Chapter 1: Introduction

Musculoskeletal (MS) injuries have been identified as the most common health problem in Thoroughbred racehorses. The injuries represent an economic cost to industry in terms of treatment cost and lost opportunity to race. The high number of MS injuries in racehorses, has also raised welfare concerns (Mundy 2000).

The Thoroughbred racing industry needs to be proactive in the implementation of measures that reduce the occurrence and impact of MS injuries. However, design of such measures requires a better understanding of the impact of MS injuries on performance and the factors associated with MS injuries.

This thesis presents the results of a longitudinal study of two- and three-year-old Thoroughbred horses that was conducted to investigate the epidemiology of MS injuries. Chapter 2 of the thesis is a review of the current literature relating to MS injuries and the issues surrounding the use of a population based approach to understand injuries.

Chapter 3 describes the design and implementation of the longitudinal study and outlines the size and scope of the study.

Chapters 4 and 5 provide a profile of the two- and three-year-old horses enrolled in the study. Chapter 4 describes the frequency of MS injuries and uses multivariable survival techniques to determine the factors that influence the time to first start in a race or barrier trial and time to recovery in horses after an initial injury. Chapter 5 describes the training preparations and racing patterns in the study cohort and uses multivariable methods to describe the factors that influence these patterns.

Chapter 6 presents the results of a multivariable logistic regression to describe risk factors for lower limb forelimb MS injuries. The analyses presented in this chapter focuses on the time when horses are first exposed to high-speed exercise.

Chapter 7 use a counting process form of the Cox regression model to investigate risk factors for the first MS injury. It was hypothesized that the hazards for different types of MS injuries would differ. Therefore a competing risk framework was used to investigate injury-specific hazards for shin soreness, joint injuries and other forms of lameness.

The thesis concludes with a general discussion of the results. References cited in the PhD are listed at the end of the thesis.

Chapter 2: Literature review

2.1 Introduction

Musculoskeletal (MS) injuries are the most common health problem in Thoroughbred racehorses (Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Perkins *et al.* 2004a, Perkins *et al.* 2004b). Studies of horses in training have reported that the cumulative incidence of musculoskeletal (MS) injuries ranged from 36% in a two-year-study (Rossdale 1989) to over 50% in 81 day (Kobluk *et al.* 1990b), nine month (Lindner and Dingerkus 1993) and two-year (Bailey *et al.* 1999) study period. These MS injuries incur both direct and indirect costs.

Direct costs included lost opportunity to race and treatment cost. Bailey (1999 reported that 45% of horses enrolled in a longitudinal study did not race during their two-year-old season. Bailey concluded that the principal reason for this was the high number of cases of low grade injuries and other health problems. However, no statistical tests were performed to determine if those horses that sustained an injury were less likely to race than those that did not sustain an injury.

Indirect costs associated with MS injuries are difficult to quantify. They include risk of death or injury to the jockey and welfare implications of MS injuries. While all MS injuries are a welfare concern, those that occur during a race are in the full view of race goers and are often replayed in television news reports. The injuries are often dramatic and impact negatively on the public perception of racing.

The direct and indirect cost to the Thoroughbred racing industry associated with MS injuries makes it desirable to understand factors that affect the risk of MS injuries. Increased understanding of these factors may facilitate the development of strategies to reduce the incidence and/or impact of MS injuries. The aim of this review is to describe the epidemiology of MS injuries and to describe some of the methodological considerations when conducting population based studies.

2.2 Epidemiology and MS injuries in horses

Epidemiological studies aim to identify factors that may prevent or reduce the impact of MS injuries. The components of epidemiology are descriptive and analytical (Caine *et al.* 1996). Descriptive epidemiology attempts to quantify the occurrence of MS injury, while analytical epidemiology aims to determine factors that modify the risk of an event occurring, and/or reduce its severity. Descriptive studies represent the first step in any epidemiological investigation and when combined with reviews of case histories can be used to generate hypotheses about variables potentially associated with MS injuries. These hypotheses can be tested in analytical studies to determine if exposure to the variable(s) causes an alteration in the risk of a MS injury occurring.

Previously, epidemiological methods have been used to investigate problems that occur only once, affect a small proportion of the population and require professional treatment and/or are reported to a regulatory body (Cumming *et al.* 1990, Eisen 1999). In contrast, the cumulative incidence of musculoskeletal (MS) injuries in horses during training in study periods of between 81 days and two-years ranged from 36% to 57% (Mason and Bourke 1973, Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Aida *et al.* 2001) and injuries tend to recur in affected horses (Lindner and Dingerkus 1993, Bailey *et al.* 1999, Perkins *et al.* 2004a). In addition, training-related injuries are not always diagnosed or treated by a veterinarian or reported to a regulatory body. Therefore, it is difficult to detect many MS injuries. This creates a number of problems when conducting epidemiological investigations of MS injuries. These problems relate to case definition, study design and measures of association.

2.3 Defining MS injuries

The initial step in any epidemiological study is to develop a clear case definition and determine how the cases will be detected (Cumming *et al.* 1990). Case definitions for fatal MS injuries, especially those that are racing-related, are relatively simple. However, bias may be introduced when studying injuries that result in death or euthanasia as the decision to euthanase a horse may be based on factors other than the severity of the injury, such as breeding potential.

Defining non-fatal MS injuries is considerably more difficult than fatal MS injuries. Previous studies have used the terms lame (Lindner and Dingerkus 1993, Ross *et al.* 1999) and unsound (Bourke 1990, Axelsson *et al.* 2001). However, the criteria used to define a horse as lame or unsound were not provided. As well, the impact of the injuries on training and racing was not clearly defined. Studies of non-fatal racing-related MS injuries have defined an injury as any reported problem involving the musculoskeletal system that was followed by a period of time in which the horse did not race (JRA

1991, Cohen *et al.* 1997, Cohen *et al.* 1999a, Hill *et al.* 2001) or barrier trial (Bailey 1998). The problem with definitions that rely on the horse not racing for a period of time is that a decision to alter training and racing may be based on a number of factors unrelated to the presence of an injury or its severity. These factors include lack of suitable races and breeding potential. Bailey *et al.* (1999) and Rossdale *et al.* (1989) defined a non-fatal MS injury during training as a problem involving the MS system that resulted in modified training or the horse resting at pasture. The concept of 'modified training' is a subjective measure of impact and the severity at which training is modified is likely to vary between trainers. More recently, a study in New Zealand defined a MS injury as a problem involving the MS system that resulted in the horse leaving the stable for a period of more than seven days (Perkins *et al.* 2004a, Perkins *et al.* 2004b). A horse being removed from the stable is a clearly defined event but it is worth noting that the severity of injury that would result in a horse ceasing training and thus being removed from the stable may vary between trainers.

The issue of case definition is further complicated when examining specific types of non-fatal injuries. Bailey (1999) divided musculoskeletal conditions into a number of categories including tendon strain, ligament sprain, carpal problems, fetlock problems, other joints, dorsal metacarpal disease or "shin soreness" and sesamoid problems. For example, a horse classified as suffering from a fetlock problem may have had a sesamoid problem or a suspensory ligament problem. To avoid this type of misclassification, it would be beneficial to divide injuries based on the anatomical location of the problem. Unfortunately, this may result in a heterogenous group of cases, making it difficult to determine a casual pathway (Hyams 1998, Viikari-Juntura and Riihimaki 1999).

When defining non-fatal MS injuries it is also necessary to define the outcome of interest: the rate of injury or the horse that sustained the injury (Cumming *et al.* 1990, Eisen 1999). If the aim is to determine why some horses sustain more injuries than others then the appropriate unit of interest is the injured horse. If the purpose is to determine why some horses sustain an MS injury at a particular point in time, then the outcome should be the injury event not the injured horse. An advantage of studying the injury event is that certain exposures that vary over time and are triggers for the injury may be identified, thereby determining those factors that cause a horse to sustain a MS injury now rather than later.

If the outcome of interest is the event rather than the individual, it is likely to create clustering as one individual may experience more than one event (Cumming *et al.* 1990, Eisen 1999). The clustering should be accounted for in order to obtain valid estimates of the effects of exposure variables on the outcome. If clustering is ignored, it may result in standard errors that are too small and, may in some types of models, result in incorrect parameter estimates (Dohoo *et al.* 2003, pp 463-4). Clustering can be handled using an estimate of the intra-class correlation coefficient (ICC), or overdispersion, to inflate the standard errors of the regression coefficients (Dohoo *et al.* 2003, pp 463-4). However, this approach does not correct the bias in parameter estimates that may occur as a result of clustering. The issues of bias parameter estimates, and conservative standard errors, can be addressed using a variety of analytical techniques including generalized linear models, overdispersed exponential families and adaptations of the proportional hazards model that include frailty terms (Cumming *et al.* 1990). Alternatively, the clustering can be removed from the data set by restricting attention to one event. For example the event of interest can be the first injury, the most recent injury or an injury in a specified time period.

2.4 Observational study design

Studies can be defined as experimental or observational (Dohoo *et al.* 2003, pp 140-2). Experimental studies are those in which the investigator controls the allocation of individuals to study groups. For example, horses may be allocated to a certain type of training program. If the allocation to treatment groups is random, this is referred to as a randomised control trial. In contrast, in observational studies the investigators do not attempt to influence the natural course of events. Rather they make observations of what happens to the subjects enrolled in the study. Common types of observational studies include cohort and case-control studies. There are also a variety of hybrid study types, including case-crossover and nested case-control studies. The main advantage of observational studies is that the natural occurrence of MS studies is investigated (Thrusfield 1995, p 23). If an experimental approach is taken, such as exercising horses on a treadmill, then some of the factors that interact with the factor under investigation (e.g. tracks) are lost.

2.4.1 Case-control

Case-control studies begin with the identification of a group of individuals that suffered the event of interest (cases) and those that did not (controls) (Caine *et al.* 1996, Robertson 1998). A number of case-control studies have been conducted to investigate both fatal and non-fatal injuries that occur during racing (Mohammed *et al.* 1991, Estberg *et al.* 1993, Estberg *et al.* 1995, Estberg *et al.* 1996a, Kane *et al.* 1996, Bailey *et al.* 1997a, Cohen *et al.* 1997, Bailey *et al.* 1998, Estberg *et al.* 1998a, Estberg *et al.* 1998b, Cohen *et al.* 1999a, Cohen *et al.* 2000b, Hernandez *et al.* 2001).

One factor affecting the external validity of a case control study is the selection of cases. In order to create an unbiased estimate of risk, all the cases, or an unbiased sub-sample of the population, need to be included. If the cases are racing MS injuries, selection of cases is relatively easy because the majority of racing bodies employ a race day veterinarian and maintain records of race day injuries. If the focus of the study is non-fatal racing related MS injuries, then some cases may be missed because they may not be detected by the race day officials. When the outcome is a non-fatal training-related MS injury, it is difficult to identify all cases because veterinarians are not involved in the diagnosis and treatment of all injuries.

In case-control studies, another factor impacting on the validity of the study is the selection of controls. It is important that controls are selected from the same population as the cases (Szklo 1998, Dohoo *et al.* 2003 p 167). If controls are not selected from the same at-risk population as cases, they may have different exposure histories and this may bias the estimates of effects. This means that in an investigation of risk factors for injuries that occur while racing the controls need to be selected from all horses at risk of a racing injury; that is, all horses that have raced. Similarly, when examining injuries that occur during training, the population at risk of injury is all horses in training at the time the injury occurred.

The primary advantage of a case-control study is that it can be conducted relatively cheaply and efficiently (Thrusfield 1995,p 223). When the cases and controls are selected from a well defined, at-risk population, associations between a variable and outcome can be determined using smaller numbers than would be required in a cohort study. This is especially useful if the outcome is rare.

A problem with many case-control studies is that data are often collected retrospective to the event. This means that existing records or recall must be relied on to provide previous exposure to the potential risk factors and confounders of interest (Thrusfield 1995, p 223). It is possible that knowledge of the individual's health status may bias recall of the exposures in a non-systematic manner. Issues of recall bias may be overcome by using a nested case-control design. A nested case-control study usually implies that the entire source population from which cases are derived has been enumerated and followed (Dohoo *et al.* 2003, p 165). Typically, this means that the case-control study is nested within a cohort study. Exposure data are then collected prospectively and at the end of the study controls are then selected for each case from the unaffected individuals at risk at that point in time (Samet and Munoz 1998b, Szklo 1998, Thomas 1998).

Another disadvantage of the case control study design is that its inherent nature makes it difficult to study repeat events, such as non-fatal MS injuries (Eisen 1999). Some of these issues can be overcome uses variation of the case control study, called a case-crossover study (Maclure 1991, Eisen 1999)

2.4.2 Case-crossover study

A classic crossover study involves the comparison of interventions by randomly giving the subjects each of the treatments and measuring the change in the outcome variable (Maclure 1991, Eisen 1999). When using a case-crossover study, each event is treated as a "case" and one or more previous exposure periods in the same individual are selected as "controls". Regardless of whether the exposure data is collected retrospectively or prospectively, the analysis is the same as for a case-control study. A case-crossover design is of use when the exposure and outcome are related over time. Ideally, the exposure is the trigger for the event or is closely followed by a transient increase in risk.

The case-crossover design has been used in human medical epidemiology to investigate myocardial infarction (Maclure 1991) and the relationship between car accidents and mobile phone usage (Eisen 1999). In the horse, Estberg *et al.* (1998a) and Carrier *et al.* (1998a) have used the case-crossover study design to investigate the immediate effect of short periods of exposure to high-speed exercise on the risk of fatal injuries.

The main advantage of a case-crossover design is that the subject acts as its own control (Maclure 1991, Eisen 1999). This means that there is perfect control of those confounders, within an individual, that remain constant over time. Another advantage of the case-crossover design is that information relating to the entire exposure can be incorporated and time-varying risk patterns can be investigated (Estberg *et al.* 1998a).

The primary disadvantage of a case-crossover design is that it cannot be used to investigate risk factors that do not vary over time and problems exist when there is a time lag between the exposure and outcome. To date, case-crossover studies have not been used to investigate recurrent events. However, recent advances in repeated measures of variance mean that the case-crossover study could be adapted to handle recurrent health problems (Eisen 1999).

2.4.3 Cohort studies

In a cohort study, a group, or cohort, is selected and followed over a defined interval. During this interval, data relating to the health outcome(s) and possibly exposure(s) of interest are collected. Within populations of horses, cohort studies have been used to describe the frequency of health problems in the Thoroughbred racehorse population (Jeffcott *et al.* 1982, Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Perkins *et al.* 2004a, Perkins *et al.* 2004b). There have also been several other cohort studies of populations of Thoroughbred racehorses with the aim of identifying risk factors for all MS injuries (Kobluk *et al.*, Kobluk *et al.* 1990b), shin soreness (Moyer *et al.* 1991, Moyer and Fisher 1992, Boston and Nunamaker 2000, Verheyen *et al.* 2005), suspensory ligament injuries (Hill *et al.* 2001) and pelvic and tibial stress fractures (Verheyen *et al.* 2003).

There are several advantages to the cohort study. Firstly, the exposure status for each subject is normally determined before the health status is known. Therefore, knowledge of the health status will not impact on the exposure data. Another advantage is that time is incorporated, making it possible to investigate the relationship between a number of risk factors and several different outcomes (Samet and Munoz 1998b, Szklo 1998). The study factors and health status are repeatedly measured making it possible to measure their variability over time (Samet and Munoz 1998b, Szklo 1998, Eisen 1999). Therefore, a cohort study is ideal for investigating common and recurrent health problems such as non-fatal MS injuries (Eisen 1999).

The main disadvantage of cohort studies is that they are expensive and can take a relatively long time to complete (Thrusfield 1995). This is a particular problem when investigating "rare" types of MS injuries because resources are allocated to the collection and analysis of data that do not substantially impact on the results (Samet and Munoz 1998b, Szklo 1998, Thomas 1998). This can be overcome by using nested case-control and case-cohort designs. In both nested case-control and case-cohort designs, the cases are all those that occur in the study population (i.e. cohort). The difference between a case-cohort and a nested case-control design is the way in which the control group is selected. In a case-cohort study, the controls are selected from the whole cohort, often at the commencement of the study. In a nested case-control study, the controls are selected from all those individuals at risk of the event at the time a case occurs.

