048	239	1.17	0.96	1.44	0.12	
Age (years)	2	718	187	Ref			<0.001	
	3	696	128	0.71	0.55	0.9	0.01	
	4	421	59	0.54	0.39	0.74	<0.001	
	>=5	333	81	0.93	0.7	1.25	0.65	
	unknown	13	4					
Race year	1997	235	75	1.76	1.29	2.39	<0.001	
	1998	1005	213	1.17	0.94	1.45	0.17	
	1999	941	171	Ref			0.002	
Season	Summer	560	134	Ref			0.03	
	Autumn	621	117	0.79	0.6	1.03	0.09	
	Winter	469	78	0.7	0.51	0.94	0.02	
	Spring	531	130	1.02	0.78	1.34	0.87	
TAS at start	2 or 3	1357	271	Ref				
	4 or 5	824	188	1.14	0.93	1.4	0.2	
Preparation	1	1091	294	Ref			<0.001	
	2	628	126	0.74	0.59	0.94	0.01	
	3+	462	39	0.31	0.22	0.45	<0.001	
Any starts in	No	542	165	Ref				
	Yes	1639	294	0.59	0.48	0.73	<0.001	
Training day	None	2098	439	Ref				
	Any	83	20	1.15	0.7	1.9	0.58	
Duration of training preparation ^b				0.95	0.93	0.97	<0.001	
Number of starts per 2wk of training preparation				0.56	0.37	0.84	0.005	

TAS= training activity score

Ref= reference level for comparison

^a Trainer #15 omitted because of zero cases

^b 1 unit change = 2 weeks

Table 7.3. Results of univariate logistic regression screening of potential risk factors for lower limb musculoskeletal injury in racehorses with odds ratio (OR), 95% confidence interval of odds ratio (95% CI), and p-values. Data drawn from 1,933 training populations and 1,148 horses and included 294 cases of musculoskeletal injury. Data from preparations that had at least one start in a trial or race during the preparation.

Variable	Category	Control n	Case n	OR	95% CI		p-value
					Lower	Upper	
Trainer	1	71	15	Ref			0.009
	2	46	7	0.72	0.27	1.90	0.51
	3	33	9	1.29	0.51	3.25	0.59
	4	9	1	0.53	0.06	4.47	0.56
	5	106	20	0.89	0.43	1.86	0.76
	6	112	23	0.97	0.48	1.99	0.94
	7	93	13	0.66	0.30	1.48	0.31
	8	66	8	0.57	0.23	1.44	0.24
	9	34	10	1.39	0.57	3.42	0.47
	10	75	11	0.69	0.30	1.61	0.40
	11	56	9	0.76	0.31	1.87	0.55
	12	104	16	0.73	0.34	1.57	0.42
	13	163	28	0.81	0.41	1.62	0.56
	14	153	24	0.74	0.37	1.50	0.41
	15 ^a	18	0				
	16	166	12	0.34	0.15	0.77	0.01
	17	80	21	1.24	0.60	2.59	0.56
	18	48	15	1.48	0.66	3.30	0.34
	19	163	37	1.07	0.55	2.08	0.83
	20	43	15	1.65	0.73	3.71	0.23
Track	1	464	85	Ref			0.39
	2	48	15	1.71	0.91	3.18	0.094
	3	71	15	1.15	0.63	2.11	0.64

	4	196	35	0.97	0.64	1.49	0.91
	5	860	144	0.91	0.68	1.22	0.55
Gender	Female	852	144	Ref			
	Male	787	150	1.13	0.88	1.45	0.34
Age (years)	2	394	96	Ref			<0.001
	3	566	88	0.64	0.46	0.88	0.005
	4	381	46	0.50	0.34	0.72	0
	>=5	298	64	0.88	0.62	1.25	0.48
Race year	1997	171	47	1.76	1.20	2.57	0.004
	1998	759	136	1.14	0.87	1.50	0.33
	1999	709	111	Ref			0.01
Season	Summer	432	94	Ref			0.007
	Autumn	485	84	0.80	0.58	1.10	0.16
	Winter	337	38	0.52	0.35	0.78	0.001
	Spring	385	78	0.93	0.67	1.30	0.67
TAS at start of preparation	2 or 3	913	149	Ref			
	4 or 5	726	145	1.22	0.95	1.57	0.11
Preparation number	1	761	179	Ref			<0.001
	2	489	88	0.77	0.58	1.01	0.06
	3+	389	27	0.30	0.19	0.45	<0.001
Multiple starts in the preparation	No	266	97	Ref			
	Yes	1373	197	0.39	0.30	0.52	<0.001
Proportion of starts that were trials	<=0.2	746	90	Ref			
	>0.2	893	204	1.89	1.45	2.47	<0.001
Proportion of starts with place=1st, 2nd or 3rd	<=0.2	630	121	Ref			
	>0.2	1009	173	0.89	0.69	1.15	0.38
Hurdle or steeplechase starts	None	1586	286	Ref			
	Any	53	8	0.84	0.39	1.78	0.64
Distance change from 2nd last to last start	None	216	26	Ref			0.001
	Reduction	696	158	1.89	1.21	2.93	0.005
	Increase	727	110	1.26	0.80	1.98	0.32
Training days at TAS=1	None	1560	276	Ref			

Started in a race with prizemoney >\$50,000	Any	79	18	1.29	0.76	2.18	0.35
	No	1500	278	Ref			
Highest class of start during preparation	Yes	139	16	0.62	0.36	1.06	0.08
	Trial	436	120	Ref			<0.001
	Race <=\$50,000	1064	158	0.54	0.42	0.70	<0.001
	Race >\$50,000	139	16	0.42	0.24	0.73	0.002
Duration of training preparation (2wks)			0.95	0.92	0.97	<0.001	
Time to first start (2wks)			0.99	0.94	1.05	0.86	
Maximal race distance (200m)			0.89	0.85	0.94	<0.001	
Cumulative start distance (200m per 2wks)			0.85	0.80	0.91	<0.001	
Cumulative start distance in last 30 days (200m)			0.94	0.92	0.96	<0.001	

TAS= training activity score

Ref= reference level for comparison

^a Trainer #15 omitted because of zero cases

Table 7.4. Results of multivariate, logistic regression model of risk factors for lower limb musculoskeletal injury in training racehorses, with odds ratio (OR), 95% confidence interval of odds ratio (95% CI), and p-values. Data drawn from 2,640 training preparations involving 1,384 horses and included 459 cases of musculoskeletal injury. Data include training preparations with and without starts in trials or races.

Variable	Category	Coefficient ^t	se	p-value	OR	95% CI	
						Lower	Upper
Age (years)	2	Ref					
	3	-0.06	0.13	0.65	0.94	0.72	1.23
	4	-0.21	0.17	0.22	0.81	0.58	1.14
	5	0.32	0.16	0.04	1.38	1.01	1.88
Year	1997	0.65	0.19	0.001	1.91	1.32	2.76
	1998	-0.02	0.12	0.87	0.98	0.78	1.23
	1999	Ref					
Season	Summer	Ref					
	Autumn	-0.25	0.15	0.09	0.78	0.58	1.04
	Winter	-0.63	0.18	<0.001	0.53	0.38	0.75
	Spring	-0.12	0.14	0.42	0.89	0.67	1.18
Preparation number	1	Ref					
	2	-0.22	0.14	0.11	0.80	0.62	1.05
	3+	-1.03	0.20	<0.001	0.36	0.24	0.53
Starts during the preparation	None	Ref					
	Any	-0.32	0.13	0.01	0.72	0.56	0.93
Duration of preparation	<= 20 weeks	Ref					
	>20 weeks	-0.45	0.14	0.002	0.64	0.48	0.84
Trainer	1	Ref					
	2	-0.57	0.34	0.10	0.57	0.29	1.10
	3	0.22	0.36	0.53	1.25	0.62	2.51
	4	-0.70	0.53	0.19	0.50	0.18	1.40
	5	-0.03	0.25	0.91	0.97	0.59	1.59
	6	-0.19	0.24	0.42	0.82	0.51	1.32
	7	-0.66	0.32	0.04	0.52	0.28	0.96
	8	-0.45	0.31	0.14	0.64	0.35	1.16
	9	-0.53	0.43	0.21	0.59	0.25	1.36
	10	-0.02	0.27	0.95	0.98	0.58	1.66
	11	-0.30	0.34	0.39	0.74	0.38	1.46
	12	-0.23	0.26	0.37	0.79	0.48	1.31
	13	-0.20	0.26	0.44	0.82	0.50	1.35
	14	-0.19	0.25	0.44	0.82	0.50	1.35
	15 ^a	0.00					
	16	-1.09	0.30	<0.001	0.34	0.18	0.61
	17	0.03	0.25	0.92	1.03	0.63	1.67
18	0.34	0.32	0.28	1.40	0.75	2.62	
19	0.14	0.22	0.54	1.14	0.74	1.77	
20	-0.03	0.31	0.92	0.97	0.52	1.79	

^a Trainer #15 omitted because of zero cases

Results of the multivariate logistic regression model assessing risk factors for lower limb MSI in horses during training are presented in Table 7.4. The final model had a deviance of 2,266 with 2,568 degrees of freedom, and returned a chi-squared statistic of 13.78 with 8 degrees of freedom (p -value= 0.09) on a Hosmer-Lemeshow goodness-of-fit test using groups based on deciles of estimated probabilities. A total of 42 observations had standardised residuals greater than 3 or less than -3, equivalent to 1.6% of all observations in the dataset. The highest observed value of $\Delta\beta$ was 0.68, suggesting that removal of the associated covariate pattern would have relatively little effect on the estimated coefficients. Elevated $\Delta\chi^2$ statistics (greater than 30) were reported for four cases, all with year=1999 but not displaying any other consistent pattern in covariate values. Repeating the analysis after removal of the four cases with the largest $\Delta\chi^2$ statistics, altered the coefficients by more than 10% for year=1998, preparation number=3, age=3- and 4-years, and trainer=7 and 17, but did not change the significance of any coefficient relative to the reference levels or the direction of the effect, and changed the standard error terms by less than 7%. The addition of a fixed effect coding for trainer resulted in a significant improvement in the model based on the change in $-2 \log$ likelihood (change in $-2LL=36.3$, $DF=18$, $p= 0.006$), and there was evidence of significant variation in the odds of injury between different trainers. One trainer with 24 rows of data had no cases and these data were omitted from the final model because of the complete absence of case information within that level of trainer. Addition of a clustering effect at the level of horse to the model already containing a fixed effect coding for trainer, resulted in no change in the values of coefficients and increases of up to 9.2% and 21.6% in the standard error terms for coefficients associated with variables other than trainer and with levels of trainer, respectively.

Increased odds of injury were observed in horses aged 5-years or older compared with 2-year-olds ($p= 0.04$), and in 1997 compared with 1999 ($p=0.001$). A reduction in the odds of injury was observed in winter relative to summer ($p<0.001$), the third or later preparations relative to the first preparation for a horse ($p<0.001$), preparations associated with any starts relative to those without any starts ($p=0.01$), and in preparations longer than 20 weeks in duration relative to those that were ≤ 20 weeks ($p=0.002$). A binary variable was used to represent duration of training preparation in

the final model because the continuous variable was found to violate the assumption of linearity in the logit.

Results of the multivariate logistic regression model assessing risk factors for MSI in the subset of horse-preparations that were associated with at least one start in an official trial or race, are presented in Table 7.5. The final model had a deviance of 1,468 with 1,882 degrees of freedom, and returned a chi-squared statistic of 7.55 with 8 degrees of freedom (p -value= 0.48) on a Hosmer-Lemeshow goodness-of-fit test using groups based on deciles of estimated probabilities. There were four standardised residuals greater than 3 or less than -3, equivalent to 0.2% of the observations. The highest observed value of $\Delta\beta$ was 0.83. The $\Delta\chi^2$ statistic identified three covariate patterns that were poorly fit by the model ($\Delta\chi^2 > 40$), and the $\Delta\beta$ values for these covariates were less 0.26. The final analysis was repeated separately after removal of the rows associated with the four largest standardised residuals, three largest $\Delta\chi^2$ statistic values, and four largest values of $\Delta\beta$. There was no change in significance or direction of the coefficients for the risk factors, and inspection of covariate values revealed all values to be plausible, and as a result no observations were removed from the dataset.

Table 7.5. Results of multivariate, logistic regression model of risk factors for lower limb MSI in racehorses, with odds ratio (OR), 95% confidence interval of odds ratio (95% CI), and p-values. Data drawn from 1,933 training populations and 1,148 horses and included 294 cases of musculoskeletal injury. Data restricted to those training preparations that had at least one start in a trial or race during the preparation.

Variable	Category	Coefficient	se	p-value	OR	95% CI	
						Lower	Upper
Age (years)	2	Ref					
	3	0.049	0.18	0.79	1.05	0.74	1.50
	4	0.082	0.22	0.72	1.08	0.70	1.68
	5	0.799	0.22	<0.001	2.22	1.45	3.40
Year	1997	0.746	0.26	0.004	2.11	1.27	3.52
	1998	-0.01	0.16	0.95	0.99	0.73	1.34
	1999	Ref					
Season	Summer	Ref					
	Autumn	-0.109	0.18	0.54	0.90	0.63	1.27
	Winter	-0.863	0.23	<0.001	0.42	0.27	0.66
	Spring	-0.297	0.18	0.10	0.74	0.52	1.06
Preparation number	1	Ref					
	2	-0.136	0.17	0.42	0.87	0.63	1.21
	3+	-1.005	0.25	<0.001	0.37	0.22	0.60
Multiple starts during preparation	No	Ref					
	Yes	-0.39	0.17	0.02	0.68	0.49	0.95
Proportion of starts that were trials	<=0.2	Ref					
	>0.2	0.41	0.17	0.01	1.50	1.08	2.08
Distance raced in last 30 days ^a		-0.07	0.01	<0.001	0.93	0.91	0.96
Square of distance raced in last 30 days		0.0016	0.0004	<0.001	1.002	1.001	1.002
Trainer	1	Ref					
	2	-0.47	0.52	0.37	0.62	0.22	1.73
	3	0.21	0.48	0.67	1.23	0.48	3.13
	4	-0.81	1.01	0.42	0.44	0.06	3.25
	5	-0.02	0.36	0.96	0.98	0.48	2.01
	6	0.17	0.36	0.63	1.19	0.59	2.39
	7	-0.46	0.43	0.27	0.63	0.27	1.45
	8	-0.61	0.45	0.18	0.54	0.22	1.32
	9	-0.70	0.52	0.18	0.50	0.18	1.38
	10	-0.22	0.42	0.60	0.81	0.36	1.82
	11	-0.41	0.43	0.35	0.66	0.28	1.56
	12	-0.58	0.40	0.15	0.56	0.26	1.23
	13	-0.05	0.33	0.89	0.96	0.50	1.84
	14	-0.21	0.35	0.54	0.81	0.41	1.60
	15 ^b	0					
	16	-1.15	0.41	0.01	0.32	0.14	0.72
	17	0.10	0.37	0.78	1.11	0.54	2.28
	18	0.37	0.39	0.35	1.44	0.67	3.12
	19	0.17	0.32	0.60	1.19	0.63	2.24
	20	0.39	0.39	0.33	1.47	0.68	3.18

se= standard error

^a Centered by subtracting the mean and unit=200m

^b Trainer #15 omitted because of zero cases

The addition of a fixed effect coding for trainer resulted in a significant improvement in the model based on the change in $-2 \log$ likelihood (change in $-2LL=31$, $DF=18$, $p=0.03$). One trainer with 18 rows of data had no cases and these data were omitted from the final model because of the complete absence of case information within that level of trainer. Addition of a clustering effect at the level of horse to the model already containing a fixed effect coding for trainer, resulted in no change in the values of coefficients and increases of up to 14% in the standard error terms for coefficients, and the highest changes were observed in standard error terms associated with categories of trainer.