2.5 Measures of association

When conducting analytical studies, it is necessary to compare the relative frequency of a health problem in different groups of the study population (Reid 1998). For example, injury rates may be compared in different age groups, in males and females, between training tracks or between training surfaces. When comparing the different populations the common measures of effect are relative risk and odds ratios (Thrusfield 1995, Reid 1998). Relative risk describes the increase in the probability that a health problem will occur if a subject is exposed to the factor of interest (Beaudeau and Fourichon 1998). The term 'relative risk' is used to describe the ratio of cumulative incidence, or prevalence, in the exposed and unexposed group (Dohoo *et al.* 2003, pp 463-4). The relative risk can be computed for cohort studies, and in some cross-sectional, studies. However, relative risk can not be computed using the results of a case-control study because the probability of disease in these studies is determined by the ratio of cases to controls. In these circumstances the odds ratio is used to determine the strength and direction of the association.

A measure that can be used in case control study is the odds ratio. The odds ratio is calculated by determining the ratio between the proportion of cases exposed to a risk factor, compared to the proportion of controls exposed. The odds ratio is not a proportion and cannot be interpreted as the probability of risk (Thrusfield 1995, Reid 1998). If the event affects less than 5% of the population it is a good approximation of relative risk (Callas *et al.* 1998). However, if the problem affects more than 5%, then the odds ratio will not provide an accurate estimate of risk.

2.6 Frequency and impact of MS injuries

2.6.1 Racing-related MS injuries

The rate of injuries per 1000 racing starts from these studies are summarised in Table 2.1. There are some differences in rates for fatal and non-fatal racing-related injuries. These differences may be because of regional differences, but may also be due to differences in study design, population and definitions of injuries. The regional differences may be true differences but may also reflect differences in training and management strategies rather than true regional differences.

Table 2.1: Details of studies and incidence rates for all musculoskeletal injuries (MSI) and fatal MSI, per 1000 starts in flat racing.

Source	Location	Duration of Study	Number of tracks	MSI/1000 starts	Fatal MSI/1000 starts
Bailey, 1997a	Australia	1985-1995	2	2.4	0.3
Bailey, 1998	Australia	1988-1995	4	2.9	0.6
Hill *et al.*, 1986	New York, USA	1983-1985	3	7.3	1.1
Pelso *et al.*, 1994	Kentucky, USA	1992-1993	4	3.3	1.4
Estberg *et al.,*, 1996	California, USA	1991	15	NR	1.7
McKee, 1995	UK	1987-1993	39	NR	0.8
Williams *et al.*, 2001	UK	1996-1998	19	4.0	NR

NR-Not reported

A two-year longitudinal study examining causes of death in Thoroughbreds and Quarter horses at California racetracks reported 496 fatalities during racing (208), training (195) and non-exercise related activities (93) (Johnson *et al.* 1994). The majority of fatalities were in Thoroughbreds (432), with MS injuries accounting for approximately 80% of deaths. Similarly, a three-year retrospective study of fatal and non-fatal health problems at British flat and National Hunt racetracks found that 82% of the health problems involved the musculoskeletal system (Williams *et al.* 2001). Furthermore, 27% of all problems resulted in death or euthanasia.

Several studies have reported that the majority of racing-related injuries involve the forelimb (JRA 1991, Johnson *et al.* 1994, McKee 1995, Williams *et al.* 2001). Johnson *et al.* (1994) reported that the most common types of fatal MS injuries were fractures (83%) and ruptured ligaments (10%). The most common fracture sites were the proximal sesamoid bones, third metacarpal bone and humerus. Similarly, fatal injuries in flat and National Hunt flat races, in the UK, commonly involved the metacarpal and carpal bones (McKee 1995). In contrast, the shoulder was the most common site for fracture in hurdles and steeplechases.

A 17-month retrospective study investigating fatal and non-fatal racing injuries in Kentucky, USA, found that 86% of injuries were located between the carpus and metacarpophalangeal joint (Peloso *et al.* 1994). The suspensory apparatus was involved in 45% of injuries. Fatal injuries were more likely to involve the left forelimb, sesamoid and third metacarpal, whereas non-fatal injuries were more likely to involve the superficial digital flexor tendon. Similarly, a three-year investigation of fatal and non-fatal injuries at flat and National Hunt races in the UK found that the flexor tendons and suspensory ligaments were involved in 46% of injuries (Williams *et al.* 2001).

2.6.2 Training-related MS injuries

In studies ranging in duration from 81 days to two-years, the cumulative incidence of MS injuries in horses during training has been reported to range from 36% to 57% (Mason and Bourke 1973, Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Aida *et al.* 2001). Furthermore, the MS injuries were found to recur in affected animals (Lindner and Dingerkus 1993, Bailey 1998, Perkins *et al.* 2004a). This is supported by a nine-month prospective investigation of 308 Thoroughbreds trained at a racetrack in Germany. In this investigation 70% horses suffered from at least one episode in which training was reduced or prevented due to health problems (Lindner and Dingerkus 1993). Of the horses that had an episode in which training was reduced or prevented, 115 had one episode, 75 had two, 22 had three and four horses had more than three. Fifty-seven percent of these episodes were due to lameness. However, this study did not describe the types of lameness.

A prospective study at Canterbury Downs, USA, reported that 61% of horses sustained an injury severe enough to result in the reduction or prevention of training (Kobluk *et al.* 1990b). Thirty-six percent of injuries involved bony/"hard tissues", 57% were "soft" tissues and 7% were not musculoskeletal in origin (Robinson *et al.* 1988). While the results are consistent with other studies, it is important to note that this was a pilot study that went for 81 days and involved only 95 horses (Kobluk *et al.* 1990b). Furthermore the estimate of prevalence in this study may have been imprecise because of numerous losses to follow up and incomplete records.

In the Newmarket area, UK, a two-year prospective study involving 314 racehorses reported that 36% of horses suffered from a lameness that resulted in training being reduced or prevented (Rossdale *et al.* 1985). Lameness was reported in a further 16% of horses, but the trainer did not consider the problem severe enough to modify training. It was also found that lameness accounted for 68% of all modified training days. The most common causes of lameness were foot problems (19%), muscular problems (18%), carpal joint problems (14%), fetlock joint problems (14%), tendon problems (14%) and shin soreness (9%). Overall 68% of all lost training days were associated with lameness.

At the end of the two-year-old racing season 40% of horses in Melbourne, Australia were reported as unsound at the end of the racing season (Mason and Bourke 1973). However, the definition for "unsound" was not provided. The most common problems were shin soreness (46%), carpal problems (6.8%), splints (5.4%), fetlock problems (3.8%) and sesamoiditis (2.2%).

In Sydney, Australia, a two-year prospective study of 169 young Thoroughbred racehorses reported that 85% of horses suffered some health problem that resulted in a modified training day and/or time resting at pasture (Bailey 1998). The majority of problems encountered by this cohort were low-grade injuries and disease. The most common health complaints were shin soreness and fetlock problems, which affected 42% and 25% of horses respectively. Of the horses that suffered from shin soreness, 40% developed the problem for a second or third time by the end of the 3-year-old racing season. Similarly, the recurrence of fetlock problems was 48%.

Bailey (1998b) also found that shin soreness accounted for the greatest percentage of lost training days during the two- and three-year-old racing season. Shin soreness was also associated with the greatest percentage of weeks spent resting at pasture in the two-year-old racing season. In the three-year-old racing season, fetlock problems accounted for the greatest percentage of weeks spent resting at pasture.

The horses in study conducted by Bailey (1998b) were selected from the premier yearling sales. These horses represent a subset of the horse population that are thought to have superior conformation and perceived breeding value. Furthermore, the cost of these horses is more than others and as such the owners may differ in their expectations, either protective or pushy. In order to follow these horses a subpopulation of the 'best' trainers in country must be enrolled.

2.7 Risk factors for MS injuries

2.7.1 Sex

Studies investigating the association between sex and risk of catastrophic injury have produced conflicting results. In the USA, a study of racing injuries found that in two-year-old Thoroughbreds, colts were over-represented (Wilson *et al.* 1996). This is supported by Rooney (1983b) who found significantly more fractures in stallions and colts than in geldings. However, neither of these studies used multivariable techniques to control for potential confounders. Mohammed *et al.* (1991), Bailey *et al.* (1997a) and Bailey *et al.* (1998) found no association between sex and risk of catastrophic injury. In contrast, other studies have found males to be at increased risk of catastrophic injury (Estberg *et al.* 1998a, Estberg *et al.* 1998b, Hernandez *et al.* 2001). Estberg *et al.* (1998) postulated that a possible reason for the differences between the two sexes may be because an owner may be more prepared to pay treatment costs for a female as it can be used for breeding.

Studies of non-catastrophic injuries in populations of horses in training have also produced conflicting results. A study of suspensory apparatus injuries in Thoroughbred racehorses during training has shown that gender was not a risk factor (Hill *et al.* 2001). Univariable analysis by Perkins *et al.* (2004a) reported that males were 2.5 times more likely than females to sustain a tendon or ligament injury and 0.7 times less likely than females to sustain a non-fracture case of lameness. This was supported by the results from multivariable analyses that found males were 2.57 times more risk of suspensory apparatus injury and 1.74 time higher risk of superficial digital flexor tendon injury than females (Perkins *et al.* 2005). As with investigations of fatal MS injuries when investigating the relationship between sex and injury, it is important to consider differences in economic value of male and female horses. When a gelding stops racing, there is little or no opportunity for an owner to receive any economic return on their investment. Similarly, only a few entire males are of economic value in the breeding industry. In contrast, females can be used for breeding and therefore retain some economic value when they cease racing.

2.7.2 Age

Descriptive studies of training-related MS injuries have reported that the rate of injuries varies between age groups, with the highest levels reported in two-years olds (Lindner and Dingerkus 1993, Perkins *et al.* 2004a, Perkins *et al.* 2004b). When different types of injuries are considered, the rate of shin soreness is highest in two-year-olds and decreases with increasing age (Perkins *et al.* 2004a). A study found that the risk of fatal MS injury was less in two-year-old Thoroughbred racehorses than older horses (Wilson *et al.* 1996). The study also reported that two-year-olds sustained significantly fewer soft tissue injuries and carpal fractures and more upper limb long bone fractures than older horses. A descriptive analysis of racing injuries in Quarterhorses found that two-year-olds were not any more likely to sustain an injury (Cohen *et al.* 1999a). However, none of the studies used analytical techniques to control for confounding. When controlling for confounding several studies have reported that the risk of a horse sustaining a severe injury is greatest in older horses (Mohammed *et al.* 1992, Bailey *et al.* 1997a, Bailey *et al.* 1998, Carrier *et al.* 1998, Estberg *et al.* 1998b, Williams *et al.* 2001). This is supported by a study that reported the risk of non-fatal suspensory apparatus injury was 2.3 times more in horses five years or older than in horses less than five (Hill *et al.* 2001).

Caution is advised when interpreting these studies as the results may be biased by confounders such as previous exposure to training and racing and age. Generally speaking, older horses have been in training for longer periods of time and therefore are likely to have been exposed to more high-speed exercise. In contrast, younger horses tend to be commencing training for the first time. It is possible to determine if the higher rate of injuries in two-year-olds is due to age or the commencement of training. Anecdotal evidence suggests that older horses commencing training for the first time will also develop shin soreness (Buckingham *et al.* 1990).

To date, there have been no well design prospective studies to determine if older horses are at less risk at the commencement of training than younger horses. In addition, there have been no studies to determine if older horses that have had less training are at less risk of injury than horses of the same age. In the absences of well designed prospective studies it is difficult to determine if age, the degree of exposure to training or a combination of these factors are risk factors for MS injuries.

Should a study be undertaken to investigate the relationship between injuries, age and exposure to training, it is likely to be biased by the 'healthy horse' effect. The, "healthy horse" effect occurs as those horses that are still in training are, on the whole, healthier than those horses that are no longer training, because those horses that are not racing, or training, are often able unable to compete because they have suffered an episode of ill health. Therefore, differences in injury rates could be due to age, adaptation to exercise, the health horse effect or a combination of these factors.

2.7.3 Skeletal Immaturity

A survey of a small number of Victorian trainers and veterinarians found that the majority believed immaturity and "too much too soon" were the major risk factors for shin soreness (Buckingham and Jeffcott 1990). This is supported by Mason and Bourke (1973) who reported that horses commencing racing or "hard training" when skeletally immature, as measured by closure of the distal radial epiphyseal, had a higher incidence of carpal problems and shin soreness. However, the authors did not define hard training and their analysis did not control for potential confounders. Moreover, a study of 113 Standardbred racehorses failed to find any correlation between distal radius physeal closure and incidence of injury (Gabel *et al.* 1977). Based on this studies, it is apparent that further research is required to determine if there is a causal link between skeletal immaturity and risk of MS injury.

2.7.4 Bone strength

Bone strength will influence its ability to withstand repeated loading. The total strength of the bone is determined by its stiffness or elasticity, mineral density and shape (Firth

2004). Studies in Quarter horses have shown that those with a greater cortical mass in the dorsal and medial metacarpal at the commencement of a training program had a lower injury rate (Nielsen *et al.* 1997). The significances of these findings is difficult to assess because the authors did not detail the types of injuries that were included.

Davies *et al.* (1999) have measured the cortical thickness and develop a radiographic index to describe the shape of the bone. The index relates the width of the dorsal cortex to that of the palmar cortex, and using this index the group reported that it was possible to predict when a Thoroughbred racehorse would become shin sore. Use of this technique in a clinical setting would require careful standardisation and this may limit its widespread application. Furthermore, methods such as those used by Davies *et al.* (1999) do not take into consideration intra-cortical porosity and can not detect changes in trabecular bone (Firth 2004).

Studies investigating the relationship between bone strength and injury are complicated by the dynamic nature of bone. Studies have shown that bone mass and geometry change in response to changes in the normal loading pattern. If the load decreases then loss of bone mass occurs. In contrast, if the load increases then the bone mass and strength will increase. Investigations of the relationship between changes in bone mass and geometry are limited by lack of cost effective measures to measure bone response to exercise (Firth 2004).

2.7.5 Body Size and Composition

Body size affects the magnitude of forces applied to skeletal tissue and could theoretically be a risk factor for a MS injury. In human studies, there are conflicting results regarding the relationship between body size and composition (Knutzen and Hart 1996). Some studies have reported that taller, heavier individuals are at greatest risk of injury, and other studies have reported no effect. To the author’s knowledge, there have been no studies to investigate these factors in Thoroughbred racehorses, although, a cross-sectional study of Icelandic horses found sound horses were 6 mm taller, at the croup, than unsound horses (Axelsson *et al.* 2001). However, the definition of sound and unsound was not provided and the clinical usefulness of a 6 mm difference is unclear. Clearly, further research is required to assess the impact of body size and composition on risk of injury.

2.7.6 Conformation

A few studies have examined the relationship between MS injury and conformation. One prospective study measured several variables relating to body shape (Kobluk *et al.* 1990b). These variables are described in Table 2.2. There was no significant association between the ratios of measurements in the forelimb and hindlimb and MS injury. A cross-sectional study subjectively described horse shape and conformation and measured a number of angles in the forelimb and hindlimb (Axelsson *et al.* 2001). Multivariate analysis found that an eight-degree reduction in the angle between the axis of the tarsal and the third metatarsal bone was the only measure of conformation associated with an increased risk of degenerative joint disease in the distal tarsus of Icelandic horse. The size of the difference limits its clinical usefulness.

Table 2.2: Conformation measurements obtained from 95 horses in an 81-day prospective study.

Limb	Index	Measurement
Fore-limb	Antebrachium length	Elbow joint to mid carpus
	3rd Metacarpal length	Mid carpus to fetlock joint
	Pastern length	Fetlock joint to coronary band
Hind-limb	Tibia length	Stifle joint to tibio-tarsal joint
	3rd Metatarsal length	Tibio-tarsal joint to fetlock joint
	Pastern length	Fetlock joint to coronary band

Adapted from Kobluk *et al.* (1990)

2.7.7 Shoeing and hoof angles

A study in Japan found that horses fitted with plates for racing and training had lower injury rates than those that were not fitted with plates (JRA 1991). The reduction in risk may be because shoeing and hoof trimming can alter hoof angles and correct conformation faults such as “bucked carpals” and “standing under” (Bushe *et al.* 1990). A prospective study involving 95 horses measured the hoof angles and subjectively evaluated the foot for balance (Kobluk *et al.* 1990a). The results showed an association between low fore hoof angles and MS injury, but no association between steep hoof angles and injury. However, the analysis did not use multivariable techniques to control for any potential confounders. Furthermore the outcome in this study was all MS injury and the heterogeneous nature of the outcome may have biased results towards the null.

Using multi-variable techniques, at least two studies have demonstrated an association between shoeing and risk of MS injury. A case-control study in California, USA, involving horses that died or were euthanased with a MS injury reported that changes to shoeing could be used to modify the risk of fatal MS injury (Kane *et al.* 1998). In this study, controls were selected from horses that died or were euthanased for reasons other than a MS injury. Thus the exposure of controls to other risk factors may have been different to the cases and these differences may have biased the results. In a prospective study, the risk of suspensory apparatus was found to increase when a toe grab was used, and when the hoof was trimmed to perfect mediolateral symmetry (Hill *et al.* 2001). The authors reported that reducing the difference between toe and heel angles decreased the risk of suspensory apparatus injury. It is worth noting that shoeing practices differ between countries, due to differences in the rules of racing. The regional differences may limit the usefulness of these studies to the wider population of horses and the relative importance of shoeing as a risk factor for MS injuries. This highlights the importance of conducting country-, or region,- specific research.

2.7.8 Previous or pre-existing injury

Case studies have shown that injured horses often have either a previous injury or a pre-existing low grade MS injury (JRA 1991, Stover *et al.* 1992, Stover *et al.* 1993). This suggests that previous or pre-existing injury may be a risk factor for MS injury. However, case studies do not examine the underlying distribution of the risk factor in the population. Therefore, it is necessary to review the results from analytical studies to determine if previous or pre-existing injuries are risk factors for MS injury.

Several analytical studies have reported a relationship between a previous or pre-existing complaint and risk of MS injury. A case-control study found that abnormality in the suspensory ligament detected during the pre-race inspection was associated with a three-fold increased in the risk of any kind of MS injury during the race and five-fold increase in risk of an injury involving the suspensory apparatus (Cohen *et al.* 1999b). This is supported by a 90-day longitudinal study, that found a pre-existing sub clinical or mild suspensory apparatus injury was a risk factor for all types of MS injuries and suspensory apparatus injuries (Hill *et al.* 2001). In three- and four-year-old Standardbred racehorses, the presence of radiographic changes before the age of two resulted in a two-fold increase in the risk of lameness (Gaustad *et al.* 1995). The results of these studies highlight the need for a prospective study to examine the relationship between factors that occur in the event and post event stage of an injury which may increase or decrease the risk of another MS injury.

2.7.9 Fatigue

Rooney (1983a) reported that fatigue is a significant factor in the cause of lameness, particularly in horses working at speed. In order to quantify fatigue, 234 races were examined. The velocity drop between the last and next-to-last segments was calculated and used to give the races a fatigue rating. Analysis of the data showed that a high fatigue rating was associated with certain track conditions and an increased number of breakdowns.

This may also be because when the muscle is fatigued it is unable to reduce the stresses and strain on the bone (Brunker *et al.* 1999, pp 9-10). Laboratory studies horses have shown that an inability to attain a previous maximum exercise speed in a subsequent run, within the same exercise period, is associated with an increase in bone strain (Davies 1996). Muscle fatigue has also been associated with distinctive changes in stride pattern and length in Thoroughbreds (Leach and Sprigings 1979). It has been suggested that this uncoordinated movement may result in excessive forces on some tendons and may increase the risk of tendon injury (Goodship and Birch 2001).

2.7.10 Genetics

The relationship between genetics and health problems is a relatively new area in epidemiology (Samet and Munoz 1998a). A study of Standardbreds in Norway revealed that an index relating to sire was associated with MS injury (Gaustad *et al.* 1995). The authors concluded that the sire index was significant because of genetic factors. Another study involving Icelandic horses found that, after controlling for age and a number of other risk factors, the prevalence of hind limb lameness varied between offspring groups (Axelsson *et al.* 2001). More research is required to determine the relationship between genetics, environment and the onset of MS injuries.

2.7.11 Training-related factors

Several studies have reported differences in injury rates between equine operations. Wilson *et al.* (1997) reported that there was a significant variation in race day injury rates between trainers. Two prospective studies have also reported that the prevalence of training related MS injuries differed between operations (Rossdale 1989, Ross and Kaneene 1996b). A study of training and health problems Thoroughbred in racehorses showed that there were differences in the training patterns between trainers, and that stables with higher average exercise scores had lower injury rates (Kobluk *et al.* 1990b). The results of these studies support a hypothesis that factors relating to training may be risk factors for injuries.

A study of horses involved variety of activities reported that horses that raced were 1.75 times more likely to suffer an episode of lameness than those not involved in racing (Ross and Kaneene 1996a). Estberg *et al.* (1998a) found that the risk of MS injury increased if a horse was exposed to an excessive amount of high speed exercise, either in official workouts or races, in the previous 60 days. In this study exposure to high speed exercise was quantified using an index called the average rate of distance accumulation (ARDA): calculated by dividing the total distance accumulated, in the previous 60 days, by the number of days between the first and last exercise event. Exposure was considered excessive if the distance exceed the 75th percentile for the ARDA. The authors reported specific year specific cut offs because the quality of the data varied between calendar years. In 1990 the only HS exercise events recorded were races, while HS gallops during training were recorded the authors noted that it was not optimal, many of which were addressed in the second year (i.e. 1992). To overcome the differences, in data quality the authors calculated calendar year specific threshold values. Due to potential age differences age class specific threshold were also calculated for each calendar year (Table 2.3).

Verheyen and Woods (2003) have reported an association between increasing distances cantered, in a 30-day period, and risk of tibial and pelvic stress fracture. The group found no association between distances trained at high-speed and risk of stress fracture. It is difficult to comment further on the results of these studies, as the speeds typically associated canter and high-speed work were not described.

Table 2.3: Year- and age-specific cut off values for the average rate of distance accumulation of racing-speed exercise in 60 days, above which the time period was classified as a hazard period.

	Cut off values for accumulation of racing speed (meters)			
Calendar year	2-year olds	3-year-olds	4-year-olds	≥ 5-year-olds
≤1990	114	126	126	134
1991	172	138	156	142
1992	152	170	190	182

Adapted from Estberg *et al.* (1998a)

Verheyen *et al.* (2005) reported an increased risk of dorsometcarpal disease with increased exposure to canter (≤15 seconds/furlong) and high-speed (>15 seconds/furlong) exercise in one, two and four weeks periods. The results of Verheyen *et al.* (2005) contradict Boston and Nunamaker (2000) who reported a protective effect of exposure to speeds ≥ 900 m/minute and an increase in risk associated with increased exposure to speeds around 600 m/minute. Verheyen *et al.* (2005) suggested that the most likely reason for this is that Boston and Nunamaker (2000) determined average distances trained in each week by dividing the cumulative sum of distance at each speed during the whole training period by the time at risk. Results presented in their paper showed that when exposure to high-speed exercise was quantified in this manner, the risk of dorsometcarpal disease decreased with increasing average weekly distances. In contrast, when exposure was quantified using shorter time intervals of one week, two-weeks and one month, the risk of dorsometcarpal disease increased as the distance trained at high-speed increase. Another possible reason for the difference between the current study and Verheyen *et al.* (2005) included methodological differences between the studies such as differences in data collection methods. In Verheyen *et al.* all the data were collected prospectively whilst Boston and Nunamaker (2000) used a combination of prospective and retrospective data collection, and in some cases the retrospective records were 20-years old. Over time, the accuracy of the record keeping and the extrinsic risk factors could have changed. In addition, the commencement of the study may have caused reporting to be altered.

The results of Boston and Nunamaker (2000) may also have been biased by confounding and informative censoring. The results may have been confounded by a number of factors including pre-existing injury and training centre. It is possible that the increased risk associated with training horses at speeds of approximately 660 m/minute may be confounded by pre-existing injury. For example, when the horse has mild shin soreness the trainer may increase the distance trained at 660 m/minute to compensate for the lack of training at speeds between 900 and 960 m/minute. Differences in training centre may also have confounded the results. Analytically it would have proven difficult to evaluate the training venue as a risk factor because only two of the five trainers trained at the same venue. The authors did analyse data from the two trainers separately and reported that the results were consistent with the rest of the study. The data from these trainers may have been highly influential in the analysis. Unfortunately the authors did not report the results when these trainers were removed from the analysis.

Boston and Nunamaker (2000) used survival analysis techniques for data analysis. When using these techniques, informative censoring is always a concern (Allison 2001b). Informative censoring occurs when an animal is lost to follow-up with a problem that could be caused by exposure to the study factor. For example, informative censoring would occur if a horse was lost to follow-up due to a fetlock injury. In work conducted by Boston and Nunamaker (2000), 161 of the 226 horses were lost to follow-up and the authors did not provide reasons for the losses to follow-up. If the horses that were lost to follow-up sustained another MS injury, this could have biased the relationship between shin soreness and distances trained at 600 m/minute and between 900 m/minute and 960 m/minute. Unfortunately, the authors did not perform sensitivity analysis to allow the reader to determine the effect of informative censoring should it have occurred. Therefore, it is difficult to recommend this training program as it may increase the risk of other types of MS injuries.

The results of the previous studies each support a hypothesis that MS injuries are the result of accelerated micro-damage caused by repeated loading of the bone (Riggs and Evans 1990, Nunamaker 1996). At a microscopic level, the first signs of microaccelerated remodelling are vascular congestion, thrombosis and resorption of the bone tissue (Brunker *et al.* 1999 pp 8-9). Once accelerated remodelling has commenced, continual loading of the bone will increase the size of the resorptive cavities (Riggs and Evans 1990, Nunamaker 1996). This will result in the appearance of micro fractures that extend into the cortex causing a marked reduction in bone strength. Post mortem examination of horses that had undergone gallop exercise and develop bucked shins reported that there was localised congestion and oedema of the periosteum and subcutaneous tissue (Katayama *et al.* 2001). Furthermore, there was lamellar bone formation and intracortical lytic change evident on micrographs. None of these changes were evident in two unexercised controls. Studies in humans indicate that in the initial stages these changes do not produce any symptoms (Brunker *et al.* 1999, p 9). However, as remodelling progresses mild pain occurs during exercise and even if the loading is stopped then pain will persist even after the completion of exercise. Complete fracture may even occur as there is insufficient bone to withstand the load.

2.7.12 Extended breaks for training

Laboratory studies have shown that the bone of horses that are box rested undergoes significant changes (Firth 2004). These studies support a hypothesis that extended breaks from training will place the horse at risk of MS injury when they resume training. This view is also supported by population based studies. In Kentucky, research has shown that horses that had not completed an official high-speed work or raced in the previous month were at increased of suffering from a non-fatal racing related MS injury (Cohen *et al.* 2000a). Carrier *et al.* (1998) also reported that horses returning after a lay-up of more than 60 days were at increased risk of humeral or pelvic fracture. In both these studies the absence of exposure to high speed exercise do not necessarily equate to a break from training. Furthermore, no information was collected as to the reason for the lay-up. Consequently, it is not possible to determine if the risk factors were a break from high-speed exercise, previous or pre-existing MS injury or a combination of both factors.

2.7.13 Track-related factors

The role that factors associated with racetrack design and management play in the onset of MS injury is unclear. Hill *et al.* (1986) concluded that there was not a significant difference in injury rate between racetracks used for Thoroughbred racing. Bailey (1998b) commented that while there was no significant difference overall, there was a significant difference in fracture rates between Saratoga and Aqueduct racetracks. Peloso *et al.* (1994) also reported that there was no difference in injury rates at four Kentucky racetracks. However, the results reported by Peloso *et al.* (1994) do not truly reflect the opportunity for injury at each track, as the injury rates were reported per race day rather than per race start (Bailey 1998). Other studies in the USA have reported that the fatality rate for two-year-olds racing at different dirt tracks ranged from 0 to 4.14 per 1,000 starts (Wilson *et al.* 1996). Unfortunately, none of these studies used multivariable techniques and the variation in fatality rates may be due to a number of factors including differences in the gender distributions of race entrants (Estberg *et al.* 1996b).

When using a multivariate analysis to control for factors such as age and gender, Mohammed *et al.* (1991) reported that horses racing at one track were at less risk of sustaining a MS injury. The results of this study are supported by Bailey *et al.* (1998) who reported that one of four metropolitan racetracks in Melbourne, Australia, was associated with a significant increase in risk. In contrast, when using a multivariate approach to analysis of risk factors for injury at two racetracks in Sydney, Australia, there was no significant difference between tracks (Bailey *et al.* 1997a).

Comparison of injury rates pre- and post-track reconstruction in Thoroughbreds in Japan (Oikawa *et al.* 1994) and Standardbreds in Australia found a significant reduction in injuries post reconstruction (Evans and Walsh 1997). Whilst the results of these studies are conflicting, there appears to be sufficient evidence to support a hypothesis that factors associated with the design and management of racetracks are risk factors for MS injury. These factors may include racetrack geometry, track surface, track condition, camber, starting chutes and thatch accumulation and grass roots.

<u>Racetrack geometry</u>

Several studies have reported a clustering of severe and fatal race day accidents at or near the home turn (Hill *et al.* 1986, Clanton *et al.* 1991, JRA 1991, Oikawa *et al.* 1994, Peloso *et al.* 1994, Wilson *et al.* 1996). Fredricson *et al.* (1975b) suggested that the increased risk of injury associated with turns is attributable to centrifugal force. Centrifugal force creates an outward pull on the horse and tends to divert the animal from the track. Studies in Standardbreds show that moving around a corner causes abnormal gait and increases the temperature in the fetlock joint (Crawford and Leach 1984). The magnitude of the force and the difference in forces between the forelimbs is accentuated when speed is increased (Davies 1996) and the radius of the corner is reduced (Fredricson *et al.* 1975b).

It follows that decreasing the speed at which the horse enters the turn or increasing the radius of the turn will reduce the centrifugal force and may decrease the risk of MS injury (Fredricson *et al.* 1975a, Fredricson *et al.* 1975b). This is supported by evidence from a racetrack reconstruction in Japan where the third and fourth turns were widened, and an incline was added in the straight between the two turns (Oikawa *et al.* 1994). Examination of injury rates pre- and post-reconstruction also found a significant reduction in the incidence of fatal MS injuries.

Another way of reducing the centrifugal force acting on the horse when it negotiates a turn is to increase the banking (Fredricson *et al.* 1975a, Fredricson *et al.* 1975b). The amount of banking required is dependent on the radii of the curve and the speed with which the horse enters the turn. The relationship between radii, banking and speed is shown in Table 2.4.

When a horse enters and exits a corner it must readjust its balance, thereby increasing the force on its limbs (Fredricson *et al.* 1975a, Fredricson *et al.* 1975b). The unbalancing effect of corners may be minimised by the use of transitional curves, that is, curves with differing radii. The introduction of transitional curves can be beneficial even if the curve is underbanked. However, the unbalancing effects can only be fully reduced by adequate banking. Increasing the banking of semicircular curves and introducing transitional curves at one Scandinavian Standardbred racetrack resulted in a marked reduction in gait asymmetry and heat in the fetlock joint (Fredricson *et al.* 1975a, Fredricson *et al.* 1975b). These results suggest that the strain on the limbs whilst negotiating the corners had been reduced and it was hypothesised that this would reduce injury rates. Subsequent surveys of trainers at the reconstructed racetrack found that the majority perceived that there had been a reduction in injuries (Fredricson *et al.* 1976). However, there was no quantitative analysis of injury data pre- and post-track reconstruction.