As shown in Table 7.5, the odds of MSI in horses starting in at least one trial or race were increased in horses aged 5-years or older compared with 2-year olds ($p<0.001$), in the 1997–1998 season compared with the 1999–2000 season ($p=0.004$), and in those preparations where trials represented more than 20% of all starts ($p=0.01$). A reduction in the odds of MSI was observed in preparations ending in winter compared with those ending in summer ($p<0.001$). The odds of MSI in winter was also lower than in autumn ($p=0.001$), or spring ($p<0.017$). Horses in their third or later preparation had lower likelihood of MSI compared with horses in their first preparation ($p<0.001$) and there was a reduced odds of MSI in preparations containing more than one start relative to those with only one start ($p=0.01$). The final model contained both linear and quadratic terms for the continuous explanatory variable representing cumulative distance raced in the last 30-days of the preparation. The minimum, maximum, average, standard deviation, and median cumulative distance raced in the last 30-days in case-preparations was 0, 63, 8.2, 8.4, and 6 furlongs (1 furlong = 200 metres), respectively, while for control preparations, values were 0, 68, 11.6, 8.4, and 10, respectively. Control preparations were associated with higher cumulative start distances in the last 30-days of a preparation when compared with case preparations. The effect of the quadratic term on the relationship between the cumulative distance raced in the last 30-days and the probability of being a case, is shown in Figure 7.1. As the cumulative distance raced in the last 30-days increased from the minimum value, the likelihood of MSI declined to a nadir around 13–25 furlongs and then began to increase again. The wider confidence intervals as cumulative distance increased reflect greater uncertainty in the predictions and were likely to be a result of smaller numbers of observations with larger cumulative start distances.

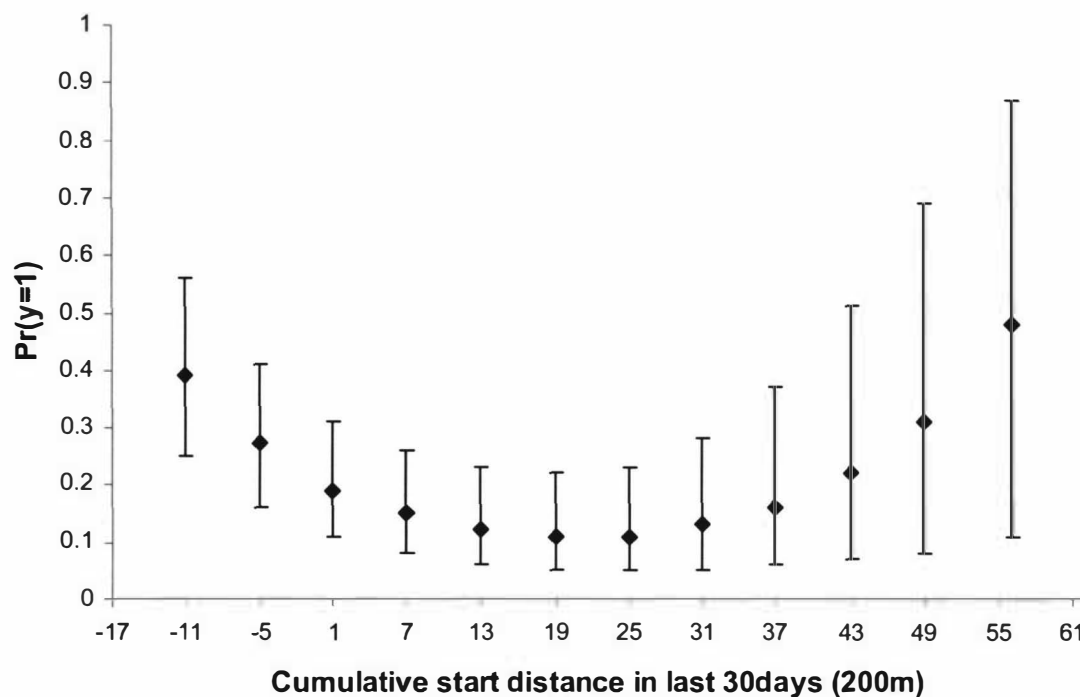


Figure 7.1. Predicted probabilities of the outcome being a case ($\text{Pr}(y=1)$), generated from the logistic regression model presented in Table 5, while values of the centered explanatory variable coding for cumulative distance raced in the last 30 days of a training preparation were varied from -11 to 56 , with the quadratic term set to the square of this number. Values of other explanatory variables were set equal to reference levels (age=2-years, year=1999–2000, season=summer, preparation number=1, multiple starts during preparation=no, proportion of starts that were trials ≤ 0.2), and trainer was set equal to 19 (coding for the trainer with the largest number of horse-preparations in the dataset). Intervals represent a 95% confidence interval.

Discussion

The present study used a combination of data sources to investigate risk factors for lower limb musculoskeletal injury in training and racing Thoroughbreds. Data from a large scale, longitudinal study were combined with electronic data obtained from NZTR to produce a dataset containing health and performance data on horses in training, and information on race and trial starts. The trainers participating in the study were not a randomly selected sample from the population of New Zealand trainers, and were chosen as a convenience sample from major training locations in the central and southern regions of the North Island.

Nested case–control studies are commonly performed on datasets derived from a longitudinal study, in part because it removes the necessity to measure all variables of interest on all animals. In the present study, information on variables of interest were available for all animals enrolled in the study, and there were no limitations imposed by software and computing capability, and a decision was made to retain all data for analyses from complete training preparations. This eliminated potential issues surrounding selection of controls for analysis and ensured that all available data were utilised in analyses.

All horses being trained at a participating stable were enrolled in the study so there was no opportunity for bias by trainers selecting horses for inclusion in the study. Data on injuries and conditions affecting racehorses in training were collected from trainers and the variable level of veterinary involvement in diagnosis was a potential source of bias in the study (see Perkins et al 2005b for details and discussion on veterinary involvement in diagnoses). Investigation of veterinary involvement in diagnoses revealed that there were selected conditions such as shin soreness where trainers made the diagnosis and rarely involved a veterinarian, while for other conditions a veterinarian was consulted most or all of the time. The results were consistent with the hypothesis that trainers might be less inclined to involve a veterinarian for conditions that they were familiar with, that presented generally with a consistent set of clinical signs, and where management of affected horses involved either training modification or rest with little necessity for veterinary intervention. Examples of such conditions included shin soreness, jarring up, some tendon injuries such as obvious swelling involving the superficial digital flexor tendon in the distal palmar metacarpal region, and mild lameness. A major potential bias in collecting diagnostic information from trainers was the possibility of misclassification of the type of injury or anatomic location. While trainers could also have classified injured horses as un–injured or vice–versa, this was considered less likely to occur with the possible exception of very mild conditions, because all trainers were full–time professionals, experienced in training and handling horses, and able to detect changes in gait and behaviour consistent with lameness and other conditions.

Data generated in the present study on racehorse injuries included any condition affecting the musculoskeletal system that resulted in a spell greater than 7–days in duration. Case data were therefore not directly comparable to studies limited to fatalities

(Johnson et al 1994; Estberg et al 1995, 1996a, 1996b, 1996c, 1998a, 1998b; Carrier et al 1998). Case data in the present study were also not directly comparable to studies of injuries incurred during a race (Peloso et al 1994; Cohen et al 1994, 1997, 1999; Bailey et al 1997), because data in the present study included injuries incurred either in a race or in training, as well as in racehorses that had not started in a trial or race prior to injury. Thirty-nine percent of fatalities that occurred in racehorses at a California racetrack were reported to be associated with training activities and not with racing (Johnson et al 1994), reinforcing the importance of considering injury data from all training horses and not just those horses in training that had started in a trial or race. Injury data used in the present study may be considered to reflect the breadth and range in severity of injuries that occur in a population of racehorses in training. The use of trainers as the primary source of injury information in the present study meant that there was more potential for misclassification bias in the present study compared with studies that derived injury data from necropsies or veterinary reports (Johnson et al 1994; Peloso et al 1994; Estberg et al 1995, 1996a, 1996b, 1996c, 1998a, 1998b; Bailey et al 1997; Cohen et al 1994, 1997, 1999; Carrier et al 1998; Williams et al 2001).

Measures of exercise intensity utilised in the current study were limited to data on races and trials that were obtained from NZTR. The measures of exercise intensity derived in this paper from NZTR records of trials and races appeared to be equivalent to those described in several other studies of racehorse injuries that incorporated information on officially timed workout sessions and races (Estberg et al 1995, 1996a, 1996b, 1996c, 1998a, 1998b; Carrier et al 1998, Cohen et al 2000). Although desirable to collect, detailed data relating to distances travelled and speed during training activity, and information on the training surface used by a horse on any given day, were not logistically possible to collect in this study. At most training venues in New Zealand trainers have a choice on any given day of several training surfaces such as sand, ploughed dirt, and turf, and several venues had more than one sand or ploughed dirt track. On any given day an individual horse may train on more than one surface and few trainers maintained detailed records on the particular surfaces used for all horses in their stables. It was also not possible to collect accurate information on distances and speeds during training sessions without having study personnel present at all training sessions. NZTR records of trials and races do represent an accurate measure of racing speed exercise accumulated by any horse. These measures were considered to be an under

representation of the total high-speed exercise load accumulated by any horse during a training preparation.

The outcome variable used in this study was defined as a first-occurrence injury to the lower limbs (foot to carpus or hock in fore- and hindlimbs, respectively), that resulted in an interruption to training >7-days in duration, and excluded accidental injuries resulting from misadventure unrelated to training activity. The most common sites of musculoskeletal injury in Thoroughbred racehorses have been demonstrated to involve structures at or below the carpus in the forelimb and hock in the hindlimb, and forelimb injuries were far more common than hindlimb (Peloso et al 1994; Cohen et al 1997; Williams et al 2001). A common pathogenesis was hypothesised to be involved in racehorse MSI, associated with accumulation of mild to moderate damage over time at a rate that exceeded the healing capacity of the affected tissues, as has been previously proposed for suspensory apparatus injury and humeral fractures in racehorses (Stover et al 1992; Hill et al 2001).

In our study, two different analyses were performed, the first employing information from all 459 incident cases. This analysis was not able to assess risk factors derived from start data because not all horses had started in a trial or race. The second analysis was restricted to those training preparations that were associated with one or more starts and therefore allowed inclusion of information derived from NZTR records of trials and races. In both analyses, injuries resulting in a case classification could have occurred either during training or during a race or trial start. The different associations observed in the two analyses may be attributed in part to different combinations of risk factors under consideration but also due to potential differences in the underlying populations of horses.

Adjustment for potential correlations associated with clustering was considered at the level of the horse by generating robust standard errors using horse identity as a clustering option, and at the level of trainer by adding trainer as a fixed effect to final models. Addition of a fixed effect coding for trainer resulted in a significant improvement in $-2 \log$ likelihood in both the training and starting models. Adding trainer to the models resulted in one trainer (trainer #15) being dropped from the model in Stata because of a complete absence of cases for that trainer, resulting in a loss of degrees of freedom and potentially of non-case information from that stable. A single case was randomly selected from all other cases and re-assigned to trainer #15 and the

analysis repeated in an attempt to determine the impact of omission of data from this trainer in the final models. In the training dataset the maximal observed change in coefficients and standard error terms for variables other than trainer was 5.1% and 2.1%, respectively and no changes were observed in statistical significance for any term. In the starting dataset maximal changes of 7.4% and 2% were observed in coefficients and standard error terms, respectively, for variables other than trainer, and no changes were observed in statistical significance for any variable. These results suggested little impact on the analyses from omitting non-case information from trainer #15.

Allowing for clustering at the level of horse in a model that already contained trainer, resulted in an increase in the magnitude of standard error terms with the size of the increase ranging from negligible to a maximum of 21.6%, and had no impact on direction of effect or significance of any variable. These findings of relatively little impact of clustering at the horse level were consistent with the fact that most horses contributed only one preparation and the average number of preparations per horse was less than 2 in both datasets.

There was evidence of significant variation in odds of MSI between trainers in both the analyses though this effect was largely due to one or two trainers. Coefficients and odds ratios were reported for individual trainer effects though the specific trainers involved in the study were not of primary interest. An alternative approach to analysis was to ignore the clustering at the horse level because of the low average number of preparations per horse and incorporate the effect of trainer as a clustering variable, or, to incorporate both horse and trainer effects as random variables in a multilevel, mixed effects model. The approach used in the present paper was considered appropriate as a means of accounting for both the possible clustering at the horse level and the effect of clustering at the trainer level. The significant effect of trainer does indicate that further research could be directed into better understanding variations in training methods between trainers and their associations with risk of MSI.

Older horses were more likely to be injured than younger horses with similar results in both analyses. There was no difference in either analysis between 2-year olds and horses aged either 3- or 4-years. These results were consistent with a non-linear pattern of age associated risk with little evidence of change in risk from 2-years to 4-years, followed by a rise in risk once horses reach 5-years of age. These findings were

consistent with previous reports. Estberg et al (1998a) reported a slight increase in age specific risk of catastrophic injury in California racehorses from 2- to 4-years of age followed by a levelling in risk, while Bailey et al (1997) reported a progressive rise in risk of serious injury as horse age increased (Bailey et al 1997). There was also evidence to suggest that risk of specific injuries may be age-dependent, for example shin soreness in younger horses (Moyer et al 1991), and tendon and ligament injuries in older horses (Williams et al 2001). Age-associated risk may in part be due to loss of healing or adaptive capacity in musculoskeletal structures as horses age, a change that has been documented for tendon and ligaments (Patterson-Kane et al 1997).

The finding of a significant effect of race year on risk of injury was unexpected. The past several years have seen rationalisation in the New Zealand Thoroughbred racing industry with reductions in the number of available races, the number of racing venues, and the number of starting horses as reported in a non-peer reviewed industry summary (Aldridge 2001). It is possible that these changes were associated with improvements in racetrack preparation and maintenance, potentially reducing the risk of injury. The effect of year may also be due in part to climatic effects associated with rainfall, temperature and wind, all of which can have major impacts on track surface characteristics. The finding that winter was associated with reduced odds of injury relative to other seasons may be due to higher moisture levels in racetrack surfaces in winter as a consequence of rainfall during a time of relatively lower temperatures and reduced evaporation. The observed seasonal effect in the present study was consistent with that reported by Mohammed et al (1991), while others have reported no association between injury risk and weather indices (Clanton et al 1991). In addition, the population of horses training at different times of the year may vary, and training methods may also reflect both season and horse population. The more capable horses were likely to be trained for higher profile and more valuable races, typically held in spring, early summer, and perhaps autumn. Less capable horses, and 2-year olds in their first preparations may be more likely to be in training in winter. Some of these effects were accounted for in the multivariate models but other unmeasured variables may be associated with the apparent effect of season.

A number of factors may be associated with the apparent reduction in likelihood of MSI in horses in later preparations compared with those in their first training preparation. Preparation number represented the number of the preparation in the longitudinal study

and not the lifetime preparation number for any horse, with the exception of horses that entered training for the first time during the study. Increasing preparation number therefore may have been a proxy for increased experience and adaptation to the demands of training in a general sense and also increased familiarity and understanding by trainers about each horse's individual responses to training and to conditions that might interfere with training. Horses in later preparations also were returning to work after a spell period and there were potential impacts resulting from the reason for the previous spell and the duration of the spell period. This information was not considered for inclusion in the statistical models because it was only available for preparations other than the first.

Horses that started in more trials in a preparation appeared to be at higher odds of MSI compared with those horses starting in fewer trials, though the low odds ratio (OR=1.5, 95% CI 1.08–2.08) and indicated a degree of caution in interpreting this effect as important. Trials represented officially sanctioned events that were run either to enable a horse to gain preference for a subsequent start in a particular race by virtue of a winning or place–getting performance in a trial (qualifying trials), or to provide race–like opportunities for education and training of novice horses and riders (non–qualifying trials). Horses returning to work after a spell are often entered in a trial as part of their final preparation before beginning to race. Horses that compete in a higher proportion of trials may represent animals that were not well adapted to the demands of training and racing, or not performing well enough to gain entry into races. These attributes may also be associated with lower potential value of the horses involved. It is possible that these horses may be carrying mild or chronic conditions, or recovering from previous MSI, events that could both impair performance to some level, and predispose them to subsequent MSI. Alternatively it is possible that low value horses are trained until they either perform, or incur an injury requiring spelling or retirement.