Table 2.4: The optimal percentage (%) elevation of turns at racetracks given the radius of the racetrack and the velocity of the horse.

Velocity	Curve radius (m)						
(meters/minute)	50	75	100	125	150	175	200
857	42	28	21	17	14	12	10
800	36	24	18	15	12	10	9
750	32	21	16	13	11	9	8
705	28	19	14	11	9	8	7
666	25	17	13	10	8	7	6

Adapted from Fredricson *et al.* (1975)

Analysis of injury data from a Standardbred racetrack in Sydney, Australia, pre- and post- reconstruction found a significant reduction in injury rates (Evans and Walsh 1997). The banking was increased from 4.8 to 5.7 degrees. Whilst the degree of banking was not optimal for an 800-metre track there was a significant reduction in total injury rate from 8.5 to 6.6 per 1000 starts.

These results suggest that reducing the speed with which horses enter the corner, widening the corner, introduction of transitional curves and increasing the banking could result in significant reductions in injury rates. Ideally, all turns at a racetrack would be adequately banked and make use of transitional turns. However, given the clustering of injuries around the home turn (Hill *et al.* 1986, Clanton *et al.* 1991, JRA 1991, Oikawa *et al.* 1994, Peloso *et al.* 1994, Wilson *et al.* 1996), priority should be given to this section of the track.

<u>Track surface</u>

In the horse, the relationship between track surface and MS injury is unclear. The resilience of the track surface has a great influence on the impact forces. Hard surfaces are considered a problem because the ground reaction forces are increased, thereby increasing the strain on the bone (Brunker *et al.* 1999, p 11). Alternatively, soft surfaces, whilst providing cushioning, may hasten muscle fatigue (Brunker *et al.* 1999 p 11), which would also increase the strain on the bone (Yoshikawa *et al.* 1994, Davies

1996). Studies of horses trained for 5 months and over a cumulative distance of 152 km found that there was greater thickening of trabeculae and lower porosity in the proximal bone of horses trained on dirt tracks compared to the more compliant woodchip tracks (Young *et al.* 1991).

Davies (1996) reported that changes in track surface did not alter bone strain. This suggests that surface type is not a risk factor for MS injuries, a hypothesis supported by Robinson *et al.* (1988) who found that there was no difference in injury rates between turf and dirt surfaces at one racetrack in Minnesota. However, analysis of data from all racetracks in the USA (Mundy 1997) and Japan (JRA 1991) found that compared to dirt tracks the average fatality rate was lower on turf surfaces.

Examination of injuries at New York Association tracks reported that the incidence of fractures was greatest on dirt, however, there were no difference in the incidence of soft tissue injuries between dirt and turf surfaces (Hill *et al.* 1986). This is supported by a case-control study that found horses racing on dirt were approximately three times more likely to sustain an injury than horses racing on turf (Mohammed *et al.* 1991). Furthermore, horses racing on turf were less likely to sustain a severe injury (Mohammed *et al.* 1992). In the UK, the injury rate was significantly greater for horses racing on equitrack and fibersand than for those racing on turf (Williams *et al.* 2001). In particular, the rate of sesamoid/fetlock injuries and flexor tendon/suspensory injuries was almost double that recorded during turf races. The difference in injury rates for other types of injuries was not significant.

There has been limited research examining the effect of training surfaces on MS injuries. Studies examining sand and soil material found that soil surfaces are better at cushioning the impact and preventing hoof rotation (Zebarth and Sheard 1985). This suggests that when compared to sand surfaces, soil tracks may be associated with a reduced risk of MS injury.

A prospective study, in the USA, found that horses trained on wood fibre were at less risk of injury than those trained on dirt surfaces (Moyer *et al.* 1991, Moyer and Fisher 1992). In this study 34% of horses that trained exclusively on dirt developed shin soreness whilst only 13.5% of horses training on woodchip suffered the complaint. In addition, horses training on woodchip accumulated 86 miles of fast work before the onset of shin soreness, whilst horses trained on dirt accumulated only 32 miles.

In the situations considered by Moyer *et al.* (1991 and 1992) training surfaces were located at training centres. Consequently the observed difference between the two surfaces may have been due to factors such as the degree of banking in turns (Evans and Walsh 1997) and the track geometry (Fredricson *et al.* 1975a, Fredricson *et al.* 1975b). In addition Moyer and Fisher's study (1992) did not control for any aspect of training because the authors observed that the trainers appeared to train in an identical manner. However, no quantitative evidence was provided to support this conclusion.

Track Condition

There are conflicting reports in the literature regarding the role surface condition plays in the onset of injury. An investigation of racing injuries detected by the race day veterinarian at two racetracks in Sydney, Australia, reported that track condition was not a risk factor for MS injuries (Bailey *et al.* 1997a). Similarly, Wilson *et al.* (1986) reported that there was no association between track condition and overall injury rates. However, there was an increased risk of fracture in two-year-old racing on non-fast dirt tracks. In addition, Mohammed *et al.* (1991) and Pelso *et al.* (1994) found no association between track condition and injury rates.

In contrast, Cheney *et al.*(1973) reported that there was a positive linear association between track hardness and the percentage of horses reported as injured. However, in this study injury data was collected by sending a questionnaire to trainers. Therefore the results could have been affected by recall bias and response rates. In addition, the analysis did not control for other factors that might have affected the results.

A study of serious injuries at four metropolitan racetracks in Australia found that after controlling for age, racetrack and type of racing, the risk of injury was 3.4 times greater on a fast track than on a slow track (Bailey *et al.* 1998). Similarly, a study of MS injuries in flat races and the National Hunt in the UK reported that there was a reduction in fatalities as the racing surfaces became softer (Williams *et al.* 2001).

Hill *et al.* (1986) reported that at one dirt track, the risk of fracture was greatest on a muddy track and the risk of soft tissue injuries was greatest on a fast dirt track (Hill *et al.* 1986). However, these associations were not repeated at any other racetracks in the study and overall injury rates were not affected by the condition of the track.

A study of two-year-old Thoroughbred and Quarterhorses found that injuries were associated with a non-fast dirt track (Wilson *et al.* 1996). The results of Wilson *et al.* (1996) are supported by Mohammed *et al.* (1992) who reported that when horses were racing on muddy dirt they were more likely to sustain a severe MS injury. Similarly, a study of MS injuries in Japan reported that horses racing on dirt were at increased risk than when racing on heavy tracks (JRA 1991). The researchers suggested that this was because the high water content reduced or eliminated the shock-absorbing qualities of the cushioning sand. The results of these studies show that the water content of the surface alters risk of injury. Soil moisture and therefore surface hardness can be controlled through irrigation and drainage (Zebarth and Sheard 1985). More research is required to determine optimal water levels for the training and racing surfaces.

Camber

Racetracks may be designed with camber to the inside rail to allow adequate drainage (Fredricson *et al.* 1976). Studies in humans suggest that uneven ground and slanted roads are a risk factor for MS injuries in runners because they increase the force on the lower extremity (Knutzen and Hart 1996, Brunker *et al.* 1999 p 11). However, Davies (1996) reported that there was no change in strain on the bone when the camber was altered.

Starting chutes

Clanton (1991) reported that the majority of injuries that resulted in the horse being removed by ambulance occurred near high traffic areas such as starting chutes. Laboratory studies have shown that cantering a horse over a surface that has been used during daily training increased the peak vertical forces on the limb (Kai *et al.* 1999). This would seem to suggest a reason for high traffic areas being associated with MS injury. However, there is insufficient evidence to prove a causation.

Thatch accumulation and grass roots

Other areas of concern are thatch accumulation, mowing height and turf roots. Examination of impact and sheer resistance suggests that thatch accumulation and mowing height do not have a significant impact on racing surface hardness (Zebarth and Sheard 1985). In contrast, turf roots were responsible for an increase in impact and sheer resistance. Whilst surface hardness has been identified as a risk factor for MS injury, there is no direct evidence linking the accumulation of turf roots and injury.

2.7.14 Seasonal effects

Presently the role of season in the onset of a MS injury has not been adequately addressed. A retrospective descriptive study of injuries in Japan noted that fatal and non-fatal fractures whilst racing were more common in early spring (JRA 1991). In contrast, training injuries were more common during winter. Similarly, a nine-month prospective investigation study in Germany noted that the incidence of lameness was highest in February (Lindner and Dingerkus 1993). However, neither study controlled for confounders. Therefore it is difficult to determine if the seasonal effects observed in these studies are a true result or due to the effect of exposure to other variables, such as previous racing and track condition.

A case-control study using analytical methods to control for a number of potential confounders reported that horses racing in summer were three times more likely to sustain a MS injury than those racing in winter (Mohammed *et al.* 1991). However, this study relied on racing histories and therefore may have been biased by other unmeasured factors including changes in the level of high-speed exercise coincident with the season.

A study of training injuries in Japan reported that more MS injuries occurred in February and April (Aida *et al.* 2001). The authors noted that the seasonal effect did not appear to correlate to the “training menu”. However, the authors did not describe the variables that were included in the “training menu” or the statistical techniques used to investigate the association.

2.7.15 Stable Management

There are a number of issues relating to the management of a stable that could be risk factors for MS injuries. Analysis of data collected in the Michigan Equine Monitoring System (MEMS) found that horses on larger operations were at less risk of lameness while those on operations with a higher level of veterinary and farrier involvement were at greater risk (Ross and Kaneene 1996b). It is not clear if this relationship represents a true alteration in risk or if the differences reflect the level of detection of MS injuries or higher level of involvement because their injury rates are higher.

2.7.16 Rider

The risk of fatal injury was higher in horses ridden by amateur than those ridden by professional jockeys in National Hunt Race (McKee 1995). The relationship between rider and risk of injury could have been confounded by a number of factors including an increased likelihood of amateur riders being placed on older horses and horses with pre-existing injuries. Evidence from laboratory studies have shown that riders can redistribute their weight over the forelimbs (Schamhardt *et al.* 1991). The overall difference were small and there is no further evidence of an association between rider skill and injury.

Weight of the rider may also play a role in the onset of MS injury. Studies have demonstrated that increasing the load a horse carries increases the ground reaction forces (Schamhardt *et al.* 1991). This increase in ground reaction forces could increase the load placed on the skeletal tissue. Therefore, it is possible that the use of heavier riders could increase the incidence of injury. It is possible that training without a rider, for example on a treadmill, may help to reduce lameness.

2.8 Conclusion

Musculoskeletal (MS) injuries have been identified as a common health problem in Thoroughbred racehorses (Bailey *et al.* 1999, Perkins *et al.* 2004a, Perkins *et al.* 2004b). The most common MS injuries in two- and three-year olds have been identified as shin soreness (Bailey *et al.* 1999, Perkins *et al.* 2004a) and problems involving the carpus and fetlock joints (Bailey *et al.* 1999). These MS injuries incur both direct and indirect costs. These direct costs include lost opportunity to race and treatment costs. The indirect costs relate to the negative impact of MS injuries on the public perception of racing and are difficult if not impossible to quantify.

After reviewing the literature it is clear, that despite a number of studies, further research is required to better understand the casual pathway for MS injuries. In particular, there has been almost a complete absence of any investigations that have collected data on daily training in an effort to understand the training related risk factors for MS injuries. Studies that utilize daily training records are fundamental to the understanding of training related risk factors for MS injuries. An understanding of the risk factors for MS injuries would facilitate the design of strategies that may reduce the occurrence and impact of MS injuries.

The aim of this thesis was to investigate the epidemiology of MS injuries in Australian two- and three-year-old Thoroughbred racehorses. More specifically the thesis aimed to:

- Describe the incidence of MS injuries;
- Determine the impact of MS injuries using a variety of measures of performance; and
- Determine risk factors for MS injuries, in particular shin soreness.

Chapter 3: Design, implementation and management of an epidemiological investigation of musculoskeletal injuries in Thoroughbred racehorses

Abstract

AIM: To describe the methodology of a longitudinal study used to investigate the epidemiology of musculoskeletal (MS) injuries in two- and three-year-old Thoroughbred racehorses.

METHODS: Professional trainers from five racetracks were convenience sampled. Training and injury data were collected at fortnightly intervals. The training data were aggregated into units referred to as “preparations”. A preparation ended when the horse left the stable for more than seven days. Characteristics of the trainers who were enrolled in the study and complied with the protocol were compared with the group that refused to participate or were removed from the study for failing to comply. Data quality was assessed using two separate outcomes: number of days with missing training data per 100 training days, and the number of incorrectly recorded starts per 100 starts.

RESULTS: Fourteen trainers contributed a total of 451 two-year-old Thoroughbred horses, 1, 272 preparations, and 78, 154 training days to the study. Of the 323 horses enrolled in the 2000/01 racing season, 219 contributed three-year-old data to the study. During the study period 8%, of training days had missing training data and 3% of the 1, 986 starts in the races or barrier trials were incorrectly recorded. The rate of incorrect entries varied with both study month and trainer. Similarly, the rate of training days with missing data varied between trainers and with study month.

CONCLUSIONS: This study is the largest undertaken in Australia to examine risk factors for MS injuries in horses in training. Trainers were sampled using non-probabilistic methods because the data collection process required a high level of compliance. Examination of incorrect records and days with missing training data indicated that there was variability in data quality during the study period and between trainers. The variation in data quality between trainers should be considered as a reason for trainer effects in multivariate models.

3.1 Introduction

Musculoskeletal (MS) injuries are the most common health problem in Thoroughbred racehorses (Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Perkins *et al.* 2004a, Perkins *et al.* 2004b). In Australia, a study of two- and three-year-old Thoroughbred racehorse reported that during the study period 85% of horses suffered a health problem that either prevented training or resulted in the horse resting at pasture (Bailey 1998). The researchers also found that shin soreness and fetlock problems were the most common health problems affecting 46% and 25% of horses, respectively.

Presently research has focused on describing the frequencies with which injuries occur (Jeffcott *et al.* 1982, Rossdale 1989, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Perkins *et al.* 2004a, Perkins *et al.* 2004b, Verheyen and Wood 2004), in identifying risk factors for fatalities that occur either during racing or training (Estberg *et al.* 1995, Estberg *et al.* 1996a, Estberg *et al.* 1996b, Carrier *et al.* 1998, Estberg *et al.* 1998a), and non-fatal racing-related injuries (Hill *et al.* 1986, Mohammed *et al.* 1991, Mohammed *et al.* 1992, Peloso *et al.* 1994, Wilson *et al.* 1996, Cohen *et al.* 1997, Wilson *et al.* 1997, Bailey *et al.* 1998, Estberg *et al.* 1998b, Hill *et al.* 2001, Parkin and Clegg 2004). There has only been a small number of studies investigating risk factors for non-fatal training-related MS injuries (Kobluk *et al.* 1990a, Kobluk *et al.* 1990b, Moyer *et al.* 1991, Moyer and Fisher 1992, Boston and Nunamaker 2000, Hill *et al.* 2001, Verheyen *et al.* 2003).

The high number of MS injuries in two-year-olds in training and the lack of research in the literature was a major motivation behind the funding of this study. The aim of this study was to use prospective methods to describe the epidemiology of MS injuries in Australian two- and three-year-old Thoroughbred racehorses. Specifically, the study aimed to:

- Describe the incidence of MS injuries;
- Determine the impact of MS injuries using a variety of measure of performance; and
- Determine risk factors for a MS injuries, in particular shin soreness.

This chapter describes the design, implementation and management of the longitudinal study. Descriptive and multivariable analysis of this data will be presented in subsequent chapters.