The two final models each contained variables representing measurements of exercise exposure. In the training dataset, preparations longer than 20 weeks in duration, and those where any starts occurred were associated with reduced likelihood of MSI. Both these measures indirectly represented level of exposure to high–speed exercise. Duration of training preparation was not retained in the second multivariate model and cumulative distance raced in the last 30–days was best represented by addition of a quadratic term to the model. As the cumulative distance raced increased, there was a

decline in the risk of MSI with the rate of decline levelling and then increasing as cumulative distance increased towards the maximum value. Increasing accumulation of high-speed exercise has been hypothesised as a risk factor for MSI in racehorses, and several authors reported associations between increased measures of cumulative exercise intensity and injury (Estberg et al 1995, 1996a, 1998a). Other studies have reported no association between measures of exercise intensity score and injury risk (Hill et al 2001), or a protective association (Cohen et al 2000). While musculoskeletal injuries may occur acutely in racehorses without any pre-existing condition, there appears to be general support for the hypothesis that many clinical musculoskeletal injuries are preceded by some level of cumulative microdamage over a period of time preceding the acute event, and associated with the stress of repetitive exercise (Pool et al 1990; Stover et al 1992; Hill et al 2001). The precise nature of any relationship between exercise and injury risk remains unclear however, due in part to difficulties in measuring exercise exposure. Most studies evaluating cumulative exercise intensity have used measures derived from official race records of distances run in trials and races, as in the present study. Such measures ignore any contribution from training and are at best an approximation of the exposure of horses to high-speed exercise. There are also issues surrounding the choice of an exposure window in which to produce exercise-intensity measures, and previous choices ranged from 7 (Hill et al 2001), to 30 (Estberg et al 1998a), or 60 days (Estberg et al 1995). Too short a window may not allow sufficient exposure to increase the risk of subsequent injury. Too long a window may result in failure to observe an exposure-risk relationship as a result of other data being incorporated into the analysis. Against this must be weighed the practical requirements of choosing a window long enough to allow sufficient data collection for analytical purposes. The present study considered both 30- and 60-day windows and selected a 30-day window for the final model based on comparison of likelihood ratio test statistics. Finally, the nature of any relationship between exercise history and injury was considered to be complex and multimodal. Horses that are currently racing may be considered a biased subset of the population of racehorses and may have a lower risk of injury than the entire population of training and racing horses, as an expression of survival bias (Dohoo et al 2003, pp 214). Survival bias may have contributed to the apparent protective effect observed in the present study between injury risk and increasing exposure to putative risk factors including the number of race

starts in a preparation, cumulative distance raced in the last 30 days of a preparation, and duration of the training preparation.

In conclusion, the present study has yielded valuable information on various exposures related to injury risk in training and racing horses in New Zealand. Further work is required particularly on the association between exercise exposure and injury risk to advance our understanding of the pathogenesis of musculoskeletal injury.

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Chapter 8

Risk factors for injury to the superficial digital flexor tendon and suspensory apparatus in Thoroughbred racehorses *

* Published as: NR Perkins, SWJ Reid, RS Morris. *New Zealand Veterinary Journal*, 53(3), 184-192, 2005.

Abstract

AIM: To investigate risk factors for injury to the superficial digital flexor tendon (SDFT) and suspensory apparatus (SA) of the forelimbs in Thoroughbred racehorses in New Zealand.

METHODS: Poisson and negative binomial regression with exposure time represented by cumulative training days for each horse study were used to relate explanatory variables to the incidence rate of cases of superficial digital flexor tendonitis (SDFT: $n=51$), and injuries involving the suspensory apparatus (SA: $n=48$). Only the first occurrence of an injury within any one horse was eligible for inclusion and all data from subsequent training preparations involving case horses was excluded from analyses. Separate analyses were run for data from horses in training regardless of whether they had started in a trial or race, and using a subset of these data restricted to those preparations associated with at least one start in a trial or race. Results were reported as incidence rate ratios (IRR) and 95% confidence intervals (CI).

RESULTS: Male horses had higher risk of injury to the SA (IRR 2.57, $p=0.005$) and tended to have a higher risk of injury to the SDFT (IRR 1.74, $p=0.09$) than female horses. Increasing age was associated with increased risk of injury. Horses aged 4– and ≥ 5 –years were 6.76 ($p<0.001$) and 15.26 ($p<0.001$) times more likely to incur injury to the SDFT, and 2.91 ($p=0.02$) and 3.54 ($p=0.005$) times more likely to incur injury to the SA, respectively, than 2–year olds. Horses were more likely to suffer an injury to the SDFT or SA if in a training preparation that was not associated with any starts in official trials or races compared with those preparations that were associated with $>one$ start ($p<0.001$), and more likely to injure the SA compared with preparations containing one start ($p=0.03$). The incidence rate (IR) of injury to the SDFT tended to be lower between November–January (IRR 0.78, $p=0.08$) and February–April (IRR 0.75, $p=0.08$) compared with August–October.

There was no association between injury to the SDFT or SA and training activity score (TAS) at the start of a training preparation, presence of spell periods <7 –days in duration during a training preparation in the population of training racehorses ($p>0.05$).

None of the additional variables considered in the restricted subset of data from training preparations that contained at least one start in a trial or race, showed a significant

association with incidence of injury to the SDFT or SA, including the cumulative distance raced in the last 30–days of a training preparation.

CONCLUSION: This study has identified risk factors for injury to the SDFT and SA in New Zealand racehorses. Injuries were more likely in males, older horses and in horses in training preparations without any starts. There was no evidence of association between injury and cumulative high–speed exercise.

Introduction

Musculoskeletal injuries in racehorses may involve disruptive change in a single type of tissue such as muscle, tendon, ligament, cartilage or bone, or some combination of these. The major anatomical sites of injury to the tendons or ligaments in Thoroughbred racehorses are the SDFT and ligaments associated with the SA (suspensory ligament and distal sesamoidean ligaments) of the lower forelimb (Cohen et al 1997; Hill et al 2001; Williams et al 2001). The most common reported combination of anatomical sites affected by serious injury in racing horses was the suspensory ligament and proximal sesamoid bones of the forelimb (Cohen et al 1997) and the most common site of musculoskeletal injury in racehorses that died or were euthanised while training or racing at California racetracks, was the proximal sesamoid bone and suspensory apparatus and the third metacarpal bone (Johnson et al 1994). A number of studies have since utilised an outcome measure defined as injury or failure of the SA of the forelimb that included any condition involving the suspensory ligament, distal sesamoidean ligaments or the proximal sesamoid bones (Kane et al 1996, 1998; Cohen et al 1997, 1999).

Injuries to structures of either the SDFT or SA represent an important cause of wastage in racehorses, both because of morbidity and because affected animals may be forced to retire from racing or endure prolonged recovery periods before they are capable of returning to athletic function (Goodship et al 1994). Cumulative incidence estimates of 30% for injuries involving the SDFT in training horses have been proposed (Goodship et al 1994), while a recent longitudinal study reported an incidence rate of injury of tendons or ligaments of 2.77 cases per 1,000 race starts in flat–racing Thoroughbreds in the United Kingdom (Williams et al 2001). Injuries of the tendons and ligaments have been reported as the most common limb injury in Thoroughbreds in the United Kingdom, accounting for 46% of all limb injuries (Williams et al 2001), and injury of

the SA of the forelimbs was reported in 59/132 (44.7%) cases of injuries that occurred during racing in Kentucky (Peloso et al 1994). The prognosis for racehorses with injured SDFTs is best described as guarded and as many as 20–60% of affected horses reportedly return to racing but up to 80% subsequently sustain a recurrent injury (Dowling et al 2000). Dyson et al (1995) reported up to 86% of cases of forelimb proximal suspensory desmitis returning to full work after treatment and rehabilitation but a guarded long-term prognosis as a result of the risk of reoccurrence (Dyson et al 1995). In contrast, desmitis involving the distal regions of the suspensory ligament or suspensory ligament branches was associated with a higher risk of catastrophic breakdown of the SA and a poorer prognosis. Breakdown of the SA may involve fracture of the proximal sesamoid bones, avulsion of the distal sesamoidean ligaments, or severe disruption of the suspensory ligament body or branches (Dyson et al 1995; Kane et al 1996, 1998), and is almost always a career-ending injury and may result in euthanasia of the affected horse.

The past several years have seen considerable developments in the understanding of the pathogenesis of injuries of the tendons and ligaments as evidenced by review articles discussing the SDFT (Dowling et al 2000; Smith et al 2000) and suspensory ligament desmitis (Dyson et al 1995). A number of studies have investigated risk factors for injury to the SDFT or SA in racehorses. A study of racehorses euthanised while training or racing at California racetracks reported that more ruptured ligaments occurred as a result of injuries sustained during racing than during training, and that no ruptured ligaments occurred in 2-year-olds (Johnson et al 1994). A case-control study of racehorses in Kentucky reported increased odds of injury to the SA of the forelimb in horses that had pre-race summary assessments of increased risk of injury, detectable pre-race abnormality involving the SA or fetlock joint, a change in the lead limb in the 12 seconds prior to injury occurring, increase in race distance from the previous start, and increasing number of career wins (Cohen et al 1997). Increased odds of catastrophic injury to the SA were observed in horses shod with toe grabs (Kane et al 1996) and reduced odds in horses shod with rim shoes (Kane et al 1996), and measures of sole area and toe-heel angle of the feet were also reported to be significantly associated with fatal injury to the SA in California racehorses (Kane et al 1998). A recent study of injuries of the SDFT and suspensory ligament in Thoroughbreds in Japan reported increased prevalence of both injuries in intact males compared with

females or geldings and as age increased (Kasashami et al 2004), and intensive exercise has been hypothesised as a risk factor in observational (Hill et al 2001), and simulation studies (Hill et al 2003).

The aim of the present case–control study was to investigate risk factors that might influence the incidence rate of injuries of the SDFT and structures of the SA of the forelimb in racehorses training and racing in New Zealand.

Materials and methods

Details of the design of the longitudinal study have been described previously (Perkins et al 2005a,b). Briefly data were collected at approximately monthly intervals over a 34–month period from 20 trainers located in the central and lower regions of the North Island of New Zealand, commencing in October 1997. All horses trained at stables of participating trainers were enrolled in the study and data collection involved 1,571 horses and 554,745 study days. Trainers represented a convenience sample selected from five major regional training venues based on their willingness to participate in the study.

Data collection

A custom designed questionnaire was used at each visit to collect data on all horses in the stable concerning training and racing activity since the last visit, and any conditions or injuries that resulted in interference with training and racing. Injuries and other conditions interfering with training or racing were only recorded if they resulted in an interruption to training that was more than 7–days in duration, in order to minimise recording of trivial events.

Complete training preparations began on the day a horse entered a stable to begin training, and ended when the horse began a spell period that was >7–days in duration, retired from racing, or died. Incomplete training preparations had a known start date as for complete preparations but did not have a known end date and included instances where horses changed trainers to a trainer not participating in the study while still in training, and those horses that were in training at the time the study ended. The recorded end date for incomplete training preparations was the last day the horse was in the stable or the day the study ended. Horses contributed one or more training preparations to the study and successive training preparations in the same horse were separated by a spell period.

A training activity score (TAS) was used to record the level of training activity achieved by each horse in the period between visits. TASs were defined as spell (TAS=1), walk or trot (TAS=2), activity up to but not exceeding a canter (TAS=3), fast work but not yet starting in a trial or race (TAS=4), and horses that had started in at least one trial or race since the last visit (TAS=5).

Data were collected at multiple levels. Trainer level information included trainer identity and the identities of all horses being trained by that trainer. Trainers in New Zealand have a fixed location and do not move between training venues. Training venues are maintained by raceclubs responsible for maintenance of track surfaces at the venue. Most venues have multiple tracks available for use by trainers. Horse level variables included horse identity, gender (male or female), and birthdate. Training preparation variables included start and end dates, whether a preparation was complete or incomplete, number of starts in trials and races during the preparation, and reason for ending the preparation. Information on starts in trials and races were obtained from New Zealand Thoroughbred Racing (NZTR) records and included date of race or trial, identity of all horses that started, distance, prizemoney, and finishing position of all horses in the race or trial.

Days in each training preparation were identified by quarter and race-year. Race-years were divided into quarters using the following cutoffs; 01 November–30 January, 01 February–30 April, 01 May–31 July, and 01 August–31 October. The cutoff dates were chosen to allow a new quarter to begin on the first day of the race-year. Dates defining the start (01 August) and end (31 July) of a race-year in New Zealand are determined by the NZTR and all horses age by one year on 01 August of each year following their birth. Horse age was divided into 2-, 3-, 4-, and ≥ 5 -years and age increased by one year on 01 August of each year during the study.

A variable coding for number of starts in a training preparation was generated with three levels to represent no starts, one start, or more than one start during the preparation. Binary variables were generated to code for presence or absence of spell periods ≤ 7 days during a training preparation, and for TAS recorded at the start of a preparation (TAS= 2 or 3, TAS=4 or 5).

Additional variables were generated for those preparations in which at least one start was recorded in a trial or race. The main variable of interest in this restricted dataset

was the cumulative distance in furlongs (1 furlong=200 metres), raced in either trials or races in the last 30-days of a training preparation, as a measure of exposure to high-speed exercise. Binary variables were generated for the proportion of starts that were trials (≤ 0.2 , > 0.2), proportion of starts that resulted in 1st, 2nd or 3rd placing (≤ 0.2 , > 0.2), and presence or absence of any starts in hurdle or steeplechase races during the preparation. New Zealand Thoroughbred racing is dominated by flat races and hurdles and steeplechase events comprise about 5–6% of all races on offer in any one race-year. In addition, a categorical variable was generated to code for class of start, and had three levels representing trial, race with prizemoney $\leq \$50,000$, and race with prizemoney $> \$50,000$.

All Thoroughbred racehorses enrolled in the longitudinal study and diagnosed with an injury involving either SDFT, or components of the SA (suspensory ligament, proximal sesamoid bones of the forelimb, distal sesamoidean ligaments) were included in this study as case horses. Only the first occurrence of either injury in any one horse was classified as a case and all cases marked the end of a training preparation for that horse. All information from case horses that was collected after the first occurrence of an injury was excluded from analysis.

All training preparations that involved horses of known age, and that did not end in the horse being diagnosed as a case, were eligible to contribute time-at-risk. Training preparations that involved case-horses contributed time-at-risk up until the time of first injury to the SDFT or SA.

Two separate datasets were generated for SDFT and SA analyses. The first dataset contained all records from eligible case and non-case preparations and the second dataset was a subset of the first that contained only training preparations where at least one start had been recorded in a trial or race during that preparation. These were termed the training and starting datasets, respectively.

Statistical analysis

Poisson and negative binomial regressions were performed on the data. Exposure time for each horse was the cumulative days measured during training preparations for each horse. Each dataset contained a binary outcome variable coding for injury to the SDFT or SA.

An initial Poisson model was fitted to each dataset that contained only an intercept term and a random effect coding for horse identity, to assess for the presence of clustering at the level of horse, by determining whether a horse-level variance term was different to zero. In all models the variance at the horse level was not different from zero ($p \geq 0.5$), indicating a lack of evidence for any meaningful clustering at the level of horse. All model development was then completed by including a random effect coding for trainer identity to account for possible clustering at the trainer level.

The number of cases and the total training-days-at-risk accumulated by each trainer were used to produce incidence rate (IR) and 95% confidence interval (CI) estimates for each trainer. For those trainers that had no cases, the lower confidence interval was bounded at zero and an upper 97.5% confidence interval for IR was estimated. IRs were expressed as a rate per 1,000 horse-training-days.

Univariate Poisson regression models that contained a random effect for trainer were then fitted to obtain IR and CI measures for each variable. All variables were then considered for inclusion in multivariate models using Poisson and negative binomial regression, and a backwards stepwise model building approach, followed by consideration of plausible two-way interaction terms. Datasets were organised into covariate patterns using the covariates present in the final model and goodness-of-fit tests estimated using a Poisson regression. If the Pearson Chi-squared goodness-of-fit test returned a significant result then the analysis was completed using negative binomial regression (Gardner et al 1995; Dohoo et al 2000 Pp 391–406). Likelihood ratio tests were used to determine the significance of variables in the model and incidence rate ratios (IRR) and 95% confidence intervals for IRR estimates were used to represent associations between risk factors and outcome in final models. Residuals and outliers were assessed to determine their impact on the coefficients as described in Dohoo et al (2000, Pp 391–406).

Separate analyses were performed for SDFT injury and for SA injury and for training and starting datasets. All analyses were performed in STATA (Intercooled STATA 8.2 for Windows, StataCorp LP, College Station, Texas, USA). Variables were retained in the final model if the associated p -value was < 0.1 with values between 0.05–0.1 being identified as associated with a nonsignificant tendency towards an effect.

Results

The complete longitudinal dataset involved information on 3,333 training preparations and 1,571 horses. Seventeen horses were excluded due to unknown age, and 23 and 37 preparations were excluded from the SDFT and SA datasets, respectively, because they involved case horses returning to training after the first occurrence of injury to the SDFT or SA.

The training dataset for injury to the SDFT contained information from 51 case and 1,503 non-case horses and the starting dataset from 33 case and 1,274 non-case horses, respectively.

The training dataset for injury to the SA included 48 case and 1,506 non-case horses and the starting dataset from 29 case and 1,270 non-case horses.

Twenty trainers contributed data to the study and estimates of number of cases of injury to the SDFT and SA, training days-at-risk, IR, and CI are presented in Table 8.1 for each trainer and for the overall incidence. A total of 51 first occurrence cases of injury to the SDFT were reported with an overall IR of 0.13 cases per 1,000 horse-training-days (CI 0.098–0.17). Forty-eight cases of injury to the SA were reported for an overall IR of 0.12 (CI 0.092–0.17). When trainer was added as a random effect to a Poisson regression model containing only an intercept, there was evidence of significant variation in IR for both SDFT ($p=0.03$) and SA ($p=0.006$) at the trainer level.

Table 8.1. Number of cases, training days-at-risk, incidence rate (IR) per 1,000 training-days, and 95% confidence interval (CI) for the incidence rate, by trainer, for superficial digital flexor tendon (SDFT) and suspensory apparatus (SA) injury.

Trainer	Superficial digital flexor tendon injury					Suspensory apparatus injury				
	Cases	Days at risk	IR	95% CI		Cases	Days at risk	IR	95% CI	
				Lower	Upper				Lower	Upper
1	1	22,363	0.045	0.001	0.25	4	21,976	0.182	0.05	0.47
2	0	12,543	0	0	0.29 ^a	1	12,543	0.08	0.002	0.44
3	5	9,888	0.51	0.16	1.18	0	9,950	0	0	0.37 ^a
4	1	4,106	0.24	0.006	1.36	0	4,198	0	0	0.88 ^a
5	2	22,198	0.090	0.011	0.33	2	21,936	0.091	0.011	0.33
6	4	27,333	0.15	0.04	0.37	1	27,186	0.037	0.001	0.2
7	3	18,841	0.16	0.033	0.47	1	19,095	0.052	0.001	0.29
8	2	15,723	0.13	0.015	0.46	1	15,487	0.065	0.002	0.36
9	1	11,405	0.088	0.002	0.49	1	11,405	0.088	0.002	0.49
10	0	18,546	0	0	0.20 ^a	1	18,546	0.054	0.001	0.3
11	2	10,942	0.18	0.022	0.66	1	10,942	0.091	0.002	0.51
12	7	24,394	0.29	0.12	0.59	1	25,330	0.04	0.001	0.22
13	6	33,024	0.18	0.067	0.4	9	31,338	0.29	0.13	0.55
14	3	38,841	0.077	0.016	0.23	9	37,782	0.24	0.109	0.45
15	0	5,149	0	0	0.72 ^a	0	5,149	0	0	0.72 ^a
16	1	42,532	0.024	0.001	0.13	2	42,532	0.047	0.006	0.17
17	1	15,701	0.064	0.002	0.35	7	14,617	0.48	0.19	0.99
18	3	12,194	0.25	0.051	0.72	1	12,858	0.078	0.002	0.43
19	8	27,327	0.29	0.13	0.58	6	27,407	0.22	0.08	0.48
20	1	9,489	0.105	0.003	0.59	0	9,489	0	0	0.39 ^a
Total	51	382,539	0.13	0.099	0.18	48	379,766	0.13	0.093	0.17

^a One-sided 97.5% confidence interval

Counts of first occurrence cases, training days at risk, incidence rates (IR) and 95% confidence intervals (CI) for injury to the SDFT in different categories of age, gender, year, quarter, number of starts, presence of days at TAS=1 and TAS at the start of a preparation, are presented in Table 8.2.

Table 8.2. Number of cases of superficial digital flexor tendon injury, training days-at-risk, incidence rate (IR) per 1,000 training-days, and 95% confidence interval (CI) for the incidence rate. All estimates derived from univariate Poisson regression models that incorporated trainer as a random effect.

Variable	Category	Cases	Days at risk	IR	95% CI	
					Lower	Upper
Age (years)	2	6	106,908	0.056	0.024	0.13
	3	6	124,892	0.048	0.021	0.11
	4	12	81,670	0.15	0.080	0.28
	≥5	27	69,069	0.40	0.25	0.62
Sex	Female	14	184,973	0.079	0.044	0.14
	Male	37	197,566	0.19	0.13	0.28
Quarter	Nov–Jan	8	101,891	0.083	0.040	0.17
	Feb–Apr	14	93,179	0.16	0.087	0.28
	May–July	16	93,113	0.17	0.10	0.30
	Aug–Oct	13	94,356	0.14	0.078	0.26
Year	1996–1997	0	5,890	NE		
	1997–1998	9	60,395	0.16	0.077	0.32
	1998–1999	18	166,084	0.11	0.066	0.19
	1999–2000	24	150,170	0.16	0.10	0.26
Starts during a preparation	0	18	51,140	0.39	0.23	0.69
	1	5	36,672	0.14	0.055	0.35
	>1	28	294,727	0.096	0.060	0.15
Training days at TAS=1 during prep	None	50	355,269	0.15	0.100	0.21
	Any	1	27,270	0.038	0.005	0.28
TAS at prep start	2 or 3	32	240,066	0.14	0.092	0.22
	4 or 4	19	142,473	0.13	0.077	0.22

TAS= training activity score

NE= not estimated

IR for injury to the SDFT was highest in horses aged 5–years or older, male horses, between February–July, the 1999–2000 race–year, in preparations that did not have any starts in trials or races, preparations with no training days at TAS=1, and those preparations where TAS=2 or 3 at the beginning of the preparation.

Table 8.3. Number of cases of suspensory apparatus injury, training days–at–risk, incidence rate (IR) per 1,000 training–days, and 95% confidence interval (CI) for the incidence rate. All estimates derived from univariate Poisson regression models that incorporated trainer as a random effect.

Variable	Category	Cases	Days at risk	IR	95% CI	
					Lower	Upper
Age (years)	2	10	109,200	0.088	0.044	0.18
	3	14	124,136	0.10	0.055	0.19
	4	11	81,567	0.13	0.065	0.24
	≥5	13	69,779	0.18	0.099	0.34
Sex	Female	12	186,289	0.061	0.032	0.12
	Male	36	198,393	0.17	0.11	0.26
Quarter	Nov–Jan	16	101,710	0.15	0.083	0.26
	Feb–Apr	9	92,854	0.090	0.044	0.18
	May–July	17	93,390	0.17	0.098	0.30
	Aug–Oct	6	96,728	0.062	0.026	0.14
Year	1996–1997	0	5,890	not estimated		
	1997–1998	5	60,752	0.083	0.033	0.21
	1998–1999	25	166,663	0.14	0.085	0.23
	1999–2000	18	151,377	0.12	0.066	0.20
Starts during a preparation	0	19	55,816	0.35	0.20	0.60
	1	4	36,527	0.10	0.037	0.29
	>1	25	292,339	0.078	0.047	0.13
Training days at TAS=1 during prep	None	44	357,178	0.12	0.077	0.18
	Any	4	27,504	0.14	0.048	0.38
TAS at prep start	2 or 3	30	242,351	0.12	0.077	0.20
	4 or 4	18	142,331	0.11	0.062	0.19

TAS= training activity score

Counts of first occurrence cases, training days at risk, IRs and CIs for injury to the SA in different categories of age, gender, year, quarter, number of starts, presence of days at TAS=1 and TAS at the start of a preparation, are presented in Table 8.3. IR for injury to the SA was highest in horses aged 5-years or older, male horses, between May–July, the 1998–1999 race-year, in preparations that did not have any starts in trials or races, preparations with any training days at TAS=1, and those preparations where TAS=4 or 5 at the beginning of the preparation.

Table 8.4. Results of a multivariate, negative binomial regression model for risk of superficial digital flexor tendon injury in racehorses, reported as incidence rate ratios (IRR) and 95% confidence intervals (CI). The final model contained a random effect coding for trainer.

Variable	Category	Coefficient	se	IRR	95% CI		p-value
					Lower	Upper	
Sex	Female	Ref					
	Male	0.55	0.33	1.74	0.92	3.31	0.09
Age (years)	2	Ref					
	3	0.53	0.59	1.70	0.53	5.40	0.4
	4	1.91	0.53	6.76	2.39	19.10	<0.001
	≥5	2.73	0.49	15.26	5.83	39.97	<0.001
Starts during a prep	0	Ref					
	1	-0.93	0.52	0.40	0.14	1.10	0.07
	>1	-2.08	0.34	0.13	0.06	0.24	<0.001
Quarter	August–October	Ref					
	November–January	0.78	0.44	2.17	0.91	5.19	0.08
	February–April	0.75	0.44	2.13	0.90	5.01	0.08
	May–July	0.56	0.46	1.76	0.72	4.29	0.22

se= standard error

Ref=reference level

Table 8.4 presents results from the final model for injury to the SDFT. The goodness-of-fit test for the Poisson model returned a significant result indicating the data did not fit a Poisson distribution (Chi-squared statistic=2,277, degrees of freedom=1,341, $p<0.001$). The final model was run as both a Poisson and a negative binomial regression. Values of the coefficients and standard error terms differed by <0.01%, and log likelihood values for the two models were identical. Results presented are derived from the negative binomial model. No interaction terms were significant. The random effect for trainer was significant in the final model ($p=0.016$). The minimum and

maximum values of standardised deviance residuals were 3.4 and -1.4, respectively, and there was only a single value >3 . The largest value of Cook's statistic was 0.046 indicating that no covariate pattern had a great influence on the model coefficients. Inspection of the covariate pattern associated with the largest residuals did not reveal any unusual values and there was no reason to remove the covariate. Male horses were 1.74 (CI 0.92–3.31) times more likely to incur injury to the SDFT compared with females, though the effect was not significant ($p=0.09$). There was a progressive increase in risk with increasing age, and all age groups were significantly different to each other. IRR for 4- and ≥ 5 -year-olds compared with 3-year-olds were 3.98 (CI 1.48–10.71, $p=0.006$), and 8.99 (CI 3.61–22.37, $p<0.001$), respectively, while the IRR for ≥ 5 -year-olds compared with 4-year-olds was 2.26 (CI 1.12–4.56, $p=0.023$). There was a progressive reduction in risk of injury to the SDFT as the number of starts in a preparation increased from 0 to more than 1. The IRR for >1 start compared to 1-start only was 0.32 (CI 0.12–0.84, $p=0.02$). There was a tendency towards an effect of quarter with horses in training between November–April being more likely to incur injury to the SDFT than those in training from August–October, though the effect was not significant ($p=0.08$).

Table 8.5 presents results from the final multivariate model for injury to the SA. The goodness-of-fit test for the Poisson model returned a non-significant result indicating the data did fit a Poisson distribution (Chi-squared statistic=346, degrees of freedom=400, $p=0.97$). The final model was run as both a Poisson and negative binomial regression and the outputs of the two models were identical. No interaction terms were significant. The random effect of trainer accounted for a significant amount of variation ($p=0.005$) indicating clustering at the level of trainer.

Table 8.5. Results of a multivariate, negative binomial regression model for risk of suspensory apparatus injury in racehorses, reported as incidence rate ratios (IRR) and 95% confidence intervals (CI). The final model contained a random effect coding for trainer.

Variable	Category	Coefficient	se	IRR	95% CI		p-value
					Lower	Upper	
Sex	Female	Ref					
	Male	0.94	0.34	2.57	1.32	4.99	0.005
Age (years)	2	Ref					
	3	0.72	0.43	2.05	0.88	4.77	0.096
	4	1.07	0.47	2.91	1.16	7.28	0.02
	≥5	1.26	0.46	3.54	1.45	8.64	0.005
Starts during a preparation	0	Ref					
	1	-1.20	0.56	0.30	0.10	0.90	0.03
	>1	-1.88	0.34	0.15	0.08	0.29	<0.001

se= standard error

Ref=reference level

There were no standardised deviance residuals that were >3 or <-3 and the maximum and minimum values were 2.9 and -1.6 , respectively. The maximal value of Cook's statistic was 0.07 indicating that no covariate pattern had a great influence on the coefficient values. Results were similar to those reported for injury to the SDFT. Male horses were 2.57 (CI 1.32–4.99) times more likely to incur SA injury compared with females. Horses aged 4– ($p=0.02$) and ≥ 5 –years ($p=0.005$) were significantly more likely to incur SA injury compared with 2–year–olds, while there was a non–significant tendency for 3–year–olds to have a higher risk than the reference group ($p=0.096$). No other comparisons between age groups were significant ($p>0.05$). Preparations that had either one or $>one$ start were at less risk of SA injury compared with those that had no starts ($p=0.03$ and <0.001 , respectively), but there was no difference between preparations with one and those with $>one$ start ($p=0.22$).

None of the additional variables under consideration in the starting datasets, and that were not considered in the training datasets, were significant in either univariate or multivariate models. In the SDFT starting dataset, univariate p –values >0.25 were reported for cumulative distance raced in the last 30–days of a training preparation ($p=0.4$), proportion of starts that resulted in a 1st, 2nd or 3rd placing ($p=0.4$), proportion

of starts that were trials ($p=0.7$), class of start ($p=0.9$). The only additional variable with a univariate p -value <0.25 was whether a horse had started in any hurdle of steeplechase races during the preparation ($p=0.12$). Similar results were reported for the SA starting dataset with p -values of 0.34, 0.40, 0.18, 0.9, and 0.43 reported for cumulative distance raced in the last 30-days, proportion of starts that resulted in a 1st, 2nd or 3rd placing, proportion of starts that were trials, class of start, and whether a horse had started in any hurdle of steeplechase races during the preparation, respectively. All variables were still considered for multivariate models regardless of their univariate p -value and final multivariate models for the starting datasets did not contain any of the additional variables generated from the starting datasets that were not in the training datasets. Results from analyses of starting datasets are therefore not presented since these datasets represented restricted subsets of the training datasets with smaller sample size, smaller numbers of cases, and contributed no new information.

Discussion

This study used an epidemiologic approach to investigate potential risk factors for injury to the SDFT and SA of the forelimb in training and racing Thoroughbreds. The longitudinal study design involved prospective collection of data from an open population of horses in training. A more detailed discussion of aspects of the design of the study can be found in related publications (Perkins et al 2005a, b, c).

Trainers were not a random or representative sample from the population of all Thoroughbred trainers in New Zealand, because they represented a convenience sample of trainers from five regional venues. Venues were selected because they were major training venues that were geographically close to the principal author to facilitate data collection, and trainers were asked to participate based on a subjective assessment of their willingness to contribute information over a prolonged period of time.

There was no opportunity for trainers to exert selection bias by choosing horses to enrol in the study because all horses being trained by a participating trainer were enrolled in the study.

Diagnostic information on injuries and conditions that interfered with training and racing were collected from trainers and not from veterinarians. A nested study that involved a subset of trainers was performed to assess the level of veterinary involvement in diagnosis of conditions affecting racehorses (Perkins et al 2005b), and

reported that veterinarians were directly involved in the diagnosis of tendon and ligament injuries in 65% of cases. There was therefore a risk of misclassification either of injured horses as uninjured or uninjured horses as injured, as well as anatomical location of injury. All trainers were professionals making their livelihood from training and racing horses, all worked closely with an attending veterinary surgeon to care for their horses, and all were able to detect changes in gait and behaviour consistent with lameness and other conditions.

Measures of exercise intensity used in the present study were limited to data that could be obtained from NZTR records concerning trials and race completed by horses in New Zealand. Such information is equivalent to similar measures of exercise intensity used in a number of previous studies (Estberg et al 1995, 1996a, 1996b, 1998a, 1998b; Carrier et al 1998, Cohen et al 2000).

Data used in the present study were collected prospectively on an open population of horses observed during training and racing. A Poisson regression model was chosen for analyses because of the ability to model the incidence rate of new cases while adjusting for the amount of time each animal was at risk (Dohoo et al 2003, Pp 398–399). Negative binomial models may be considered as a generalisation of the Poisson model, that account for overdispersion by allowing the variance of the outcome to be larger than the mean (Allison 1999). The Pearson goodness-of-fit test was significant for the SDFT dataset and not significant for the SA dataset. A negative binomial model was used for the SDFT dataset though the results of the two models were not different in any meaningful way, suggesting that the amount of overdispersion in dataset had little impact on the model output.

Two different multivariate models were used in the present study to evaluate risk factors for both SDFT and SA injury. One model employed information from horses in training and included data from horses that started in trials and races as well as those that did not. The only variable related to starts that was considered in training models was a variable coding for no, one or >1 starts. The second model for each outcome was restricted to a subset of the data derived from horse preparations associated with at least one start in a trial or race, an approach designed to assess explanatory variables associated with race characteristics, particularly the cumulative race distance in the last 30-days of a training preparation. In a companion paper we have reported that the cumulative distance raced in the last 30-days of a training preparation demonstrated a

quadratic relationship with the likelihood of musculoskeletal injury in racehorses (Perkins et al 2005). There was an initial reduction in likelihood of injury as cumulative distance increased from minimal levels to a value around 20 furlongs per 30-days, and then as cumulative distance increased further the likelihood of injury began to increase. Others have also reported an association between cumulative distances raced and risk of fatal musculoskeletal injury (Estberg et al 1995, 1996a, 1998a, b).