3.2 Materials and methods

3.2.1 Funding and scope

The Rural Industry Research and Development Corporation (RIRDC) provided funding for an investigation of risk factors for shin soreness. The scope of the study was expanded because trainers indicated that they would be willing to provide the necessary data if the study included an investigation of risk factors for forelimb fetlock problems, carpal problems and tendon injuries. From a practical perspective, collecting data on the occurrence of a number of injury types was not expected to reduce the quality of data relating to shin soreness or increase the burden of data collection for either the trainer or the investigator. Furthermore, Bailey (1999) reported that forelimb fetlock joint and carpal problems were a major source of lost training days and weeks spent resting at pasture.

3.2.2 Recruitment and enrolment of trainers

Trainers were convenience sampled from those located at one of five metropolitan or provincial racetracks in New South Wales (NSW), Australia. Racetracks in Australia are classified as metropolitan, provincial or country. Metropolitan racetracks are located in the major metropolitan centre of the state. Provincial tracks are located near the metropolitan centres, and races held at provincial racetracks normally offer less prize money than those held on metropolitan racetracks. Country racetracks are all those not classified as metropolitan or provincial. Generally, races held at country racetracks offer the least prize money.

The following criteria were used for the selection of trainer:

- “Number one” or “normal” trainer's license,
- Expected to have ten or more two-year-olds enter training during the 2000/01 racing season, and
- Willingness to participate as perceived by their veterinarians and/or NSW racing officials.

A “Number one” trainer's license is a professional license that is typically awarded to a trainer with 20 or more horses in training and wins in races held on metropolitan racetracks. The decision to issue a “Number one” license is at the discretion of the Thoroughbred Racing Board of NSW and there are no criteria that stipulate how this decision is reached. Furthermore, the licence is not reviewed every year and therefore a trainer retains the license even if their stable size decreases and/or performance of the horses in their care declines. A normal trainer's license is also a professional license and is awarded to all professional trainers who do not receive a “Number one” license.

Trainers were enrolled between May and November 2000. Data collection continued until 31st July 2002 or until the trainer was lost to follow-up or removed from the study for failing to comply with the protocol. Data collected from trainers who were removed from the study for failing to comply (n = 4) were not included in any analyses.

3.2.3 Recruitment and enrolment of horses

In the 2000/01 and 2001/02 racing seasons, horses eligible to race as two-year-olds were enrolled in the study. During the 2001/02 racing season, attempts were made to recruit a third cohort of three-year-olds not previously enrolled in the study. A number of trainers were unwilling to enrol theses horses so recruitment for this cohort was discontinued. Data from these three-year-old horses (n = 37) were not included in any analyses.

All two-year-olds trained by a participating trainer were enrolled in the study when they entered the stable. Some of the eligible horses entered the training stable before 1st August, when they were still officially one-year-old. They were enrolled in the study at that time. Data were collected from the time of enrolment until either the end of the study or until the horse was lost to follow-up, which ever occurred earlier. A horse was classified as lost to follow-up if it was not in training in the last month of the study (July 2002); in this case the last training day was recorded as the date of loss to follow-up.

3.2.4 Data collection

The investigator visited trainers at approximately fortnightly intervals to enrol eligible horses and to collect training and injury data for those horses present at the stable. The injury status of all horses that left the stable between visits was confirmed during the visit. No other data were recorded when the horse was not in the stable.

At the time of enrolment, the horses' training and injury history, sex and either the racing name or breeding was noted. If sire and dam or racing name was not known, the horse was identified by its sire and sex, or its stable name. The stable name refers to the name used by stable staff to identify the horse, and could not be used to search the central registry for sex or date of birth. Sex was categorised as either male or female. The exact date of birth was determined, for those horses identified by either racing name or breeding name, using the Australian or New Zealand studbook, as appropriate.

Information on training methods, starts in races or barrier trials, and training surface were collected using a questionnaire. The questionnaire was completed by the stable staff on a daily basis or at the time of visit using stable records. The categories of training activities were developed after discussion with the trainers. The categories for the training activities that involved track work were based on the riding instructions routinely given by trainers to their track work riders. These terms are commonly used in the Australian racing and refer to the time taken for the horse to cover a metric furlong (200 m). The categories used on the questionnaire are described in Table 3.1. The number of furlongs trained at `1/2 pace', `evens', `3/4 pace' and `home on the bit' were also recorded.

When the trainer was enrolled in the study, the person who was designated to complete the questionnaire was asked to describe the training speeds they associated with the exercise activities listed on the questionnaire. All trainers in the study used and understood the meaning of the terms "trot and/or canter", "1/2 pace", "evens", "3/4 pace" and "home on the bit". There was variation between trainers in the exercise speeds typically associated with "trot" and "canter". Similarly, there was variation between trainers in the speed associated with "1/2 pace". However, all trainers agreed that the term "1/2 pace" referred to a slow gallop. Due to inconsistencies between trainers in the speeds ascribed to "1/2 pace" the distances trained at this pace were not included in any further analyses. All trainers associated "evens" with a gallop speed of 15 seconds to the furlong, or 800 m/minute. Some trainers reported that their definition of "3/4 pace" was synonymous with "evens" and others used the term to refer to a speed "slightly quicker than evens", that is, 13 to 14 seconds per furlong, or 860 to 890 m/minute. All trainers agreed that "home on the bit" was a gallop pace faster than "3/4 pace" or "evens". Some trainers noted that there was a fifth gallop speed, "home off the bit", that denoted a gallop at, or near, race pace. The person completing the questionnaire was instructed to report any training at this pace, or any other gallop speed greater than "evens" or "3/4 pace" as "home on the bit".

The injury status of all horses that left the stable between visits was confirmed during the fortnightly visit. If a horse had a problem involving the musculoskeletal system, additional information relating to the nature of the injury was recorded, including the anatomical location and the type of problem. For example, an injury may have been swelling and heat in the fetlock joint with no known cause, or it may have been caused by degenerative joint disease or sprained suspensory ligament. The information concerning the injury was provided by the trainer, and a veterinarian may or may not have been involved in the diagnosis. A problem involving the musculoskeletal system was classified as an injury if it resulted in the horse leaving the stable for more than seven days and was the direct result of training (e.g. injuries such as stone bruises were excluded). The start time for an injury was recorded as the day the horse left the stable.

Table 3.1 Categories for the training activities, gaits and expected speeds used in the questionnaire in a longitudinal study investigating musculoskeletal (MS) injuries in two- and three-year-old Thoroughbred racehorses.

Activity	**Gait**	**Expect speed**
Box rest	N/A	N/A
Walk only	N/A	N/A
Walk and swim only	N/A	N/A
Trot and/or canter	Trot or canter	Less than 600 m/minute
'Evens' or '3/4 pace'	Gallop	800 to 890 m/minute
'Home on the bit'	Gallop	≥ 890 m/minute
Trial	Gallop	At or near race pace
Race	Gallop	Race pace

N/A = Not applicable

3.2.5 Data management and validation

Training and injury data were manually entered into a customized database (Microsoft Access, 2000). For all horses enrolled in the study, records of starts in races and official barrier trials in Australia and New Zealand were obtained from a commercial database (AAP, HorseSearch ™). Records of starts in the study database were compared to the records from the commercial database. If there were inconsistencies between the study database and the commercial database, the commercial database was treated as correct, and the errors in the study database were corrected but marked as incorrect entries to facilitate further analysis. At the completion of the study, training records were inspected for outliers and inconsistency, and any suspect values checked against the paper records. Changes were made to the study database only when the information varied from the paper records.

3.2.6 Classification of study time

Each horse contributed horse-days to the study from the time of enrolment until either the end of the study or when they were lost to follow-up. Horse days were categorised as "training-days" if the horse was in the stable, or "spell days" if the horse was away from the stable. Training days were grouped into units referred to as preparations. A preparation began on the day that the horse was enrolled in the study, or when a horse returned to training after an absence of more than seven days from the stable. The preparation continued until the horse was lost to follow-up or left the stable for more than seven consecutive days. A training preparation was classified as incomplete if it finished because either the study ended or the trainer was lost to follow-up.

An individual horse could contribute more than one preparation whilst enrolled in the study. Preparations that began while the horse was a two-year-old were classified as belonging to the two-year season even when they ended when they ended in the official three-year-old racing season. Similarly, preparations that began while the horse was a three-year-old were classified as belonging to the three-year-old racing season even when they ended in the official three-year-old racing season. Those preparations that began when the horse was officially one-year-old were also classified as belonging to the two-year-old season.

3.2.7 Statistical analysis

Trainer characteristics for those that were enrolled in the study and complied with the protocol were compared to those that refused to participate or were removed from the study for failing to comply. Three criteria were used for these comparisons: number of boxes (≤ 15 boxes, 16-30 boxes or > 30 boxes), track type (metropolitan or provincial) and type of trainer's licence (Normal or Number one). Fisher exact tests were conducted to determine if there were significant differences between the two groups of trainers for any of these criteria.

The reasons for losses to follow-up were categorised as trainer lost to follow-up, horse changed trainer, death or unknown. Horses with unknown reasons were sub-divided into those lost to follow-up less than 6 months before the end of the study and those greater or equal to 6 months before the end of the study. The number and percentage of horses in each category were determined and results presented stratified by cohort.

The duration of follow-up was estimated using Kaplan-Meier methods. When estimating the duration of follow-up the interval was defined as the cumulative sum of study days from the time of enrolment until the last recorded training day. Those horses that were not lost to follow-up at the end of the study period were treated as right censored observations. Results were presented stratified by cohort.

The number of horses contributing preparations, number of preparations and the number of training days during the 27-month study period were determined. The results were presented stratified by age class and sex, and by trainer and sex.

Data quality was assessed using two separate outcomes: number of days with missing training data per 100 training days and the number of incorrectly recorded starts per 100 starts. Results were presented stratified by study month and trainer.

Statistical analysis was completed using SAS (Version 8 for Windows) and graphics generated in R for Windows (version 2.0) and Microsoft Excel (2000). The level of significance was set at $P<0.05$.

3.3 Results

All racetracks had at least one non-turf track and one turf track for training. However, use of the turf track was dependent on a number of factors including condition of the track and day of the week. Table 3.2 describes the training surfaces and swimming facilities available at each of the five racetracks.

Eighteen of the 29 trainers invited to participate in the study agreed to do so. Four of the 18 trainers were removed from the study for failing to comply with the protocol. Differences between the trainers enrolled and not enrolled or removed for failure to comply with regards to the type of license, location of stable or stable size is described in Table 3.3. The percentage of trainers, located at metropolitan tracks, was higher in the group of trainers that were enrolled in the study than in the group of trainers that not enrolled, or removed for failing to comply (57% and 20%). The percentage of trainers with a number one training license was also higher in the trainers that were enrolled in the study than those that not enrolled, or removed for failure to comply (71% and 47%). However, none of these differences were statistically significant ($P > 0.05$).

In the second year of the study three trainers were lost to follow-up because the stable was relocated ($n = 1$) or travel to the racetrack to collect data was discontinued ($n = 2$). Visits to the racetrack were discontinued because time constraints made it difficult to visit the track at fortnightly intervals. Furthermore, the costs associated with visits were considered excessive when the two trainers contributed a total of 12 horses to the study. In the second year of the study, two trainers did not enrol a second cohort of two-year-old racehorses, because they did not want to increase the burden of data collection. One of these trainers held a Number One license, was located at a metropolitan racetrack and had more than 30 boxes. In contrast, the other trainer had a normal license, was located at a provincial racetrack and had between 16 and 30 boxes.

During the study period, 451 horses were enrolled: 323 in the 2000/01 season and 128 in the 2001/02 season. Sixty eight percent (n= 219) of the horses enrolled in the 2000/01 racing season remained enrolled in the study at the start of their three-year-old racing season. Fifty percent of horses enrolled in the 2000/01 and 2001/02 racing seasons were followed for more than 434 days (Figure 3.1; 95% CI = 358-475) and 209 days (Figure 3.2; 95% CI = 170-230), respectively. At the end of the study, 125 horses remained enrolled in the study. Of these, 69 were enrolled in the 2000/01 racing season and 56 in the 2001/02 racing season. Table 3.4 provides details of the reasons for losses to follow-up and Tables A.1 and A.2 in the Appendix present the data on losses to follow-up by trainer.

The 451 enrolled horses contributed 1,272 preparations: 83, 113, 118, 90, 34 and 13 horses had one, two, three, four, five and six preparations respectively. Table 3.5 provides summary information describing the number of horses contributing data and the number of preparations, and training days by age class and sex. Table 3.6 summarises the number of horses contributing data, and the number of preparations and training days by trainer. The number of horses, complete preparations and incomplete preparations by trainer, are described in Tables A.3 and A.4 in the Appendix.

During the study period, 8% of training days (n = 6,051 days) had missing training data and 3% (n = 68) of the 1,986 starts in the races or barrier trials were incorrectly recorded. Twenty-four percent (n = 16) of the incorrectly recorded events involved races or barrier trials that occurred either the day before or after the event was recorded on the questionnaire. The rate of incorrect entries (Figure 3.3) and training days with missing data (Figure 3.4) varied significantly during the study period. The rate of incorrect entries and days with missing data also varied significantly between trainers (Figure 3.5).

Table 3.2: Type of track, training surfaces and swimming facilities available at the tracks used by the 14 trainers enrolled in a 27-month longitudinal study beginning in May 2000.

Track type	Track	Training surfaces	Swimming facilities
Provincial	1	Grass and sand	River
	2	Grass and cinders	Pool and beach
Metropolitan	3	Grass, dirt and sand	Pool and beach
	4	Grass, dirt, sand and cinders	Dam
	5	Grass and sand	Pool

Table 3.3: Count and percentage of trainers enrolled and not enrolled or removed for failing to comply in a 27-month longitudinal study beginning in May 2000.

		Enrolled (n = 14)		Not enrolled or removed from study (n = 15)		
Variable	**Category**	**N**	**%**	**N**	**%**	**P**
Location of stable	Metropolitan	8	57	3	20	0.24
	Provincial	6	43	12	80	
Type of training license	Normal	4	29	8	53	0.26
	Number 1	10	71	7	47	
Size of stable	≤15 boxes	1	7	3	20	0.77
	16-30 boxes	6	43	6	40	
	>30 boxes	7	50	6	40	

Table 3.4: Number and percentage of horses by follow-up status at the end of the study, and number and percentage with a musculoskeletal injury (MSI) in the last recorded preparation. Horses were classified as lost to follow-up if they were not in the stable in the last month of the study (July 2002). Data are derived from a total of 451 horses over a 27 month period beginning in May 2000.

	Enrolled in 2000/01 (n=323)				**Enrolled in 2001/02 (n=128)**			
Follow-up status	**Number lost to follow-up**	**% of total**	**Number with MSI**	**% with MSI**	**Number lost to follow-up**	**% of total**	**Number with MSI**	**% with MSI**
Not lost to follow-up	69	21	4	6	56	44	9	16
Trainer lost to follow-up	42	13	6	14	0	0	0	0
Horse changed to another trainer	65	20	24	37	1	0.01	1	50
Death of horse	1	0.3	0	0	0	0.0	0	0
Unknown								
Last training day < 6 months before the end of the study	86	27	27	31	61	48	24	39
Last training day ≥ 6 months before the end of the study	60	19	29	48	10	8	2	20
Total losses to follow-up	**254**	**79**	**86**	**22**	**72**	**56**	**27**	**38**

Table 3.5: Number of horses contributing data and numbers of preparations and training days contributed by age class, and sex. Data are derived from a total of 451 horses over a 27 month period commencing in May 2000. Horses enrolled in 2000/01 contributed data to both the two- and three-year-old age classes.

Age class	Sex	Horses	Preparations	Training days
2	Female	217	501	28,034
	Male	216	465	25,089
	Unknown	18	26	850
	Total	**451**	**992**	**53,973**
3	Female	111	164	14,025
	Male	77	114	10,110
	Unknown	1	2	47
	Total	**189**	**280**	**24,182**
2 and 3	Female	217	665	42,059
	Male	216	579	35,199
	Unknown	18	28	897
	Total	**451**	**1272**	**78,155**

Table 3.6: Number of horses contributing data and numbers of preparations and training days contributed by trainer and sex, Data were from a total of 451[a] horses over a 27 month period commencing in May 2000. Horses enrolled in 2000/01 contributed data to both the two- and three-year-old age classes.