No such relationship was detected in the current study and differences may be attributed to the different outcomes under study and different analytical techniques. The current study was limited to injuries to the SDFT and the SA of the forelimbs only, while our previous study (Perkins et al 2005c) defined an outcome comprised of all types of injury to all lower limbs. The current study adjusted for time-at-risk using Poisson modelling and the previous study utilised logistic regression and considered duration of training preparation as a fixed effect in the model. In addition, it is possible that the current study lacked statistical power due to the relatively low number of cases under study. In an attempt to assess this, an analysis was completed on the starting dataset by combining both outcome variables into a single outcome containing 62 cases of injury to either the SDFT or SA. The results were not different to those from the two separate starting analyses and there was no association between cumulative distance raced in the last 30-days and incidence of injury to the SDFT and SA combined ($p=0.4$). No results were presented from these models because the data represented a subset of the same data used for the training dataset and because the results were not different from those presented for the training datasets.

Similar risk factors were identified for injury of both the SDFT and SA, suggesting similarity in the pathogenesis of these two types of injury in racehorses. This was consistent with the hypothesis previously proposed that musculoskeletal injuries result from repetitive microtrauma accumulated over time at a rate that exceeds the adaptive or healing capacity of the tissue involved (Stover et al 1992; Hill et al 2001).

A number of intrinsic and extrinsic risk factors were identified in the present study as being statistically associated with injuries to the SDFT and SA, contributing to an improved understanding of soft tissue injury in racehorses.

There were clear associations between horse gender and age group and risk of injury to both the SDFT and SA. Increasing horse age was associated with a progressive increase

in injury risk, and male horses were more likely to incur injury than females. There were differences in strength of association with the observed IRRs for increasing age being considerably larger for injury to the SDFT than the SA, while the increase in risk observed in males was significant for injury to the SA and not significant for injury to the SDFT. Several previous studies reported an association between increasing age and a general risk of serious musculoskeletal injury (Hill et al 1986; Estberg et al 1996b; Bailey et al 1997; Williams et al 2001) and a recent study of Japanese racehorses reported horses ≥ 3 -years were more than twice as likely to incur injury to the SDFT or SA compared with 2-year-olds, and that the risk of either injury appeared to increase with increasing age (Kasashima et al 2004). Williams et al (2001) reported a dramatic increase in the rate (cases per 1,000 starts) of injuries involving tendons or ligaments in Thoroughbreds aged ≥ 5 -years compared with younger horses. An age-associated risk of injury to the tendon was also consistent with reports of changes in microstructure and mechanical strength of tendons in older horses that may predispose such horses to exercise-related injury involving the tendon (Gillis et al 1997; Patterson-Kane et al 1997; Smith et al 1999). Horse age was also confounded to a varying degree with other factors such as the level of exposure to training and racing. Older horses have had greater opportunity to train and race and therefore greater risk of exposure to repetitive microtrauma, a postulated predisposing cause of clinical musculoskeletal injury in racehorses (Pool and Meagherr 1990; Mohammed et al 1991). In addition, the type of training and racing activities completed by racehorses tend to change with age. Younger horses tend to spend a lower proportion of their time training and racing (Perkins et al 2004), race over shorter distances, and are less likely to start in hurdle or steeplechase events (Williams et al 2001). As a result there remains some difficulty in attributing a perceived association between age and injury to direct or indirect effects of age on musculoskeletal structures for example, or to other risk factors that may be confounded with age.

Male horses were significantly more likely to incur injuries to the SA than female horses and showed a tendency for increased risk of injury to the SDFT. Kasashima et al (2004) reported that the prevalence of injury to the SDFT and SA was higher in intact males than in geldings or females in the population of horses training and racing in Japan. It was not possible to differentiate intact males from geldings in the current study and this may have contributed to a reduced effect of gender compared to the findings by

Kasashima et al (2004). Other studies reported an increased risk of serious or catastrophic injury in male horses compared with females (Estberg et al 1996b, 1998; Cohen et al 1999; Hernandez et al 2001). Studies of catastrophic injuries have acknowledged that a gender-associated difference in management of seriously injured horses may have influenced the perception of such an association since female horses may be more likely to be treated for serious injury in order to salvage a breeding career while male horses may be more likely to be euthanised following a career-ending injury (Estberg et al 1996b). The authors are unaware of data to substantiate this hypothesis and alternative explanations for a gender effect include direct or indirect effects of sex hormones on tissue characteristics or animal behaviour, or on extrinsic factors such as training methods or racing patterns.

The tendency for an effect of quarter on injury to the SDFT was consistent with reduced risk of injury during late winter and early spring. We have previously reported a reduced risk of injury to musculoskeletal structures of the lower limbs in training preparations that ended in winter compared to other months (Perkins et al 2005c). The definitions for seasons used in the previous paper were moved by one month from those in the current paper. The current paper defined the first quarter of the racing year as 01 August to 31 October while the previous paper defined winter as 01 June to 31 August. The change in the current paper was made to avoid horses aging by one year within one quarter. Seasonal effects are considered likely to be mediated through climate related factors such as rainfall and level of evaporation, and associated effects on track surface conditions. Further work is required to determine whether this association is meaningful and which factors might be driving the association.

Horses that started in either one or >one trial or race during a training preparation had reduced risk of injury to the SDFT or SA compared with those horses that did not start in a trial or race. This variable was considered to reflect some measure of exposure to high-speed exercise and the highest risk was in the group that had accumulated the least exposure, consistent with the hypothesis that horses were at higher risk of injury to the SDFT or SA in the earlier phases of a training preparation, before they have started in an official trial or race. This hypothesis was consistent with the lack of association in the starting datasets between the cumulative distance raced in the last 30-days of a preparation and injury to either the SDFT or SA. Exposure to high-speed exercise may be less important in contributing to risk of injury to the SDFT or SA than other factors,

though this study has only identified age and gender from the other factors under consideration. This finding differs from previous studies where increased exposure to high-speed exercise has been associated with increased risk of catastrophic musculoskeletal injury (Estberg et al 1995, 1996a, 1998), and from a recent simulation study that suggested an association between cumulative high-speed distance run in training and racing and risk of injury to SA (Hill et al 2003). Differences in study design and in outcome definition may have contributed to different findings between this study and previous reports that identified an association between exercise intensity and risk of injury.

Caution is urged in interpreting a lack of association between incidence of injury to the SDFT or SA and measures of exposure to exercise in this study because of difficulties in accurately representing the exercise load accumulated by racehorses. Logistical demands in the data collection phase of this study meant that relatively little detailed information was collected on the distance covered at different velocities by horses during training and racing, or on the surface characteristics of training and racing tracks. Collecting information on these variables remains challenging though the development of miniaturised electronic equipment incorporating global positioning system (GPS) capabilities may facilitate this process in future studies.

This study identified significant risk factors for injury to the SDFT and SA in training and racing Thoroughbreds. Risk of injury was higher in male than female horses, in older horses, and in horses that had not yet started in a trial or race during a training preparation.

Acknowledgements

The authors gratefully acknowledge funding support from the New Zealand Equine Research Foundation, and NZTR for provision of data. The assistance of Ms Dagmar Fikken in data collection is also acknowledged as is the commitment and assistance of veterinarians, track managers, trainers and their staff.

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Chapter 9

Survival analysis of musculoskeletal injuries during training and racing in New Zealand Thoroughbreds

Abstract

AIM: To investigate risk factors for first occurrence of each of three classes of lower-limb, musculoskeletal injuries: shin soreness(SS), superficial digital flexor tendonitis (SDFT), and lameness (LS), in Thoroughbred racehorses in New Zealand.

METHODS: Competing risks, Cox regression was used to investigate risk factors for injury. Survival time was the number of training days ending in an outcome of interest (SS, SDFT, LS), or censoring. Data were drawn from a longitudinal study involving 1,571 racehorses over a 34-month period, with 455 MSI events comprising SS (n=156), SDFT (n=48), and lameness (n=251). Time varying covariates were incorporated where appropriate. Results are presented as hazard ratios and 95% confidence intervals.

RESULTS: Increasing horse age was associated with a reduction in hazard of SS and LS, and an increasing hazard of injury to the SDFT. Male horses had higher hazard of injury to the SDFT compared with female horses, and there was no effect of gender on hazard of SS or LS. Winter months (May–July) had lower hazards of SS and LS, and autumn months (February–April) had lower hazard of injury to the SDFT compared with summer months (November–January). The hazard of SS and LS was increased after the first start in a preparation, and the magnitude of effect for LS was dependent on the number of days from the beginning of a preparation to the first start. The hazard of injury to the SDFT was reduced in preparations where horses started in either one or >1 trial or race compared with those preparations where no starts occurred.

CONCLUSION: This study identified risk factors for first occurrence of SS, LS, and injury to the SDFT, in racehorses in training in New Zealand. Similar risk factors were identified in all models but the magnitude and direction of effects were dependent on the outcome of interest. These findings suggest that factors which precipitate injury are different for different injuries and hence that preventive interventions will need to be specifically developed for each type of injury.

Introduction

There is much interest in understanding factors that may contribute to the risk of injury in racehorses, from a desire to reduce the number of horses either lost from the industry permanently as a result of injury, or the number of training days lost while horses recuperate from injury prior to returning to a racing career.

A number of previous studies have investigated aspects of racehorse injuries, predominantly using data derived associated with fatalities that occurred either during a race (Peloso et al 1994; Cohen et al 1997, 2000; Williams et al 2001), or during training and racing (Estberg et al 1995; 1996). Very few studies have utilized information collected from horses in training to study injuries other than fatalities, despite an acknowledgement that injuries reported during training represent an important cause of losses, and that such injuries may differ in type from those reported during racing (Mizuno 1996). Most studies of injuries in racehorses have used logistic regression methodology to identify risk factors associated with injury (Estberg et al 1995; Cohen et al 2000; Pinchbeck et al 2002). Few studies have employed survival analysis techniques for identifying risk factors associated with racehorse injury (Henley et al 2003). Data collected on health and performance in racehorses during training are often well suited to survival analysis. There is typically a well defined start of time-at-risk associated with the beginning of training or the date of a race, and a well defined event time associated with the occurrence or diagnosis of an injury that interferes with training.

The purpose of this study was to investigate risk factors for musculoskeletal injuries (MSI) in racehorses by the application of survival analysis to data derived from a longitudinal study of horses in training in New Zealand.

Materials and methods

Data used in this paper were collected as part of a longitudinal study of racehorses in training in New Zealand. The study design has been described previously (Perkins et al 2005a b). Briefly data on horse health and performance were collected at approximately monthly intervals from 20 racehorse trainers in the North Island of New Zealand. Trainers represented a convenience sample of professional trainers that were considered likely to be willing to participate in the study and that were located at one of five major regional training venues within the central and lower regions of the North Island. All horses trained at participating stables were enrolled in the study and new enrolments were made throughout the study period.

Data collection

Custom designed questionnaires were designed to collect information on training activity and injuries and conditions that interfered with training. Electronic data on

results of official races and trials held in New Zealand during the study period, were obtained from New Zealand Thoroughbred Racing (NZTR).

Horse age was classified into categories (2-, 3-, 4- and ≥ 5 -years-old), using the official birthdate of 01 August for all Thoroughbreds in New Zealand. For models using injury to the SDFT and SS as outcomes of interest, age was recoded into a binary variable representing horses < 4 - and ≥ 4 -years. Gender was classified as male or female.

A training activity score (TAS) was used to record the level of training activity achieved by each horse at the time it entered a stable to commence training, and during the periods between successive visits. TASs were defined as spell (TAS=1), walk or trot (TAS=2), activity up but not exceeding a canter (TAS=3), fast work but not yet starting in a trial or race (TAS=4), and horses that had started in at least one trial or race since the last visit (TAS=5).

A training preparation was defined as beginning on the day that a horse entered a training stable to commence training, and ended with one of the following events: onset of a spell > 7 -days in duration, retirement from racing, death of the horse, movement of the horse from a participating trainer to another trainer not participating in the study, and the end of the study. The duration of a training preparation was the number of days from the start to the end of the preparation and was recorded as training days. Interruptions to training up to 7-days in duration were recorded as a number of days at TAS=1 during a training preparation and were not identified as spell periods. Horses were able to contribute multiple training preparations to the study and successive training preparations from an individual horse were separated by spell periods. Race-year was based on the official NZTR calendar and one race-year ran from 01 August to 31 July of the following year. Each race-year was then divided into quarters (August–October, November–January, February–April, May–July), such that a horse aged by one year at the beginning of a quarter and at the beginning of each race-year.

Data were collected on conditions or injuries associated with the end of a training preparation. Musculoskeletal conditions were classified as lameness if the horse had an abnormality of gait that prevented it from being exercised, and specific information on anatomical location and diagnosis was collected where possible.

Data were stored in a custom designed database with one row of data for each training preparation, and each row contained covariates to identify start and end dates for the preparation, horse, trainer and preparation number. Binary variables recorded for each preparation included TAS at the beginning of the preparation (TAS=2 or 3 vs 4 or 5), and presence or absence of any days at TAS=1 during a preparation. Additional categorical variables included the number of starts in trials or races during a preparation (0, 1, >1), and the number of each training preparation within each horse (1, 2, ≥ 3). For those preparations where at least one start occurred, the number of days from the beginning of the preparation to the first start was also recorded.

Case definition

A case was defined as the first occurrence for any individual horse of a MSI that involved the lower fore- or hindlimbs (foot to carpus or hock, respectively), and that was associated with the end of a training preparation. MSI were classified into one of three separate categories that included injury to the superficial digital flexor tendon (SDFT), shin soreness (SS) and lameness due to causes other than injury to the SDFT or shin soreness (LS). Injuries or conditions that were not associated with training or athletic endeavour were excluded from the case definition.

Classification of study time

Training days were recorded by quarter and race-year. Time to injury for case horses was the number of training days from the beginning of the first preparation until the onset of first occurrence of injury. Spell periods were identified in the dataset as gaps where the horse was not at risk of injury. All data from case horses that were collected after the initial injury was excluded from analysis. Non-injured horses were followed until data collection ended due to retirement or death of the horse, or if the horse was lost to followup due to changing trainers or the end of the study.

Statistical analysis

A categorical outcome variable was created that coded for the three specific outcomes (SDFT, SS, LS) and all other horses were recorded as censored. Cox proportional hazards regression analysis for competing risks was used to analyse the data. Data were arranged in a counting process form with each row of data representing an interval of time for one horse where all explanatory variables had values that were constant over that interval (Therneau and Grambsch 2000, Pp 68–74). Multiple intervals and therefore

rows of data were allowed for each horse with covariates identifying the horse, the date each interval started and ended, and whether the interval ended with injury or not. Time varying covariates included race–year, quarter, age of horse, preparation number, TAS at start of preparation, and presence or absence of any days during a training preparation at TAS=1. In addition a time–varying, binary explanatory variable was constructed to allow comparison between the non–racing and racing portions of a training preparation. The non–racing portion of a training preparation was defined as the time from the start of a preparation until the day of the first start in a trial or race, or the end of the preparation for those preparations where no starts occurred. The racing portion was defined as that period beginning with the first trial or race start, and ending when the preparation ended.

The competing risks approach assumed an individual animal was exposed to a number of types of events which may not occur simultaneously, and only the first occurrence of any of these events was considered (Kalbfleisch and Prentice 2002). A general form of the model may be specified as follows:

$$h_{ij}(t) = \lambda_{0j}(t) \exp\{\beta_j \mathbf{x}_i(t)\}$$

The left side of the equation denoted the hazard for event type j at time t for the i th horse. The right side was made up of a baseline hazard function which could vary across the j event types, and a vector of covariates $\mathbf{x}_i(t)$, some of which varied with time. The associated coefficient vector β_j was subscripted to indicate the effect of covariates may be different for different event types. For each specific event type, censored observations included events of other types and losses to follow–up (Allison 1995 Pp 185–208).

Model building was completed using a backwards stepwise approach to produce a final main effects model containing only significant covariates, and all excluded covariates were then re–tested one at a time in the final model to ensure that significant covariates were not omitted. Biologically plausible two–way interactions between covariates included in the main effects model were then considered and retained if they were associated with a likelihood ratio test p –value <0.05 . The proportional hazards assumption was tested for each covariate by applying a statistical test using generalised linear regression to test for a non–zero slope of the scaled Schoenfeld residuals against time as described in Dohoo et al (2003, Pp 436), and by the addition of a covariate by

survival–time interaction to the model for each covariate. Overall fit of the model was assessed by graphically comparing the fit of cumulative Cox–Snell residuals to a unit exponential distribution (Dohoo et al 2003, Pp 438–40), and by plotting deviance residuals against survival time. The assumption of noninformative censoring was assessed by repeating each analysis with all censored animals recoded as if they were cases and examining the change in coefficients in each model, as described by Allison (1995, Pp 249–250).

The potential for clustering of horses within trainer was accounted for by using a robust variance estimator that incorporated specification of trainer as a clustering variable (Lin and Wei 1989). Results are presented as hazard ratios and 95% confidence intervals. All analyses were performed using STATA version 8.2 for Windows (SAS Institute, Cary, NC, USA), and a threshold *p*-value of 0.05 for retention of explanatory variables in the final model. Tied event times were handled using the Efron approximation (Therneau and Grambsch 2000, Pp 48–9).

Results

Of 1,571 racehorses enrolled in the study, 17 were excluded from analysis because of unknown age, and the remainder included 1,099 horses that were not diagnosed with a lower–limb MSI during the study period and 451, 156 and 48 horses that were diagnosed with LS, SS and SDFT, respectively. The median survival time in days and 95% confidence interval (CI) was 144 (CI 131–157), 103 (CI 90–117) and 157 (CI 113–350), for horses diagnosed with LS, SS and SDFT, respectively.

Table 9.1: Results of final multivariate Cox proportional hazards regression model for first occurrence of shin soreness in racehorses with time-to-event measured as training days. CI= confidence interval, se= standard error.

Variable	Coeff	se	Hazard ratio	95% CI		p-value
				Lower	Upper	
Quarter						
November–January	Ref					
February–April	0.28	0.29	1.32	0.75	2.31	0.33
May–July	0.62	0.24	1.87	1.16	2.99	0.01
August–October	0.14	0.29	1.15	0.65	2.05	0.63
Age (years)						
2–3	1.73	0.30	5.65	3.16	10.11	<0.001
≥4	Ref					
Period of training prep before or after the first start						
Prior to first start	Ref					
After first start	0.61	0.20	1.84	1.24	2.74	0.003

Shin soreness

Table 9.1 shows results of the final Cox regression model for risk factors associated with SS with cases of LS and SDFT treated as censored observations in the analysis. Horses aged <4–years had a significantly higher hazard of shin soreness compared with those aged ≥4–years (HR 5.65, $p<0.001$). An elevated hazard was also observed in winter (May–July) compared with summer (November–January), while there was no difference in hazard between either autumn (February–April, $p=0.33$) or spring (August–October, $p=0.63$), compared with summer. The period of a training preparation after the first start was associated with elevated hazard of shin soreness compared with those training days prior to the first start (HR 1.84, $p=0.003$).

Superficial Digital Flexor Tendon injury

Table 9.2 shows results of the final Cox regression model for SDFT cases with cases of SS and LS treated as censored observations in the analysis.

Table 9.2: Results of final multivariate Cox regression model for first occurrence of superficial digital flexor tendonitis (SDFT) in racehorses with time-to-event measured as training days. CI= confidence interval, se= standard error.

Variable	Coeff	se	Hazard ratio	95% CI		P value
				Lower	Upper	
Quarter						
November–January	Ref					
February–April	0.44	0.43	1.55	0.66	3.63	0.31
May–July	0.88	0.27	2.40	1.40	4.11	0.001
August–October	0.10	0.45	1.11	0.46	2.68	0.82
Age (years)						
<4	Ref					
≥4	1.80	0.50	6.07	2.28	16.18	<0.001
Gender						
Female	Ref					
Male	0.94	0.37	2.57	1.23	5.34	0.012
Number of starts in a preparation						
None	Ref					
1	-1.00	0.46	0.37	0.15	0.91	0.03
>1	-2.47	0.31	0.08	0.05	0.15	<0.001

Male horses and those aged ≥ 4 -years were at significantly higher risk of SDFT compared with females (HR 2.57, $p < 0.001$), and those aged < 4 -years (HR 6.07, $p < 0.001$). Risk of SDFT was elevated in winter months (May–July) compared with summer ($p = 0.001$), while other comparisons between quarters were not significant ($p > 0.05$). Training preparations associated with either one, or > 1 start, were associated with reduced risk of SDFT compared with those preparations where the horse did not start in any trials or races, and hazard ratios were 0.37 ($p = 0.03$) and 0.08 ($p < 0.001$) for preparations with one and > 1 start, respectively.

Lameness

Table 9.3 shows results of the final Cox regression model for LS, with cases of SS and SDFT treated as censored observations in the analysis.

Table 9.3: Results of final multivariate Cox regression model for first occurrence of lameness other than shin soreness or SDFT in racehorses with time-to-event measured as training days. CI= confidence interval, se= standard error.

Variable	Coeff	se	Hazard ratio	95% CI		P value
				Lower	Upper	
Quarter						
November–January	Ref					
February–April	0.45	0.20	1.57	1.06	2.33	0.03
May–July	0.07	0.20	1.07	0.73	2.59	0.73
August–October	-0.20	0.19	0.82	0.56	1.18	0.29
Age (years)						
2	Ref					
3	-0.33	0.16	0.72	0.53	0.98	0.03
4	-0.63	0.22	0.53	0.35	0.82	0.004
≥5	-0.23	0.24	0.80	0.50	1.26	0.34
Period of training prep before or after first start						
Prior to first start	Ref					
After first start	-2.88	1.37	0.06	0.004	0.83	0.04
ln(t)*Period of training prep before or after first start						
ln(t)*Prior to first start	Ref					
ln(t)*After first start	0.66	0.27	1.93	1.14	3.29	0.02

ln(t)* = interaction with the natural logarithm of survival time

There was an elevated risk of LS occurring in autumn compared with summer (HR 1.57, $p=0.03$), while all other comparisons between quarters were not significant ($p>0.05$). Age of horse was associated with significant variation in risk of LS with 3– ($p=0.03$) and 4–year–olds ($p=0.004$) showing reduced risk compared with 2–year–olds, while those horses ≥ 5 –years were not different to 2–year–olds ($p=0.34$). Other pair–wise comparisons between age groups were performed as follow up tests and all other comparisons returned nonsignificant results ($p>0.05$). There was a significant interaction between the natural logarithm of observed survival time, and the binary variable that represented the portion of a training preparation before or after the first start in a preparation. The results indicated a reduction in risk of LS in the period after the first start (HR 0.06, $p=0.04$), while the interaction term indicated that as survival time increased, there was a progressive increase in risk of LS (HR 1.93, $p=0.02$).

Model diagnostics

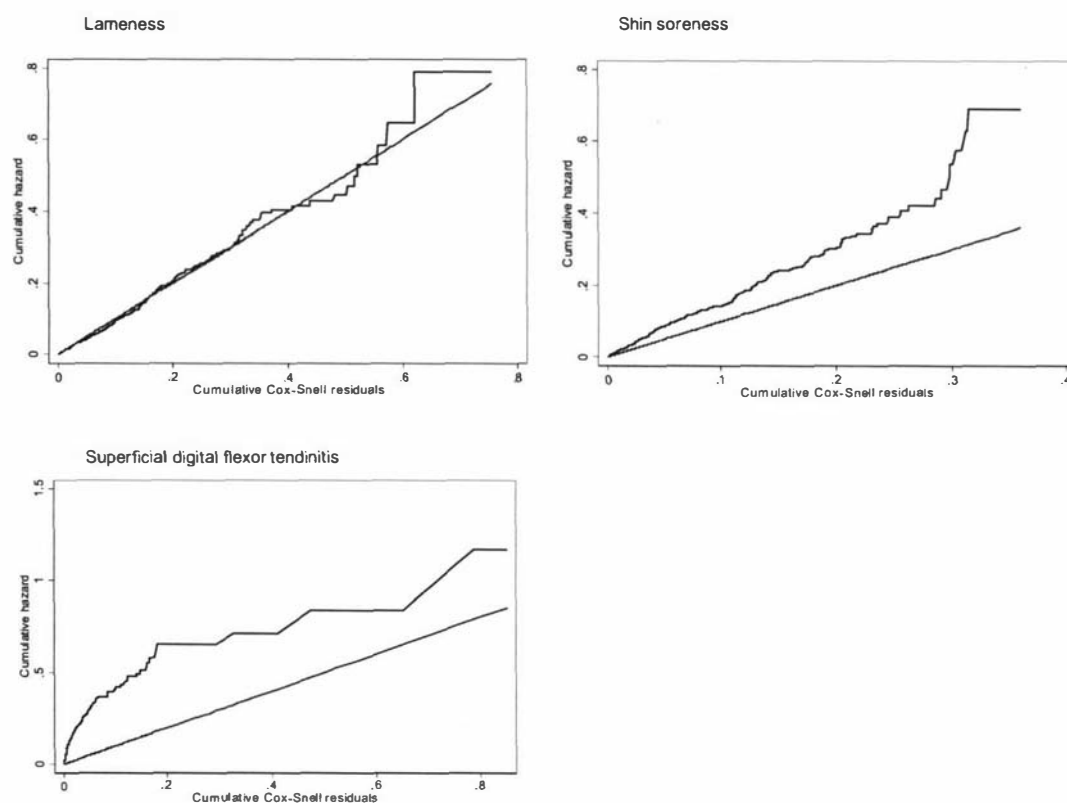


Figure 9.1: Plots of cumulative Cox–Snell residuals against cumulative hazard for the three final models and reference line with slope=1. Close agreement between fitted line and the reference line indicate good overall fit to the data.

Statistical tests of the proportional hazard assumption and interaction terms involving $\ln(\text{time})$ and each covariate in the final models, were all non-significant ($p < 0.05$) with the exception of the interaction term in Table 9.3 that involved $\ln(\text{time})$ and the binary variable representing preparation time before and after the first start in a preparation. Examination of Cox–Snell residuals demonstrated agreement with a unit exponential distribution for the third model (LS), and deviation from a straight line fit for the other two models (Figure 9.1). Examination of deviance residuals showed no evidence of poorly predicted individuals in any of the models. When each final analysis was repeated under the assumption that all censored animals became cases on their last recorded observation period there were substantial changes in the magnitude of model coefficients, indicating that informative censoring may have occurred.

Discussion

The present study involved the application of survival analysis for identifying risk factors for MSI in training and racing horses. Data used in the present study were derived from a longitudinal study of New Zealand racehorses that has been previously described by the authors (Perkins et al 2005a, b). Trainers participating in the study were selected as a convenience sample of trainers geographically close to the principal author and considered likely to contribute data over a prolonged period of time, and therefore neither the trainers nor the horses can be considered representative of the general population of Thoroughbred trainers or racehorses in New Zealand. Diagnostic information on injuries that interfered with training was collected from trainers and not from veterinarians and this constituted a potential source of bias in the study. However, all trainers regularly made use of veterinarians in the management of horses under their care and all trainers were experienced horse handlers and were considered capable of detecting abnormalities of the musculoskeletal system according to the definitions used in the study.

The authors have previously applied logistic (Perkins et al 2005c) and poisson regression (Perkins et al 2005d) techniques to data derived from the longitudinal study. Survival analysis was considered particularly appropriate for this study because of interest in time-to-event where events were different types of MSI. Additional characteristics of the data that were well suited to survival analysis included accurate recording of dates associated with various events for each horse such as the beginning and end of each training preparation, starts in trials and races, and occurrence of injuries that interfered with training, and the fact that horses were lost to follow up either temporarily as a result of spell periods, or permanently as horses exited the study for reasons other than MSI or the study ended. When a Cox regression model is used for analysis of survival data, the coefficient for an explanatory variable may be interpreted as the logarithm of a hazard ratio (Hosmer and Lemeshow 1999). Exponentiating the coefficient produces a hazard ratio. Hazard ratios have a similar form and interpretation to odds ratios from logistic regression except that in survival analysis the hazard ratio is a ratio of rates rather than of odds. For example the hazard ratio of 1.73 reported for the binary variable representing horse age in Table 1 indicates that the per unit time rate of the event of interest (occurrence of SS), in horses aged 2–3-years, at any time during the study period, was 1.73 times that of horses aged ≥ 4 -years. For a continuous

explanatory variable the hazard ratio represents the per-unit-time change in the hazard rate in response to a one-unit change in the explanatory variable.

A competing risks framework was used to produce separate Cox models for three different event types of interest. A competing risks approach was chosen for analysis because there were multiple possible types of MSI that could occur, horses were simultaneously at risk of all types of events, and our interest was in modelling only the first event that occurred. The different events were then considered to be competing to end the training time for a particular horse (Kalbfleisch and Prentice 2002; Singer and Willett 2003, Pp 586–595). Once an event of one type has occurred the horse was no longer at risk for any other type of event, leading to a risk set at the time of occurrence of an event comprised of all horses who were not yet censored and those that had not experienced any competing events. The presence of competing risks has implications for interpretation of survivor functions since survival for a particular event is conditional on the probability that the horse had not previously experienced either this event, or any other competing event. An individual who does not experience a particular type of event may well have incurred another competing event. An important assumption in competing risks analysis is that the occurrence of one event should be noninformative for all other events (Singer and Willett 2003, Pp 590). This issue influenced the choice of the three outcomes used in the present study by consideration of whether horses that experienced one event would have similar subsequent risk of other events to their peers who did not experience the competing event. SDFT and SS were the most common specific diagnoses recorded in the study and represented well defined conditions that were considered noninformative with respect to each other. All other event types were combined into a third lameness category in part because there were low numbers of animals with any specific injury, and because one type of lameness event may have influenced the risk of another type occurring, violating the noninformative assumption.

Graphical displays of survivor and cumulative hazard functions were not generated in the present study because all final models were comprised of time-varying explanatory variables. There are difficulties in generation of such plots associated with numerical integration, and in their interpretation, and Singer and Willett (2003, Pp 551) recommend restricting the presentation of results to numerical summaries.

A large number of horses were censored in the analyses with associated potential for informative censoring that can result in biased parameter estimates (Collett 1994). Horses were censored when the study ended, or if they were lost to follow up for reasons other than MSI involving the lower limbs. A crude method of sensitivity analysis to test this assumption involved changing all censored outcomes to cases under the assumption that all censored horses would have experienced an event had they not been censored (Allison 1995, Pp 249–250). The finding of substantial changes in model coefficients was suggestive of informative censoring. Racehorses that were censored as a result of retirement or changing trainers, may have been suffering from some form of MSI at the time of censoring. Interpretation is difficult given the extreme and unrealistic assumptions under this sensitivity analysis though the findings do suggest that results from this study be interpreted with caution. Studies of injuries in racehorses are likely to be associated with a high number of censored individuals because of the constant movement of horses in and out of training stables, the large number of factors that might result in censoring, and the presence of multiple possible events that can affect health and performance in horses.

Model diagnostics also indicated poorer overall model fit for cases of SS and injury to the SDFT, perhaps partially explained by the lower number of cases for these models (48 and 156, respectively) compared with the 251 reported cases of LS. Several strategies were attempted without success to try and improve this measure of model fit including addition of other excluded variables to the final models and plausible alternative forms of coding for those variables in the final models. These findings support the suggestion that model results be interpreted with some caution.

The potential for correlations between horses trained by the same trainer was accounted for in the present study by incorporating trainer as a clustering variable in all analyses for generation of robust variance terms that were adjusted for clustering. Restricting the outcome to the first event for any one horse meant that there were no instances of multiple events in any individual horse and therefore no requirement to account for clustering at the horse level. Possible extensions to the analyses presented here include incorporation of multiple events per horse rather than restricting the analyses to the first occurrence of any event, and incorporation of frailty terms as a method of accounting for clustering either within horses when allowing for multiple events, or at higher levels in a hierarchical dataset.

Comparison of the three multivariate models was suggestive of underlying commonalities in the pathogenesis of SDFT, SS and LS, while also identifying distinct variation in the relationships between predictor variables and different outcomes.

Increasing horse age was protective for SS which was consistent with previous reports that indicated shin soreness was a problem primarily of younger horses and particularly 2- and 3-year olds (Bailey et al, 1999). The relationship between age and lameness was similar with reducing risk from 2- to 4-year olds, but then no difference between horses ≥ 5 -years and any other age group. In contrast older horses were at much higher risk of injury to the SDFT, particularly horses aged ≥ 5 -years. Previous studies have reported older horses as having increased risk of serious MSI (Hill et al 1986; Mohammed et al 1991) and specifically of SDFT (Williams et al 2001). Estberg et al (1996) suggested that there may be a more complicated relationship between age and MSI with an increase in risk from 2- to 4-years of age and then a levelling or a more complicated pattern of change. This is supported by a study of fatal racehorse injuries that suggested a quadratic relationship with age in some statistical models (Henley et al 2003). Horse age was likely to be confounded to varying degrees with factors such as the level of exposure to training and racing making it difficult to elucidate clearly the nature of any association between age and injury.