	Female			**Male**		
Trainer	**Horses**	**Preparations**	**Training days**	**Horse**	**Preparations**	**Training days**
1	11	29	2012	7	21	1,547
2	4	10	304	0	0	0
3	3	6	380	5	8	517
4	6	20	623	25	66	2,729
5	26	86	6549	15	52	3,513
6	28	73	4085	49	156	8,770
7	6	17	1224	8	23	2,082
8	18	81	4870	20	38	1,653
9	3	11	738	13	27	2,645
10	11	32	2322	4	11	1,191
11	17	50	2999	15	44	2,542
12	59	187	12062	38	89	5,535
13	12	29	2128	8	20	1,420
14	13	34	1763	9	24	1,055
Total	**217**	**665**	**42059**	**216**	**579**	**35,199**

[a] Sex was unknown for 18 horses.

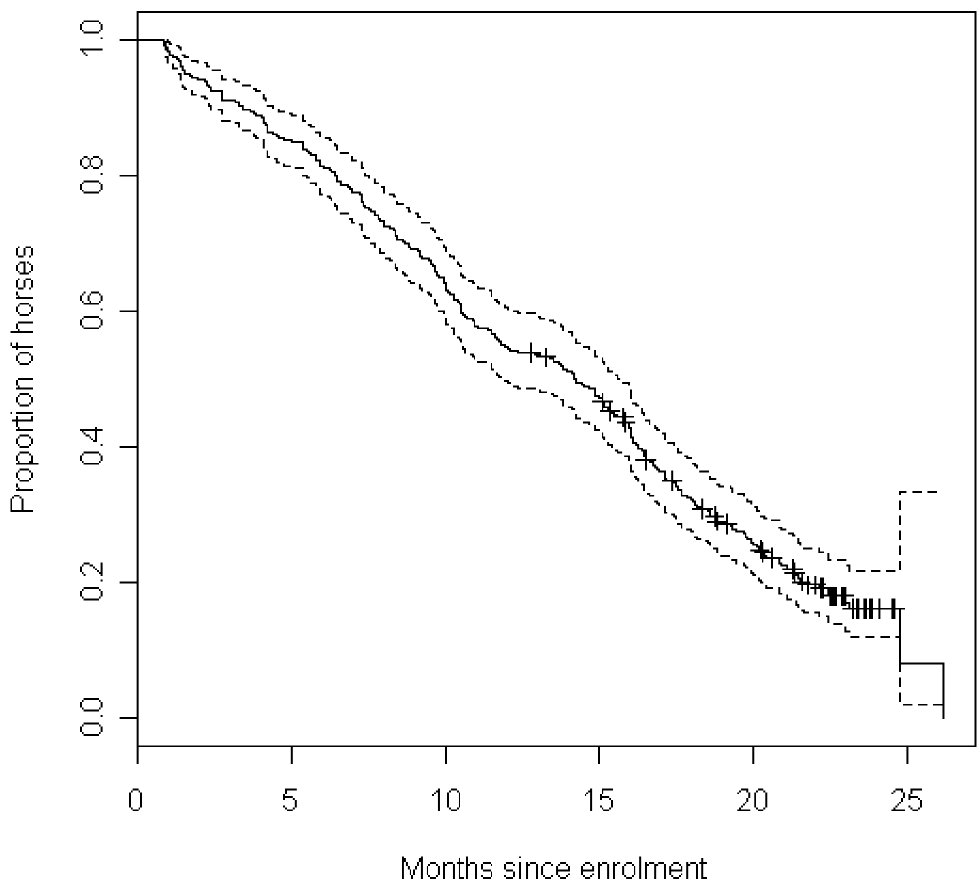

Figure 3.1: Kaplan-Meier estimate of the proportion of 323 two-year-old Thoroughbred racehorses, enrolled in the 2000/01 racing season that had not been lost to follow-up, in the days after enrolment. Dashed lines represent 95% confidence interval.

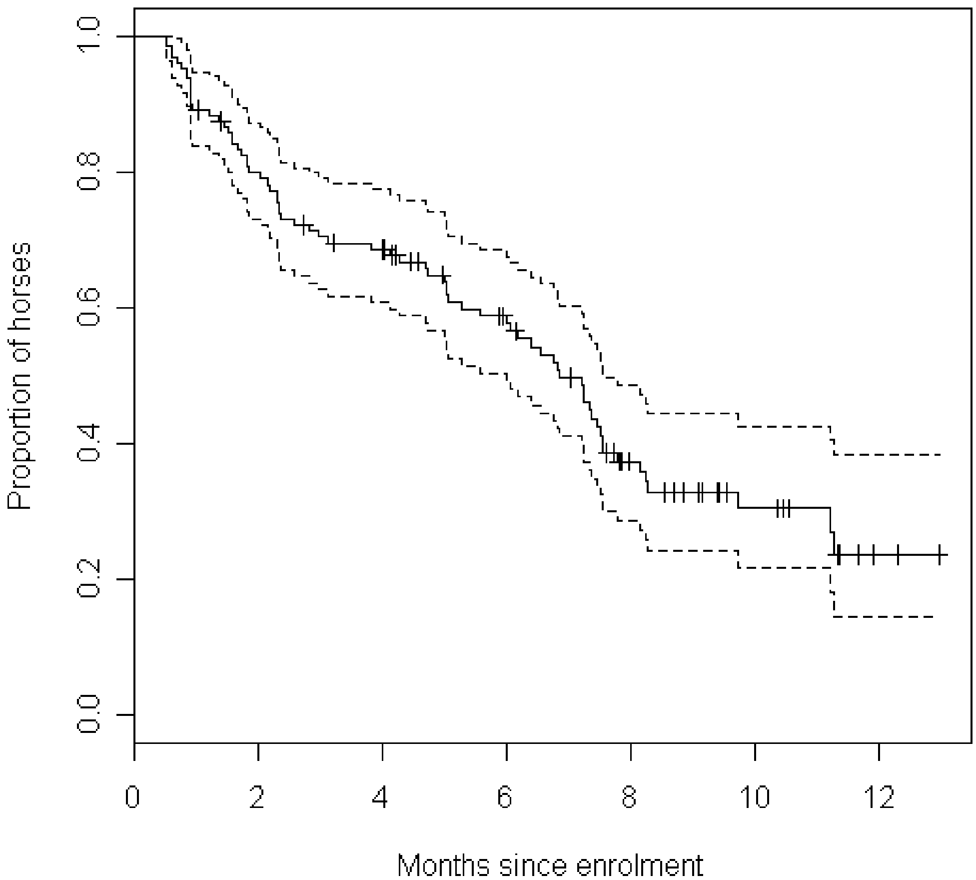

Figure 3.2: Kaplan-Meier estimate of the proportion of 128 two-year-old Thoroughbred racehorses, enrolled in the 2001/02 racing season that had not been lost to follow-up, in the days after enrolment. Dashed lines represent 95% confidence interval.

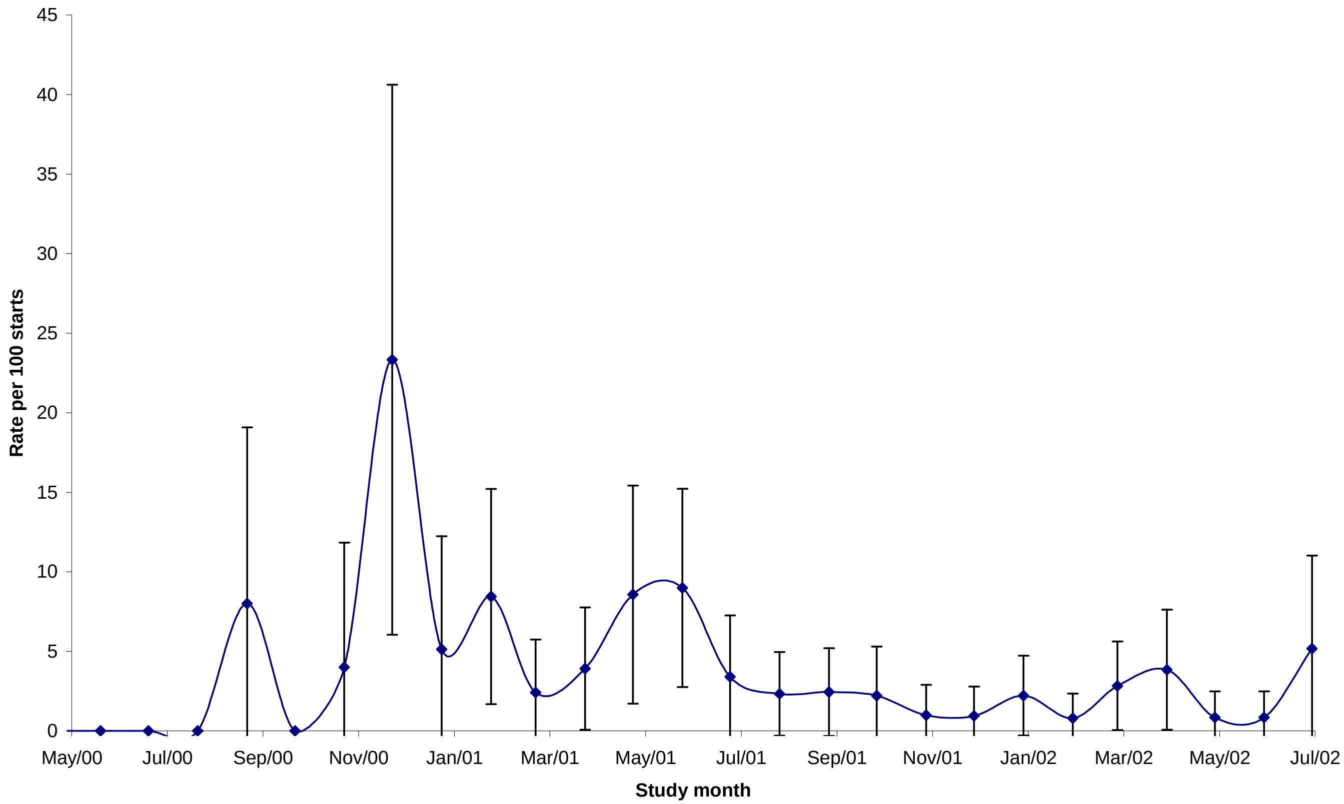

Figure 3.3: Number of starts in official barrier trials and races that were incorrectly recorded, per 100 starts, by study month. Data based on 1, 986 starts in races or official barrier trials of which 68 were incorrectly recorded. Error bars represent 95% confidence intervals (CI).

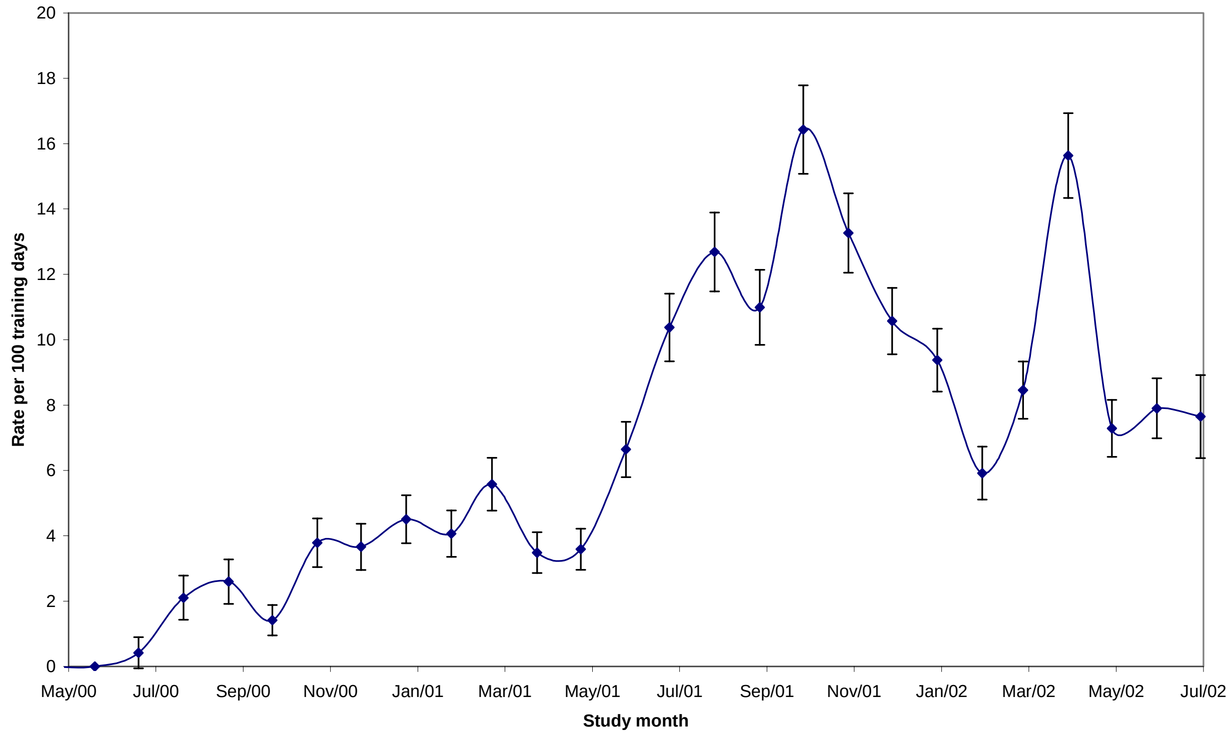

Figure 3.4: Incidence rate of missing data, as missing days per 100 training days, by study month. Data based on 78,155 training-days of which 6,051 had missing data. Error bars represent 95% confidence intervals.

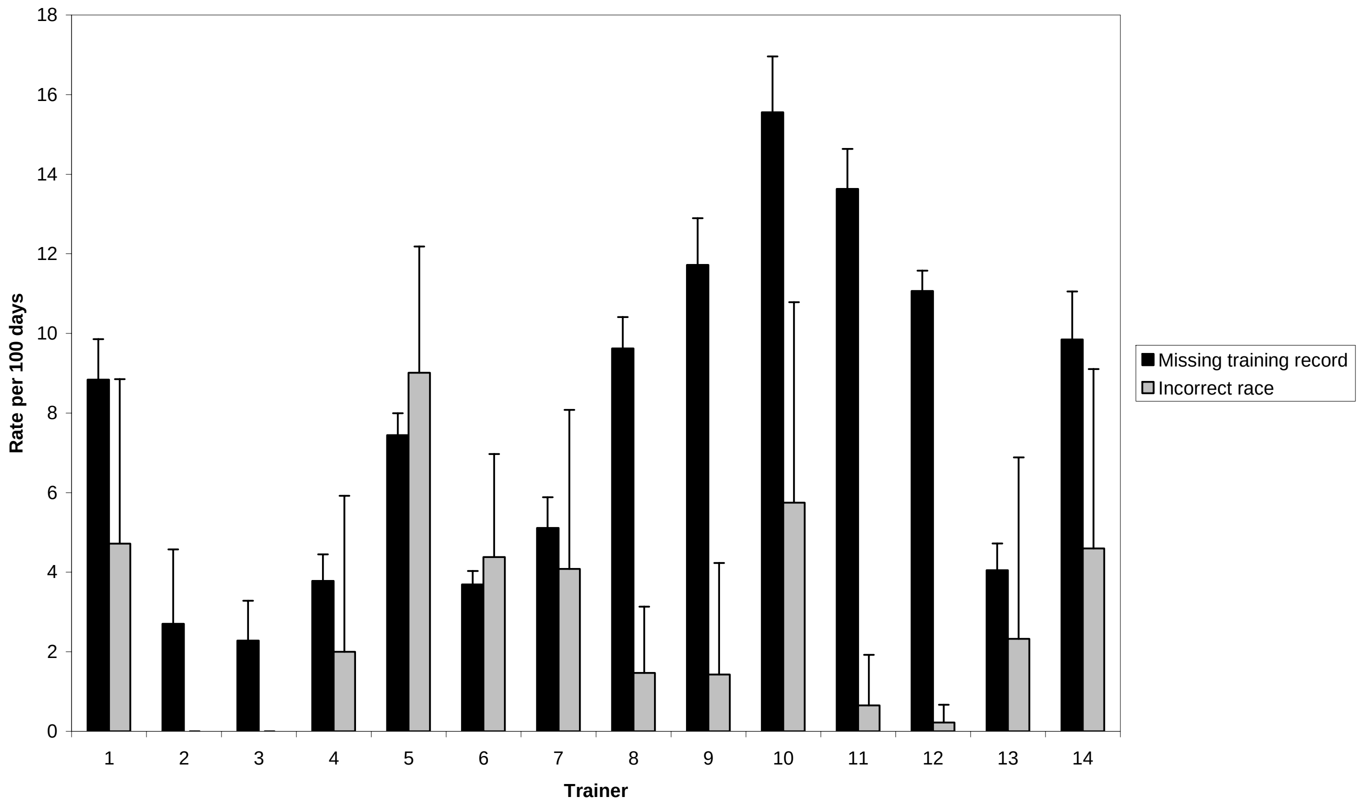

Figure 3.5: Incidence rates for training days with missing training data (per 100 training days), and starts in races or barrier trials (per 100 starts) that were incorrectly recorded by trainer. Data based on 78,154 training-days of which 6,051 had missing data and 1,986 race or barriers trials of which 68 were incorrectly recorded. Error bars represent upper 97.5% confidence intervals (CI).