Gender was identified as a risk factor only for injury to the SDFT, and male horses had a higher hazard compared with females. Kasashima et al (2004) reported that the prevalence of injury to the SDFT and SA was higher in intact males than in geldings or females in the population of horses training and racing in Japan. Further research is required to investigate possible explanations for a gender effect on risk of injury to the SDFT.

Time of year was classified into quarters in the present study using different definitions to a term defined as season in previous papers by the authors (Perkins et al 2005c, d). The definitions used in the present study were motivated by a desire to have one quarter start on 01 August in order to allow horse age to change at the beginning of one quarter. This was important in the counting process approach to organisation of data for survival analysis. The winter quarter (May–July) was associated with increased risk of injury to the SDFT and SS, while the risk of lameness was reduced in the autumn quarter (February–April) compared with summer (November–January). Seasonal effects are likely to be associated with climatic and track management factors. Records from the

New Zealand National Institute of Water and Atmospheric Research for the regions where all trainers were located, indicate that the February–April and May–July quarters were associated with the lowest and highest cumulative monthly rainfall, respectively, for all quarters of the year (data not shown). Rainfall is likely to be a major factor influencing track surface hardness and this may be mediating the association between quarter and risk of MSI in racehorses. There may also be an impact from the variation in numbers and types of races on offer at different times of the year. The authors have reported previously that the number of horses in training in New Zealand reaches a nadir during autumn and early winter before increasing again in anticipation of the spring and summer racing seasons (Perkins et al 2005a). A large increase in the number of 2-year-olds in training was observed in June–July, and in other ages during July–August. Further research is needed to determine whether the reduced risk of MSI during autumn or winter months was associated with changes in training practices, or climatic effects on track surfaces, or both.

Each statistical model included a variable that was an indirect measure of exposure to varying exercise intensity or cumulative exposure to effects of training and racing activity. The number of starts in a training preparation was retained in the final model for injury to the SDFT, while the binary variable representing division of a training preparation into periods before and after the first start was retained in the final models for SS and LS. The two explanatory variables were correlated with correlation coefficients >0.6 in all statistical models. The number of starts in a preparation is likely to under represent the cumulative effect of high speed exercise because of the failure to represent exercise associated with training. The level of under representation is likely to vary from horse to horse and would be difficult to estimate without detailed information on training patterns. The risk of SS in racehorses was increased in the portion of the preparation after the first start. An increased incidence of SS in young racehorses after the first start compared with the period of training prior to the first start has been reported previously (Moyer et al 1991). Boston and Nunamaker (2000) hypothesised that bone models and remodels in response to the exercise loads imposed upon it, and exercise that exceeds the capacity of bone to adapt and remodel will result in damage or breakdown. Increased risk of SS after the first start was consistent with the hypothesis of inadequate stimulation of bone remodelling during the training period prior to the

first start followed by bone damage and clinical SS as a result of the high speed exercise associated with racing.

As the number of starts in trials or races increased in a training preparation the risk of injury to the SDFT was reduced suggesting that racehorses were at higher risk of injury during exposure to lower exercise intensity, and that risk of injury to the SDFT fell as the horses were exposed to increasing high speed exercise. The predictor variable representing number of starts in this model was measured at the preparation level and therefore did not allow division of a preparation into components prior to and after the first start. A possible alternative explanation involves reciprocal causation where horses did not start in any trials or races as a result of previous injury to the SDFT (Singer and Willett 2003, Pp 177). There appears to be no clear evidence of association between injury to the SDFT and particular measures of exercise intensity though factors hypothesised to be associated with risk of injury include conformation, fatigue, lack of fitness, local hyperthermia in response to exercise, and any sudden excess of biomechanical force exerted on the tendon matrix (Dowling et al 2000). Further research is needed to investigate specific causal factors for injury to the SDFT in racehorses.

The relationship between the binary variable representing the portion of a training preparation before and after the first start, and LS, was complicated by incorporation of an interaction term between this variable and survival time. The interaction term was included because the main effect variable was found to have violated the proportional hazards assumption inherent in a Cox regression model. There are two commonly suggested approaches for dealing with this scenario. The first involves the use of stratified analysis with strata based on the levels of the variable in question (Singer and Willett 2003, Pp 556–562). While stratification provides a solution to the problem of non-proportional hazards it effectively precludes any interpretive scrutiny of association between the stratified variable and the outcome of interest. The alternative approach, favoured in the present study, was to include in the final model an interaction term involving the predictor variable and survival time, typically expressed as the natural logarithm of survival time (Allison, 1995, Pp 157).

Including both a time-varying predictor and its interaction with time in the same model indicates that the value of the variable changes over time, and also that the effect of the variable on the hazard changes over time. The main effect term indicates the change in

hazard after the first start and the interaction term influences the value of the hazard and also the time at which it occurs. The two coefficients can then be combined to produce a hazard ratio estimate for a given day. For that portion of a preparation prior to the first start (or entire preparations where no starts occurred), the interaction term is cancelled out and the effect represented by the coefficient for the main effect term. Once a horse has started, increasing preparation time modifies the effect. For horses that started for the first time prior to day 60 for example, the hazard ratio at day 60 can be estimated as $e^{-2.88+\ln(60)*0.66} = 0.84$. At day 100, the hazard ratio was 1.17, and at day 150 it was 8.4. This effect is consistent with an increase in the risk of lameness as the cumulative exercise load borne by the horse increases. Prior to day 78 the estimated hazard ratio was <1 and after this time it was >1 . The mean number of days from the beginning of a training preparation to the first start in horses of all ages was previously reported as 68 days (Perkins et al 2005b). The distinction between results for horses with SS and LS is that for SS the hazard associated with the onset of racing was not influenced by the time at which the first start occurred, while for LS it was.

These results are suggestive of cumulative effects of exercise that may reach a threshold beyond which further cumulative high speed exercise becomes a risk factor for injury. This relationship is consistent with the hypothesis that serious musculoskeletal injury in racehorses may be preceded by chronic microdamage accumulated over time in response to the stress of repetitive high speed exercise (Stover et al 1992; Hill et al 2001).

Caution is urged in interpreting the results of this study particularly for effects attributed to exercise loads because of difficulties in accurately measuring or representing the exercise load accumulated by a particular horse at a point in time. In addition no information was collected in the present study on track surface characteristics which may influence the stress loads incurred by the musculoskeletal system during exercise. Further work is required to develop techniques for cost effective capture of accurate data measuring exercise intensity and track hardness in order to investigate these issues in more detail.

In conclusion the present study has identified risk factors for different types of MSI in racehorses, using time-to-event data within a survival analysis framework. While similar explanatory variables were identified in the three final models, variation in the hazard ratios was consistent with the presence of differing underlying relationships

between explanatory variables for different types of injury. These findings may be useful in designing targeted studies aimed at investigating high risk periods in detail to increase our understanding of factors that influence MSI in racehorses.

Acknowledgements

The authors gratefully acknowledge funding support from the New Zealand Equine Research Foundation, and NZTR for provision of data. The assistance of Ms Dagmar Fikken in data collection is also acknowledged as is the commitment and assistance of veterinarians, track managers, trainers and their staff.

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Chapter 10

General Discussion

Introduction

Thoroughbred racing in New Zealand is arguably a business with a sporting interface (Costello and Finnegan 1988). Successful business management generally involves investment of resource into identification and correction of inefficiencies. While considerable resource has been invested into the structure and administration of the New Zealand racing industry in the last decade, little attempt has been made to investigate causes of wastage in the horses that are the lifeblood of the industry, or to implement measures designed to reduce wastage. There are several contributory factors driving the rise in awareness of wastage in racehorses, including economic impacts of losses incurred and income forgone as a result of conditions affecting horses and resulting in interruptions to training, loss of athletic ability, and retirements or deaths. In addition there is a growing awareness of the need to address concerns over welfare implications of the risks of injuries or other conditions incurred during training or racing. The ability of the racing industry to respond to such concerns either by documenting acceptable practices, or by showing evidence of improvement in horse health and performance as a result of changes in various practices, has been limited by a lack of data. The author is unaware of previous studies performed in New Zealand that would allow quantification of measures of wastage in racehorses. In fact there appear to be few studies world wide that have either attempted to measure wastage or identify causal factors in a population of training racehorses that includes horses that have raced as well as horses that have not raced.

A number of studies have used data from the California post mortem examination program to investigate aspects of musculoskeletal injuries in racehorses (Johnson et al 1994; Estberg et al 1995, 1996a, 1996b, 1998; Kane et al 1996a, 1996b, 1998; Carrier et al 1998). These data were derived from examination of fatalities that occurred on California racetracks and include conditions or injuries that occurred either during a race or during any other activity including training that involved the horse while it was resident on a racetrack under the jurisdiction of the California Horse Racing Board. The major limitation with these studies is that they are restricted to conditions that resulted

in death or euthanasia of the horse. Others have also used racing industry records to describe injuries in a population of horses starting in a race (Peloso et al 1994b, 1996; Cohen et al 1999, 2000a; Williams et al 2001). Data from such studies represent biased measures of both the types of injuries and frequency or risk of injury. These studies did not consider injuries that become apparent during training, and only included injuries that were actually reported on the racetrack, ignoring injuries that might have occurred during a race but were not diagnosed until after the horse has left the track. An important reason for lack of consideration of horses in training is simply the relative difficulty of collecting information about activity levels and injuries in training horses when compared with the ease of access to racing industry data relating to serious injuries in the population of horses that have started in a race. This is a major shortcoming in the understanding of musculoskeletal injuries in racehorses given that injuries are considered likely to result from the cumulative effects of repetitive microinjury to structures over time, meaning that the continuum of both injury risk and expression of injury should be considered to cover both training activities and racing. Previous studies have reported 43% of fatalities in Thoroughbreds occurred as a result of injury during training and 40% as a result of an injury that occurred during a race (Johnson et al 1994), while Mizuno (1996) reported that the frequency of different types of fracture was different for those injuries that occurred during racing compared with injuries that occurred during training.

A smaller number of studies have examined injuries in a population of training horses (Jeffcott et al 1982; Rosedale et al 1985; Haynes et al 1988; Lindner et al 1993; Oliver et al 1997; Bailey 1998). However, these studies have suffered from a range of shortcomings that included insufficient sample size and short study duration, resulting in difficulties in characterising or explaining different types of injury (Haynes et al 1988; Bailey 1998), lack of statistical analyses and methodological problems in analyses which were undertaken (Lindner et al 1993; Oliver et al 1997), or restriction of analyses to crude associations only (Jeffcott et al 1982; Rosedale et al 1985).

Many studies have been retrospective in nature, depending on collection of pre-existing racing industry records concerning injuries and race or trial performance. A smaller number of studies have involved prospective data collection from horses during training or racing (Haynes et al 1988; Lindner et al 1993; Oliver et al 1997; Bailey 1998; Hill et

al 2001). Discussion of advantages and disadvantages of prospective versus retrospective observational designs was presented in Chapter 2 of this thesis.

Longitudinal study design

The major strengths of the research performed as part of this thesis have been the prospective nature of data collection, the large sample size of the study population when compared with previous studies, the prolonged follow-up time, and the fact that the study sample comprised horses in training, of which a subset of horses started in at least one trial or race during the study period. This combination of attributes has not previously appeared in the scientific literature on wastage in racehorses. As a result this thesis is believed to be the first large-scale, longitudinal study of a population of horses in training.

These factors were major motivators in the decision to design and implement the research described in this thesis. The primary objectives of this thesis were to describe patterns of training and racing in New Zealand Thoroughbreds, identify major causes of wastage, and investigate possible explanatory factors that might influence the likelihood of occurrence of different types of injuries or other conditions interfering with training and racing. Both retrospective and prospective data sources were utilised in this thesis. Retrospective data included information on horse identity and on trial and race results, and were obtained electronically from NZTR. Prospective data were derived from a longitudinal study, designed and implemented for the purposes of this thesis. The prolonged study time and large number of horses involved allowed detailed description of patterns of training, racing and spelling in the New Zealand industry. In addition these characteristics allowed description of different types of musculoskeletal injury instead of having to aggregate injuries for analysis because of insufficient sample size. Previous studies employing a similar prospective design format had followed small numbers of horses over relatively short periods of time. Robinson et al (1988) followed 95 horses over a single, 5-month racing season, while Bailey (1998), followed 169 horses over 2 consecutive racing seasons. Both studies employed a fixed cohort approach and both suffered from losses to follow up during the study period, with losses of 47 from 95 (Robinson et al 1988), and 98 from 169 (Bailey 1998). The reduction in

number of horses enrolled due to losses to follow up resulted in problems in measuring outcomes of interest in both studies.

A longitudinal study approach was adopted for the major component of this thesis for several reasons. Allowing enrolment of horses at any stage of the study was felt to be more suited to the nature of the Thoroughbred industry where horses may leave a training stable at any time either temporarily or permanently, and new horses may enter at any time to begin training. In addition the study aimed to enrol over 1000 horses over a minimum of 2-years to ensure that sufficient data were accumulated on conditions of interest. It was also important that there be sufficient animal time-at-risk to provide reasonable opportunity for observing the full range of conditions that might be expected in training horses and to estimate incidence measures with reasonable precision. The longitudinal study finished with data collected from 1,571 horses over a 34-month period, exceeding the design goals and ensuring a large enough sample size for analytical purposes.

The study suffered from a number of inherent methodological limitations that affected the ability to extrapolate results and either offered potential for bias of analytical results or interfered with the ability of the study to investigate relationships of interest. Trainers were not selected randomly from the population of trainers in New Zealand. Trainers were selected from training venues in the central and lower north island because of proximity to the author, and a factor in selection was the level of confidence that they would continue to participate in the study over a prolonged period of time. All of the trainers were professional trainers who earned their livelihood from training and racing Thoroughbred horses in New Zealand. The lack of randomisation in selection of trainers does mean that the study population cannot be considered representative of the total population of Thoroughbreds in training in New Zealand.

Once trainers agreed to participate in the study all horses trained by the trainer were enrolled in the study so there was no opportunity for trainers to influence or bias selection of horses. Information on conditions and injuries that occurred in horses enrolled in the study was collected from trainers, and not from veterinarians. All trainers used veterinarians on a regular basis and the decision to request veterinary examination on any horse was at the discretion of the trainer and owner of the horse. This was a source of potential misclassification bias. While there may have been misclassification for specific diagnoses involving conditions other than shin soreness it was felt that

trainers were capable of detecting musculoskeletal abnormalities according to the definitions used in the study. The use of non-veterinary personnel as a source of information on conditions affecting racehorses has been previously discussed (Bailey et al 1999).

The longitudinal study would have benefited from incorporation of detailed measurement distances covered at different speeds and on different track surfaces for all horses during training. This would have allowed compilation of a range of measures of cumulative exercise intensity in an attempt to better characterise a possible relationship between exercise intensity and risk of musculoskeletal injury. It was not possible to collect detailed information on training activity without a drastic reduction in the number of horses enrolled in the study, a change that was considered likely to have restricted the ability of the study to observe the full breadth of conditions that may occur in a population of training horses. The longitudinal study did provide opportunity to investigate measures of activity at the start of a training preparation, and the general pattern of change as a preparation progressed. Measures based on starts in trials and races were derived from data obtained from NZTR in a similar manner to those reported by previous studies investigating the relationship between exercise and injury (Estberg et al 1995, 1996a, 1996b, 1998; Carrier et al 1998). It was similarly not possible to collect information on the track surface used by each horse for each training period since most venues have multiple track surfaces available for trainers and individual horses may use more than one track on any given day and often use different tracks on different days.

While these shortcomings do limit the scope of the work presented in this thesis, the thesis has provided a wealth of information on aspects of health and performance in Thoroughbreds in New Zealand and represents a major contribution to knowledge in this field.

Chapters 3 and 4

Chapters 3 and 4 present results from a study performed in response to interest amongst the New Zealand racing industry about the impact of a new training track on horse health and performance. An enquiry was received from the racing club after the longitudinal study had already begun. It was not possible for data derived from the longitudinal study to be used to directly address this question because training stables

from the Matamata region had not been enrolled into the longitudinal study until after the new training track was commissioned. This meant that no data describing training activities or injuries in training horses were available from the period prior to the new track being commissioned. A decision was made to use NZTR data on race and trial results in an attempt to compare a variety of measures of health and performance in the population of racehorses training during two 19-month time periods; before the new track was constructed, and after it was finished. Measures included summary statistics of starts, numbers of wins and places for horses trained at different locations, and a variable measuring whether a horse had a 6-month period of no starts following any start in the first 13-months of each 19-month time period. The latter variable was used as an indirect indicator of serious MSI. A variety of analytical approaches were utilised and no adverse impact was identified that could be attributed to the new training track. The approach used in these two chapters involved the application of a combination of 3 different multivariate analyses allowing adjustment for confounders and for the effects of clustering at different levels in the data hierarchy. Comparisons performed in these chapters were constrained by the lack of data on actual injuries from the period prior to the construction of the new track, and the use of indirect measures derived from race and trial records. However, the use of sophisticated analytical techniques, and the consistency of findings from 3 different types of analysis, provided support for the overall findings of the study.

Results from the longitudinal study

The remaining chapters in the thesis describe results derived from the longitudinal study. Chapter 5 describes patterns evident in the way racehorses are trained and raced in New Zealand. Chapter 6 describes conditions that interfered with training and racing, using incidence rate and cumulative incidence measures adjusted where appropriate by age and gender. These two chapters provide a detailed picture of the New Zealand racing industry that can serve as a source of reference information into the future. This information does not appear to have been presented in the scientific literature elsewhere in the world and these chapters therefore provide material of value to the broader population of racehorses around the world while having particular application to the New Zealand industry. Evidence was presented to document differences in the population of horses in training compared to those animals that have started in at least one trial or race. The population of training horses had higher proportions of 2- and 3-

year-olds, and lower proportions of horses aged 4-years or older, compared with the racing population. In addition, 40% of all reported musculoskeletal injuries occurred in horses that had not yet started in a trial or race, while a variable percentage of injuries in horses that had started in a trial or race were diagnosed days or weeks after the last start. These findings were consistent with the hypothesis that musculoskeletal injuries occurred largely as a result of the cumulative impact of repetitive microinjury incurred during exercise, regardless of whether the exercise occurred during a race or during training. The findings also clearly documented the importance of incorporating training horses in any study attempting to investigate issues associated with racehorse health and performance, and not restricting the study population to those horses that have previously started in a trial or race. The importance of using an incidence density approach to the epidemiological study of racehorse injuries was confirmed, with evidence of variation in training days at risk by age-group, gender, and month of the year, and the irregular nature of any horse's training program. Training methods also showed distinct variation by age-group as well, using measures such as training-days to first start, starts per 100 training-days, and duration of a training preparation. Musculoskeletal conditions were confirmed as the most common injury interfering with training, followed by respiratory, and miscellaneous conditions. Incidence rate estimates of various conditions were reported as events per 1,000 horse-training-days. The relatively large sample size in the study population allowed incidence rate estimates of overall MSI and various defined subsets of injury types including shin soreness, tendon and ligament injury, lameness non-fracture, lameness associated with bone fractures, back disease, and events associated with accidental injury or laceration. In addition incidence rate estimates were produced for upper and lower respiratory disease events. There was evidence of age-associated variation in risk of injuries of different types, reinforcing the need to account for confounders such as age when studying racehorse health and performance. The results facilitate relative assessment of the importance of various conditions to the industry using measures based on incidence rate, or outcome.

Chapters 7, 8 and 9 applied multivariate analytical techniques to investigate risk factors for various MSI while adjusting for confounders and the effects of other covariates. Chapter 7 employed a case-control approach to analyse data from the longitudinal study population using logistic regression. All non-case horses enrolled in the study were utilised as controls and the outcome of interest was the first occurrence of

musculoskeletal injury of the lower limbs. Chapter 8 describes the application of poisson regression analysis to data relating to the first occurrence of injury to the superficial digital flexor tendon and the suspensory apparatus. Exposure times were represented by cumulative training days for each horse, allowing analyses to be adjusted for the potentially variable amount of training time contributed by any one horse. Chapter 9 utilised competing risks survival analysis to allow investigation of time-to-event information while accounting for variable time-at-risk and losses to follow up using the capability of survival analysis to incorporate censored information. Three different competing events were defined for the analyses: shin soreness, injury to the superficial digital flexor tendon, and all lameness cases involving lower limb structures other than shin soreness and injury to the superficial digital flexor tendon.

A number of risk factors were identified both for MSI in general and for specific conditions including shin soreness, injury to the SDFT or SA, and other lameness cases. The relatively large sample size and prolonged study duration provided sufficient information on affected (case) and unaffected (non-case or control) animals to allow multivariate analyses to be performed using specific injury outcomes as well as non-specific outcomes. Non-specific injury outcomes involved categorising all lower-limb musculoskeletal injuries under a single binary outcome regardless of the type of injury (chapter 7). This approach is common in the veterinary literature despite evidence indicating that different specific types of injury might be associated with either different risk factors, or changes in the magnitude or even direction of effect for the same risk factor. An example of this can be seen in the association between horse age and injury, with increasing horse age being associated with reduced risk of shin soreness and increased risk of tendon and ligament injury (chapters 8 and 9). Differences were also observed in magnitude of coefficients associated with extrinsic factors for different injury types observed in chapter 9. The use of specific injury outcomes is unusual in the scientific literature concerning MSI in racehorses and this thesis therefore makes an important contribution to knowledge in this area.

Multivariate analyses confirmed the importance of accounting for intrinsic factors such as horse gender and age when investigating musculoskeletal injuries in racehorses, and also identified a number of extrinsic risk factors that explained components of the total variability in different outcomes, including factors such as race year, season, and various measures of exercise intensity.

It is important in any epidemiological study that aims to achieve a change in some measurable outcome, to identify risk factors that are amenable to manipulation. This allows recommendations to be made that may be expected to reduce risk of the outcome occurring in the future. Risk factors associated with MSI in this thesis that are amenable to manipulation are primarily associated with measures of exercise intensity. Measures of exercise intensity in racehorses have been previously identified as important in explaining at least part of the risk of musculoskeletal injury in training and racing horses, despite difficulties in elucidating the nature and magnitude of any association. There is general support for the hypothesis of a positive association between increasing exercise intensity and increased risk of MSI (Estberg et al 1995, 1996a, 1998). However, there are also studies where no such relationship has been identified (Hill et al 2001), or where increasing exercise intensity scores have been associated with reduced risk of MSI in statistical models (Cohen et al 2000a).

Chapter 7 showed a non-linear relationship between cumulative exercise intensity as measured by cumulative racing-speed distance in the last 30-days of a training preparation, and risk of injury. There was an initial decrease in risk of injury as cumulative racing-speed distance increased, that then levelled out and finally began to increase as cumulative distance increased further. The results of chapter 8 indicated that starting in one or more trials or races was protective with respect to injury affecting the SDFT or SA. The results of chapter 9 indicated that the hazard of SS was increased after the first start in a preparation. The hazard for LS was reduced after the first start though as preparation duration extended beyond the first start the hazard eventually began to increase. The hazard of injury to the SDFT was reduced in preparations where horses started in either one or >1 trial or race compared with those preparations where no starts occurred. These findings were consistent with a hypothesis that any association was likely to be different for different types of injury and potentially different types of tissues. For example the findings in chapters 8 and 9 for injury to the SDFT indicate that horses may be at higher risk of injury prior to the first start. In contrast for other conditions associated with lameness the findings from chapters 7 and 9 indicated a more complex pattern. Both chapters were consistent with increased risk of injury resulting from accumulation of exercise over time. In the survival analysis, the capacity to account for variation in the value of a covariate over time allowed investigation of the nature of the relationship between measures of exercise intensity and hazard of injury.

In contrast, explanatory variables used in the logistic regression described in chapter 7 were aggregated to the level of a training preparation and may not have captured the underlying relationships as well as the survival analysis approach. Any attempt to assess the relationship between measures of exercise exposure and MSI is likely to be simplistic because of the constraints imposed on measuring exposure to exercise and the difficulties in measuring the interaction between feet and track surface. Training induces development and adaptation in musculoskeletal tissues by inducing some level of stress and perhaps microdamage. As training progresses from preliminary slow work through to the start of fast work, and then the first race start, musculoskeletal tissues will endure multiple phases of differing levels of stress induced response and adaptation (Pool and Meagher 1990; Riggs and Evans 1990). Each horse is therefore likely to progress through periods of varying susceptibility to different types of injury depending on the level of exercise at any point in time, and the level of adaptation or microdamage currently present in tissues (Riggs and Evans 1990). The suggestion of a complex and variable relationship between exercise intensity and MSI is an important outcome of the research completed in this thesis. There has been little consideration in the veterinary literature of anything other than a simple and positive relationship between increasing exercise intensity and increasing risk of MSI.

The studies described in this thesis have identified a number of factors that influence risk for different types of injury, including information on intrinsic factors associated with injury risk. This information should be disseminated widely to help improve understanding within the horse industry about the types of injuries that are most common in horses of different age or gender classes. It is however, not possible to make specific recommendations about training programs that might be used to reduce risk of musculoskeletal injury in racehorses, because the project did not include an intervention study to test possible changes in practices in the light of the longitudinal study findings. However, a number of important advances have been made in our understanding of factors contributing to risk of MSI as a result of the research contained in this thesis. Measures of exercise intensity appeared in all multivariate models as an important type of extrinsic explanatory factor that is amenable to manipulation. The magnitude and significance of associations between exercise intensity and risk of MSI differed for different types of injury, and in some cases the direction of effect was changed. In addition, the relationship between measures of exercise intensity and MSI for lameness

appeared to be complex and showed evidence of variation over the time of a preparation.

Future research

A number of recommendations can be made about the design and conduct of further investigation of injuries in racehorses. The target population for future studies should be the population of training racehorses and not be limited to those horses starting in a race. There is a need to develop techniques for capture of data on distances covered in training, and speeds at which they are achieved, in order to be able to accurately describe measures of cumulative exercise intensity. Analysis of video images of training horses has been used to derive measures of velocity and distance but these techniques require investment in equipment, training and time (Rogers et al 2004). Interestingly Rogers et al (2004), have used video analysis to validate velocity and distance estimates provided by trainers for horses training under their care, suggesting that a simpler method involving regular recording of information derived from trainers may be suitable for measuring exercise intensity during training. The authors proposed the development of a cumulative workload index (CWI), as a product of measures of velocity and distance, for measuring cumulative exercise intensity in studies of MSI and athletic performance in racehorses (Rogers et al 2004). Researchers are also currently developing and validating methods involving the use of portable global positioning system (GPS) units attached to a horse and either storing data for subsequent download or transmitting via satellite (Kingston unpublished data 2004¹). Finally results from analyses in this thesis using specific injury types as outcomes suggest that the relationship between risk factors and outcomes varies for different types of injury. This indicates that future research should be targeted at specific types of injury in the first instance in order to understand the interrelationships between multiple risk factors that might influence injury risk. It also implies that recommendations and preventive measures may need to be tailored for different types of injury at different stages of training in order to be effective.

It will also be important to incorporate assessment of track surface characteristics in future studies attempting to identify causal factors of MSI in racehorses. Forces applied to the musculoskeletal structures in an exercising horse are dependent on gait velocity

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and measures of track resistance (hardness and frictional resistance) (Dalin et al 1985; Zebarth et al 1985; Ratzlaff et al 1997). Relationships between track surface characteristics and forces exerted on horses using those tracks, are complex and not yet well understood. There is even a suggestion that dynamic properties of different tracks may be optimal only for horses travelling within a narrow velocity range, and that the velocity range may be different for different tracks (Ratzlaff et al 1997). This area is a major limitation in the study of factors contributing to MSI in racehorses. It would be possible to account for such variation in research by restricting a study to horses that train on the same surface. This would be prohibitively restrictive in observational studies using data derived from professional trainers since trainers at almost all venues have multiple track surfaces to choose from on any given day.

Restricting a study to horses that train at a single venue, in an attempt to reduce extraneous sources of variability, is feasible in a research setting, though it would also limit the number of horses that could be studied. An example of such an approach has been described recently in a research project currently being finalised at Massey University (Firth et al 2004). Such studies are best suited to the investigation of well defined hypotheses under controlled conditions given associated experimental costs and sample size restrictions. Alternatively the development of an international, multi-centre approach to the investigation of MSIs in racehorses may allow a variety of benefits to be achieved in an observational framework. Racing jurisdictions such as Hong Kong are well suited to intensive monitoring of their training population for example. All horses training at Hong Kong are under the care of a single, centralised veterinary service, and are housed and trained at a single venue with a limited number of training tracks available. There are only two racing venues in the Hong Kong Special Administrative Region, again facilitating data collecting and reducing sources of variation. Other jurisdictions such as Japan, are also well suited to intensive monitoring for similar reasons. Development of techniques and understanding of underlying relationships between measures of cumulative exercise intensity, track surface characteristics, and injury may well be facilitated by concentrating initially on centres most amenable to intensive monitoring of horses. Techniques may then be refined and extended to other regions to allow regional variation in risk factors to be identified.

In addition, during the process of data collection for studies described in this thesis it became apparent that there was no standardized methodology for reporting of injuries to

horses incurred during training and racing in New Zealand, and no standard framework to allow collation and reporting of such injuries at the national level. Similar shortcomings are apparent elsewhere in the world and it is strongly recommended that consideration be given to the development of a centralised, web-based system for recording and reporting injuries incurred by racehorses while on a racecourse. Such a system could be easily extended to incorporate injuries incurred during training as well as during race day events, and also extended to include injuries to jockeys and other personnel working with racehorses. There would be considerable benefits to the industry at large in being able to document numbers and types of injuries in a standardized format.

It seems likely that continued advances in hardware and software capabilities will facilitate the development of real time monitoring of track characteristics and measures of exercise intensity. While initially likely to be associated with research and development investment aimed at understanding risk factors for various types of MSI, these approaches are likely to be adopted for routine monitoring of training responses to improve athletic performance and adjust training to reduce injury risks.

Conclusion

The work undertaken in this thesis highlights the complexities inherent in designing an observational study involving racehorses in training. The thesis has described typical patterns for training preparations involving Thoroughbred racehorses, and the important conditions that are associated with wastage in the racing industry. The work is considered to represent the largest epidemiological study of racehorses to date and represents a valuable source of information for the industry and as a reference source for future studies. Studies contained in this thesis have identified risk factors for selected MSIs, and identified areas requiring further research, in particular in developing methodologies for assessment of cumulative exercise intensity and track surface characteristics. This thesis has also identified the need for a centralised, standardized reporting system for injuries incurred in horses exercising on tracks under the management of NZTR licensed race clubs.

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Appendix 1: Forms used in data collection

The following is an image of the horse-level data collection sheet.

MEMS Data Collection Sheet

Last Visit Date: 23/10/1998
 Training Activity Score (last visit): 1
 Did the horse have any reduced or stopped training during the last data collection period? ... Yes

Horse: _____
 Gender: _____
 Trainer name: _____

1. If the horse was spelling at the last data collection visit (training activity score = 1), has the horse started work again?
 No - Go to next horse
 Yes ————— If Yes, what was the start date? _____

2. Current training activity score: _____
 (1=spell, 2=slow work, 3=half pace, 4=3/4 pace or faster but not racing, 5=racing, 6=other eg swimming) If activity score = 6, please explain:..... _____

3. Has the horse had a period of reduced training activity or stopped training since the last visit?
 No - Go to next horse
 Reduced training activity →
 Stopped training

Go To * Answer questions 7, 8, 12, 13, and 14 only if the reduction in training is due to any condition which results in the horse not being able to train normally.

4. Reason: _____

5. Lowest training activity score during reduction? _____

6. Number of days training activity was reduced in the time period since the last visit? _____

7*. Has the horse previously had this condition? Yes No Don't Know

8*. If the condition involves the musculoskeletal system, indicate the region affected?
 Near foreleg Off foreleg Head or neck
 Near hindleg Off hindleg Back
 Don't Know Other: _____

9. Reason: _____

10. Number of days training activity was stopped for? _____

Or

11. Date training stopped? _____ If the horse stopped work since the last visit and has not resumed work yet, please identify the date that training stopped. The date training resumes will be collected at a future visit.

12*. Has the horse previously had this condition? Yes No Don't Know

13*. If the condition involves the musculoskeletal system, indicate the region affected?
 Near foreleg Off foreleg Head or neck Don't know
 Near hindleg Off hindleg Back
 Other: _____

14*. Has the horse been operated on or is an operation planned to help correct this condition? Yes No Don't Know

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