3.4 Discussion

Data were successfully collected from 14 trainers over a 27 month period. Trainers were sampled based on three criteria: location, expected number of two-year-olds entering training and the perceived willingness of trainers to participate. Location of the stable was important because if it was too far from the study centre, the interval between visits would have had to be increased and/or additional people would be required to collect data. Both of these options were considered unsuitable as the relatively short interval between visits and the use of only one person for data collection were considered important factors for maintaining a high data quality during the study period. Expected number of horses was an important factor because it was perceived that enrolment of trainers with 10 or more horses would facilitate efficient data collection. The willingness of the trainers to participate in the study was important because data collection required a high level of compliance. Reluctance to provide the information could have compromised the quality of the data. Sampling trainers using non-probability methods was associated with a risk of bias (Thrusfield 1995, p 180). Due to limited availability of information about trainers, it was not possible to compare the selected trainers to those in the general population. Therefore the bias created by the sampling method cannot be quantified.

Selection bias, may also have occurred because a number of trainers approached declined the offer to participate in the study (n = 11) or were removed for failing to comply with the protocol (n = 4). Comparison of the trainers that participated and those that refused or were removed for failure to comply found no significant differences with regard to location, size of stable and type of training license. This suggests that the two groups of trainers did not differ systematically. However, as the groups were only compared on three factors the results should be interpreted with caution. Furthermore, differences between the two groups of trainers may not have been detected as the number of trainers were small, thus reducing the statistical power.

In addition to creating bias removal of four trainers for failing to comply with the study protocol represented a waste of resources because at the time of removal considerable time and money had been expended. In future, it would be appropriate to attempt to measure trainer compliance prior to enrolment. This could be achieved by requesting that a trainer complete a questionnaire concerning details of the training and management of their horses. Those trainers that did not complete the questionnaire or refused to answer questions would then not be enrolled in the study. It would also be advisable to enrol trainers for a "probationary" period that was sufficiently long enough to include two to three visits. If data collection during this period was satisfactory the trainer would then be asked if they would like to continue to participate in the study.

Bias may also have occurred at the level of the horse. This was minimised in this study by enrolling all two-year-olds that entered the stable of a participating trainer.

The decision was made not to collect data when horses were away from the stable because it became apparent early in the study period that the quality of this data varied both between and within trainers. A possible explanation for this variation is that when horses are spelled they are often under the care of their owner(s), and therefore the trainer is not always responsible for management decisions relating to the horse. Not collecting data when horses were away from the stable made it difficult to determine when a horse was lost to follow-up. This was because decisions regarding the future of a horse are often made when the horse was spelling. Therefore, a horse as defined as lost to follow-up if it was not in the stable in the last month of the study (July 2002). Using this definition, nearly 80% of horses enrolled in the 2000/01 racing season, and over 50% of horses enrolled in the 2001/02 racing season, were classified as lost to follow-up. Due to differences in the definition of lost to follow-up, it is not possible to make direct comparisons to other studies, such as Bailey *et al.*(1999).

The movement of the horses in and out of stables during the study period and the varying duration of time in training made it sensible to aggregate data to preparations, rather than racing seasons or horse. Training was also grouped into preparations because in Australia horses often change trainers and owners during a racing season. Therefore trainers and owners can only be expected to influence the risk of injury at the preparation level. Thus in Australia, it is appropriate to report on risk factors for MS injuries at the level of the preparation, rather than the horse.

Training information had to be collected directly from the trainer because only barrier trials and races are routinely recorded in official industry databases. A standardised questionnaire was used to collect training information in an attempt to minimise bias. The questionnaire was designed in consultation with the trainers involved in the study, and it used common industry terms that described the gait and speed of exercise training. During the study period, there were times when the questionnaire was not completed and on these occasions the training data was entered as missing. Examination of the rate of training days with missing data found variation between trainers and over the study period. The differences over the study period and between trainers suggest that the data were not missing at random. The likely cause of missing data was that the person responsible for completing the questionnaire was absent for a period of time.

Validity of the training data was investigated by comparison of the race and barrier trial start information with the information recorded in a commercial database. There was significant variation between trainers. Results showed that the rate of incorrect entries was higher in the first part of the study and decreased in the later months. This suggests that there may have been a period early in the study when trainers familiarised themselves with the data collection process. Information was not available for other training activities and so other training data could not be validated. It would seem reasonable to assume that the trends observed in the incorrect recording of starts were similar in the whole data set, although the magnitude may differ. Future studies could consider a comparison of the trainer's records of daily training activities with an independent daily record of training activities. Such a study would be able to quantify the measurement error in records of training obtained from the trainer or their staff.

To conclude, this is the largest study undertaken in Australia to examine risk factors for MS injuries in horses in training. During the study period, 451 horses were enrolled during their two-year-old racing season. Training and injury information for these horses were collected directly from the trainer. This required a high level of co-operation and therefore trainers were sampled using a non-random method. The trainers that agreed to participate in the study did not differ from those that declined the offer to participate or were removed for failing to comply with the protocol on type of training track, size of stable or type of trainer's license. Examination of incorrect records and days with missing training data for these horses indicated that there was variability during the study period and between trainers. The variation in rate of missing and incorrect records between trainers means that data quality should be considered as a reason for trainer effects in multi-variate models.

Chapter 4: Profiling Australian two- and three-year-old Thoroughbred racehorses I: Incidence and impact of musculoskeletal injuries

Abstract

AIM: To provide a description of the frequency of musculoskeletal (MS) injuries with measures that incorporate time at risk, and use multivariable techniques to describe the factors that influence the length of time to first start and length of time to recovery from MS injury.

METHODS: Professional trainers from five racetracks in NSW, Australia, were convenience sampled. Training and injury data were collected at fortnightly intervals for 27 months from May 2000. Incidence rates (IR), using training days as a measure of time at risk, were reported for initial and second injuries stratified by age class and sex. Survival analysis methods were used to investigate the length of time to first start in a race or barrier trial and the length of time to recovery after the first MS injury (measured as a start in a race or barrier trial).

RESULTS: During the study period, 428 MS injuries were recorded in association with 395 preparations in 248 two- and three-year-old Thoroughbred racehorses. Two-year-olds were 2.99 times more likely than three-year-olds to sustain an incident MS injury. The IR for all categories of MS injuries, except for tendon and ligament injuries, were higher in two-year-olds than three-year-olds, although the differences were only significant for shin soreness. Seventy-eight percent of horses enrolled in the study started, in a barrier trial or race, within one year on entering the study. After accounting for other confounders, horses that had sustained a MS injury were 0.50 times less likely to start, in a race or trial, than those that did not sustain an injury. Seventy percent of horses returned to training after their first MS injury and 55% of the horses had recovered within six months of the initial MS injury. After adjusting for clustering at the level of the trainer, the analysis showed that horses that exercised at a gallop pace ≥ 890 m/minute (but had not started in a race) prior to the onset of MS injury, were 2.14 times more likely to recover than horses whose maximum speed, prior to the onset of the first MS injury, was less than 890 m/minute. Similarly, horses that had started in a race or barrier trial were 4.01 times more likely to recover than horses whose maximum speed was less than 890 m/minute.

CONCLUSION: This study supports findings both in Australia and overseas that the most common MS injury in two- and three-year-old Thoroughbred racehorses is shin

soreness. Overall, the rate of injury was higher in two-year-olds than three-year-olds ,due mostly to a higher incidence of shin soreness in two-year-olds. The current study also showed that MS injury impacts negatively on the time to first start in a race or barrier trial. Other factors associated with the time to first start were age and trainer. Time to recovery, as measured by a start in a race or barrier trial, was shortest in horses that had galloped at speed ≥ 890 m/minute or started in a race or barrier trial. To the author's knowledge, impact of MS injuries on the length time to first start and the length time for recovery from MS injury have not previously been reported for training related MS injuries. This information may prove useful in estimating the economic cost of MS injuries.

4.1 Introduction

Musculoskeletal (MS) injuries are the most common health problem in Thoroughbred racehorses (Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Perkins *et al.* 2004a, Perkins *et al.* 2004b). Studies of horses in training have reported that the cumulative incidence of MS injuries ranged from 36% in a two-year-study (Rossdale 1989) to over 50% in 81 day (Kobluk *et al.* 1990b), nine month (Lindner and Dingerkus 1993) and two-year (Bailey *et al.* 1999) study periods.

These MS injuries represent a major economic cost to the Thoroughbred racing industry in terms of treatment cost and lost opportunity to race. Bailey (1998) reported that 45% of horses enrolled in a longitudinal study did not race during their two-year-old season. Bailey concluded that the principal reason for this was the high number of low grade injuries and other health problems. However, no statistical tests were performed to determine if those horses that sustained an injury were less likely to race than those that did not sustain an injury. It is possible that the horses that sustained MS injuries sustained them after their first start. Therefore, care should be taken in concluding that MS injuries, or other health problems, are the reason horses do not start at all as two-year-olds. The aims of this chapter were to describe the frequency of MS injury, with measures that take into consideration time-at-risk, and use multivariable techniques to describe the impact of MS injuries on time to first start and factors that influence recovery from MS injury.

4.2 Materials and methods

4.2.1 Study design

This was a longitudinal study of the epidemiology of MS injuries in two- and three-year-old racehorses. Data were collected over a 27-month period. The design, implementation and management of the study are described in Chapter 3. In summary, 14 trainers were convenience sampled from those with training-yards at metropolitan and provincial racetracks in New South Wales, Australia. The study commenced in May 2000 and concluded at the end of the 2001/02 racing season, 31st July 2002. In the 2000/01 and 2001/02 racing season, 323 and 128 two-year-olds, respectively, were enrolled in the study and followed either until the end of the study or until they were lost to follow-up. A horse was classified as lost to follow-up if it was not in the stable in the last month of the study (July 2002).

The investigator visited trainers at approximately fortnightly intervals to enrol eligible horses and collect training and injury data for those horses present at the stable. Information on training methods, starts in races or barrier trials, and training surface were collected using a questionnaire. The questionnaire was completed by the stable staff on a daily basis or at the time of visit using stable records.

If the horse had a problem involving the MS system, additional information relating to the nature of the injury was recorded, including the anatomical location and the type of problem. For example, an injury may have been swelling and heat in the fetlock joint with no known cause, or it may have been caused by degenerative joint disease or sprained suspensory ligament. The trainer provided injury information, and a veterinarian may or may not have been involved in the diagnosis. The injury status of all horses that left the stable between visits was confirmed during the fortnightly visit. No data were otherwise recorded when the horse was not in the stable.

4.2.2 Classification of study time

Training days were grouped into units referred to as preparations. A preparation began on the day that the horse was enrolled in the study, or when a horse returned to training after an absence of more than seven days from the stable. The preparation continued until the horse was lost to follow-up or left the stable for a period of more than seven consecutive days. A training preparation was classified as incomplete if it finished because either the study ended or the trainer was lost to follow-up. The period of time between consecutive preparations was termed a spell-period. A spell period that ended with the commencement of a preparation was classified as complete. Spell-periods that did not end with commencement of a preparation were classified as incomplete. An individual horse could contribute more than one preparation and spell-period whilst enrolled in the study.

4.2.3 Classification of MS injuries

A problem involving the MS system was classified as an injury if it resulted in the horse being spelled (i.e. leaving the stable for more than seven days) and was the direct result of training (i.e. injuries such as stone bruises were excluded). The date of occurrence of an injury was recorded as the day the horse left the stable to commence a spell or retire from racing, or the day a horse was euthanased or died as a result of the injury. An injury was classified as bilateral if the anatomical location and the nature of injury were the same in both legs. For example, an injury that involved swelling and heat in both forelimb fetlock joints was classified as a bilateral injury, while a horse that simultaneously sustained a fracture in the right fetlock joint and suffered from swelling and/or heat, with no known cause, in the right leg contributed two separate injuries to the database.

4.2.4 Calculation of incidence rates for MS injury

Incidence rates (IR) for the first occurrence of a MS injury were estimated by dividing the number of individual horses affected by the sum of horse-training-days at risk. Those horses that sustained a MS injury contributed training days to the time-at-risk until the date of the first MS injury. Unaffected horses contributed training-days to time-at-risk until they were lost to follow-up or until the end of the study.

In the population of horses that sustained a MS injury, the IR for a second MS injury was determined by dividing the number of horses diagnosed with a second MS injury by the total number of training-days at risk. The number of horse-training days at risk was the sum of the horse-training-days accumulated from the time the horse returned to training after the initial MS injury until the onset of a second injury, the horse was lost to follow-up, or the end of the study, which ever came first.

Age-specific IR were determined for the first and second occurrence of MS injuries. In two-year-olds the IR were calculated by dividing the number of individual horses that sustained a MS injury while officially two-years-old, by the number of horse-training-days at risk. In these calculations, horses that sustained a MS injury during their two-year-old racing season contributed time at-risk until the date of the injury. A horse that sustained a MS injury during its three-year-old racing season contributed horse-training-days to the time at-risk until the end of its two-year-old racing season. Those horses that were uninjured contributed training-days at risk until they were lost to follow-up, or until the end of the two-year-old racing season. IR for first occurrence of MS injuries in three-year-olds were based on the sub-set of horses that had not sustained a MS injury during the two-year-old racing season. Similarly, the IR for second occurrence of MS injury were based on the sub-set of horses injured, in either the two- or three-year-old season, that did not sustain a second injury in two-year-old seasons. The IR of first and second occurrence of MS injuries in three-year-olds were estimated by dividing the number of individual horses that sustained a MS injury, as three-year-olds, by the sum of training days until the onset of a MS injury, the horse was lost to follow-up, or the end of the study, which ever came first.

4.2.5 Statistical analysis

The number of MS injuries, preparations that ended with injury and horses that sustained a MS injury were determined. Counts of all MS injuries, the number of bilateral lesion, and percentage of MS injuries that were bilateral were determined by anatomical location and nature of injury. For reporting purposes, anatomical locations were classified as forelimb fetlock joint, carpal joint, third metacarpal bone, tendon or ligament injury combined, or other.

IR, with 95% confidence intervals (CI), were calculated for the first and second MS injuries and presented stratified by anatomical location and age-class. A horse that suffered from multiple injuries only contributed information more than once if the MS injuries were in difference anatomical locations. For example, a horse that left a stable with both shin soreness and sesamoiditis could contribute data to injuries involving both the fetlock joint and the third metacarpal bone. However, a horse that sustained a chip in right fetlock joint and ‘changes’ in the left fetlock joint would contribute a single observation to the numerator for MS injuries involving the fetlock joint. Incidence rate ratios (IRR) were calculated to enable comparisons of two- and three-year-olds and females and males. Results were presented only when there were significant differences.

Univariable and multivariable analytical methods were conducted to separately examine the association between a range of explanatory variables and two horse level variables: length of time to first start and length of time to recovery.

Length of time to first start was investigated using standard methods of survival analysis (Hosmer and Lemeshow 1999, pp 27-112). In these analyses, days to first start was defined as the cumulative sum of study days from enrolment in the study until the first start in a race or barrier trial. Horses that trained prior to enrolment were excluded from the current analysis, as the aim was to determine the numbers of days from the commencement of training until the first start. In these calculations, horses that were lost to follow-up before their first start, and those horses that had not started before the end of the study (31st July 2002), were right-censored. The Kaplan-Meier method was used to calculate the cumulative proportion of horses that had started in a race or barrier trial after enrolment in the study. The unconditional association between this measure and a range of explanatory variables (Table 4.1) was assessed by calculating the log-rank (Mantel-Cox) statistic. Variables associated with the length of time to first start at $P<0.30$ were investigated further using a proportional hazard regression model. Explanatory variables were selected in a backward manner and retained in the model if $P<0.05$. Variables not significant in the final model were separately added back to the model and retained if P was less than 0.05. Clustering at the trainer level was accounted for by extending the base model to include a fixed effect coding for trainer identity. The significance of the variable was assessed by calculating the deviance ratio test. All variables in the base model were retained in the final model, even if after the inclusion of the variable, coding for trainer P was greater than 0.05. The proportional hazards assumption was tested, prior to the inclusion of the term coding for trainer identity, by separately adding a variable for the interaction of the log of survival-time and each covariate in the mode. If the deviance ratio test was significant, the variable coding for the interaction was retained in the model.

Days to recovery was also investigated using standard methods of survival analysis (Hosmer and Lemeshow 1999, pp 27-112). Recovery from a MS injury was defined as a start in a race or barrier trial and time to recovery was the cumulative sum of the study days from the initial MS injury until start in a race or barrier trial. Therefore the interval contained the spell period following MS injury. An injured horse was only considered in this analysis if it returned to training after the incidence MS injury and if it was not known to have sustained a MS injury prior to enrolment in the study. In these calculations, horses were right censored if they did not start in a race or barrier trial before being lost to follow-up or the end of the study. The cumulative proportion of horses that had recovered after the MS injury was estimated using the Kalpan-Meier method. The unconditional association between the days to recovery and a number of explanatory variables (Table 4.2) was assessed using the log-rank statistic. Risk factors for the length of time to first start were investigated using a Cox-regression model. The regression model for length of time to recovery was built using the same method as the model investigating risk factors for the length of time, from enrolment, until the first start in a race or trial.

Statistical analysis was completed using R for Windows (version 2.0). The level of significance was set at $P<0.05$.

Table 4.1: Variables considered as risk factors for the length of time from enrolment in the longitudinal study to the first start in an official barrier trial or race.

Variable	Description
Age when enrolled in the study	True age[a] of the horse when it was enrolled in the study
MSI prior to the first start	One or more musculoskeletal injuries prior to the first start
Racing season enrolled	Racing season that the horse was enrolled in the study (2000/01 or /2001/02)
Sex	Male or Female

a Calculated by subtracting the date of birth from the date the horse was enrolled in the study.

Table 4.2: Variables considered as risk factors associated with the length of time from the first musculoskeletal injury (MSI) to recovery (measured as start in an official barrier trial or race).

Variable	Description
Age when enrolled in the study	True age[a] of the horse when it was enrolled in the study
Age at time of MSI	True age[b] at the time of the initial MSI
Highest training intensity prior to MSI	Highest gallop speed that the horse had trained at prior to the onset of MSI
MSI involved only the third metacarpal bone	MSI involve only the third metacarpal bone
Racing season enrolled	Racing season that the horse was enrolled in the study
Sex	Male or Female

[a] Calculated by subtracting the date of birth from the date the horse was enrolled in the study.

[b] Calculated by subtracting the date of birth from the date the horse sustained the initial MS injury.

4.3 Results

During the study period a total of 428 MS injuries were recorded in association with 395 preparations. Three-hundred and sixty-three; 31, and one preparation sustained one, two and three MS injuries respectively. The 395 preparations that ended in MS injury were recorded in 248 two- and three-year-old Thoroughbred racehorses. One hundred and forty four, 67, 31, five and one horses had one, two, three, four and five preparations, respectively, end in a MS injury. A further 13 injuries were recorded in 13 horses prior to enrolment. No further information relating to the nature of these injuries was available.

Table 4.3 describes the number of MS injuries, the number of bilateral lesions and the percentage of MS injuries that were bilateral, by anatomical location and nature of the injury. The most common site of injury was the third metacarpal bone and the most common type of injury at this site was shin soreness. Thus the terms "shin soreness" and "injuries involving the third metacarpal bone" will be used interchangeably throughout this chapter. Bilateral injuries were most common for shin soreness, and injuries involving the fetlock and carpal joints that were classified as swelling and/or heat with no identifiable cause.

Table 4.4 describes the IR for incident MS injury by age class. The rate for the first MS injury was higher in two-year-old than in three-year-old horses: two-year-olds were 2.99 (95% CI = 1.87-4.79) times more likely than three-year-olds to sustain an incident MS injury. The IR for specific types of MS injuries were higher in two-year-olds than three-year-olds for all categories of injuries, except for tendon and ligament injuries, but the differences were only significant for injuries involving the third metacarpal bone. Examination of the IRR indicated that two-year-olds were 5.1 (95% CI = 2.24-11.6) times more likely than three-year-olds to suffer from shin soreness. There was evidence of a trend towards significance for tendon and ligament injuries ($P = 0.07$) and injuries involving the fetlock ($P = 0.07$) and carpal joints ($P = 0.06$). The IR did not vary between male and females, except for shin soreness: male horses were 1.61 times (95% CI = 1.12-2.32) more likely than female horses to suffer from shin soreness.

IRs for second MS injuries, by anatomical location and age class, are described in Table 4.5. Comparison of the IRR indicated that two-year-olds were 2.89 (95% CI = 1.72-4.84) times more likely than three-year-olds to suffer from a second MS injury. When individual types of MS injuries were examined, the differences between the age classes were only significant for injuries involving the forelimb fetlock joint (IRR = 4.22; 95% CI = 1.27-14.01) and the third metacarpal bone (IRR = 23.74; 95% CI = 3.27-172.19). None of the IR for second MS injury were significantly different between male and female horses.

Analysis of the days to first start was restricted to 418 horses that had not trained prior to enrolment. The cumulative proportion of horses that had not raced two months, six months and 12 months, after enrolment in the study, were 0.82 (95% CI = 0.78-0.85), 0.56 (95% CI = 0.52-0.62) and 0.22 (95 % CI =0.18-0.24), respectively (Figure 4.1). Unconditional association between a number of explanatory variables and the length of time to first start are described in Table 4.6. Risk factors conditionally associated with the time to first start are presented in Table 4.7. The presence of MS injury prior to the first start in race or barrier trial was a significant predictor of length of time to first start. After accounting for all the other variables in the model, injured horses were 50% less likely to start in a race than uninjured horses. In this population of horses, age at the time of enrolment and trainer were also significantly associated with length of time to first start. There was also a significant interaction between the binary variable coding for age at the time of enrolment and the logarithm of observed survival time.

Seventy percent (n = 173) of horses returned to training after their first MS injury. The cumulative proportion of horses that had recovered six months, nine months, and 12 months after the incidence MS injury was 0.45 (95% CI = 0.38-0.54), 0.25 (95% CI = 0.19-0.34) and 0.18 (95% CI = 0.12-0.26), respectively (Figure 4.2). The unconditional association between length of time to recovery and a number of variables is described in Table 4.8. Risk factors conditionally associated with length of time to recovery are described in Table 4.9. The maximum speed prior to injury was a significant predictor of length of time to recovery. After adjusting for clustering at the level of the trainer, the analysis showed that horses whose maximum speed prior to the onset of the MS injury was ≥ 890 m/minute, but had not started in a race, were 2.14 (95% CI =1.25-3.65) times more likely to recover than horses whose maximum speed prior to the onset of the first

MS injury was less than 890 m/minute. Similarly, horses that had started in a race or barrier trial were 4.01 (95% CI = 2.25-7.15) times more likely to recover than horses whose maximum speed was less than 890 m/minute.

Table 4.3: Number of musculoskeletal injuries (MSI), number of bilateral injuries (n) and percentage (%) of all MSI that were bilateral, by anatomical location and nature of injury. Data from 428 injuries recorded in 248 two- and three-year-old Thoroughbred racehorses enrolled in a 27-month longitudinal study.

Location	**Nature of injury**	**Number of MSI**	**Bilateral injuries**	
			n	**%**
Forelimb fetlock joint	Degenerative changes	7	4	57
	Fracture/Chip	10	0	0
	Sesamoiditis	5	1	20
	Swelling and/or heat with no identified cause	61	32	52
	Total fetlock injuries	**83**	**37**	**45**
Carpal joint	Degenerative changes	8	4	50
	Cyst	3	0	0
	Fracture/Chip	8	0	0
	Problems with splints	8	0	0
	Swelling and/or heat with no identified cause	42	14	33
	Total carpal joint problems	**69**	**28**	**41**
Third metacarpal bone	Fracture/Chip	3	0	0
	Shin soreness	181	107	59
	Total third metacarpal bone problems	184	107	**58**
Soft tissue	Ligament	20	2	10
	Tendon	23	1	4
	Total soft tissue	**43**	**3**	**7**
Other	Back	1	0	0
	Fracture/Chip	2	0	0
	Hind limb lameness	7	1	14
	Muscle soreness	3	0	0
	Stress fracture	4	0	0
	Unidentified or unknown cause	32	1	3
	Total injuries classified as other	**49**	**2**	**4**

Table 4.4: Age class specific incidence rates (IR) estimates per 1, 000 training-days with 95% confidence interval (CI) for the first musculoskeletal injury (MSI) in Thoroughbred racehorses. Horses contributed training days at risk either to the day of their first MS injury or until they were lost to follow-up. Results based on 236 incident[a] cases of MSI and 49,373 horse-training days at risk.

Anatomical location of MSI	**2-yr-old**		**3-yr-old**		**Overall**	
	IR	**95% CI**	**IR**	**95% CI**	**IR**	**95% CI**
Forelimb fetlock joint	1.05	0.73-1.37	0.38	0.01-0.75	0.91	0.64-1.18
Carpal joint	0.87	0.58-1.16	0.29	0-0.62	0.75	0.51-0.99
Third metacarpal bone	3.03	2.48-3.58	0.58	0.12-1.04	2.51	2.07-2.95
Soft tissue injury	0.33	0.15-0.51	0.58	0.12-1.04	0.38	0.21-0.55
Other	0.49	0.27-0.71	0.1	0-0.29	0.41	0.23-0.59
Any MS injury	5.57	4.83-6.31	1.83	1.01-2.65	4.78	4.17-5.39

[a] Data from 12 horses was excluded as they sustained a MS injury prior to enrolment in the study

Table 4.5: Age class specific incidence rates (IR) estimates, per 1, 000 training-days, with 95% confidence interval (CI) for the second occurrence of musculoskeletal injury in Thoroughbred racehorses (MSI). Data restricted to horses resuming training after an initial MSI. Horses contributed training-days at-risk until either the day of their second MSI or until they were lost to follow-up. Results based on 110 cases of MSI in 19,166 horse-training days at risk.

Anatomical location of MSI	**2-yr-old**		**3-yr-old**		**Overall**	
	IR	**95% CI**	**IR**	**95% CI**	**IR**	**95% CI**
Forelimb fetlock joint	1.91	1.15-2.67	0.46	0-0.98	1.41	0.88-1.94
Carpal joint	1.11	0.53-1.69	0.46	0-0.98	0.89	0.47-1.31
Third metacarpal bone	3.58	2.53-4.63	0.15	0.15-0.45	2.4	1.71-3.09
Soft tissue injury	0.64	0.2-1.08	1.21	0.37-2.05	0.83	0.42-1.24
Other	0.87	0.35-1.39	0.46	0-0.98	0.73	0.35-1.11
Any MS injury	**7.39**	**5.89-8.89**	**2.58**	**1.35-3.81**	**5.74**	**4.67-6.81**

Table 4.6: Association between a number of independent variables and length of time, from enrolment in a longitudinal study, to the first start in a race or barrier trial for 451[a] two-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000, ordered according to the level of statistical significance.

Variable	Categorical	Number of horses		Subsequent to enrolment, the proportion of horses that had not started in a barrier trial or race at			P[b]
		Total	Censored[c]	2 months	6 months	12 months	
MSI[d] prior to first start	No	129	34	0.68	0.34	0.10	<.0001
	Yes	289	97	0.26	0.65	0.88	
Trainer	1	17	3	0.70	0.29	0	<.0001
	2	4	1	0.50	0.25	0.25	
	3	8	1	0.88	0.43	0	
	4	32	13	0.93	0.62	0	
	5	39	2	0.66	0.36	0	
	6	64	24	0.84	0.56	0.40	
	7	15	3	1.00	0.62	0.23	
	8	35	9	0.79	0.44	0.31	
	9	19	8	0.93	0.44	0.08	
	10	14	1	1.00	0.64	0.18	
	11	35	13	0.85	0.59	0.23	
	12	94	36	0.88	0.68	0.26	
	13	19	6	0.89	0.72	0.17	
	14	23	11	0.87	0.68	0.49	
Age when enrolled in the study[e]	< 24 months	178	36	0.89	0.64	0.23	0.004
	≥ 24 months	209	65	0.74	0.46	0.19	
Sex[f]	Female	202	42	0.77	0.56	0.22	0.26
	Male	198	71	0.86	0.55	0.19	
Racing season enrolled	2000/01	297	64	0.82	0.56	0.23	0.36
	2001/02	121	67	0.85	0.57	0.11	

[a] 33 horses were excluded because they had previously trained in the stables prior to enrolment in the study.

[b] P value of logrank (Mantel-Cox statistic).

[c] In these calculations, horses that did not start in an official barrier trial or race before the end of the study were right censored either when they were lost to follow-up or at the end of the study period.

[d] Musculoskeletal injury.

[e] Date of birth was unknown for 31 horses.

[f] Sex was unknown for 18 horses.

Table 4.7: Risk factors conditionally associated with the first start in a race or barrier trial, for 451[a] two-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000.

Variable	**Category**	**Beta coefficient**	**Standard error (Beta)**	**Adjusted hazard ratio (HR)**	**95% CI (HR)**	**P**
MSI[b] prior to first start	No	REF				<0.0001
	Yes	-0.7	0.13	0.5[c]	0.38-0.64	
Age when enrolled in the study	< 24 months	REF				0.0003
	≥ 24 months	2.6	0.73	13.83	3.31-57.89	
Trainer	1	REF				<0.0001
	2	0.58	0.36	1.79	0.89-3.63	
	3	0.48	0.75	1.62	0.37-7.09	
	4	0.51	0.45	1.66	0.68-4.05	
	5	0.68	0.29	1.98	1.13-3.47	
	6	-0.52	0.29	0.59	0.34-1.04	
	7	0.22	0.37	1.24	0.6-2.58	
	8	-0.17	0.31	0.84	0.46-1.56	
	9	0.65	0.38	1.91	0.91-4.03	
	10	-0.04	0.36	0.96	0.47-1.96	
	11	-0.22	0.32	0.81	0.43-1.51	
	12	-0.48	0.27	0.62	0.36-1.06	
	13	-0.27	0.37	0.76	0.37-1.56	
	14	-0.58	0.37	0.56	0.27-1.17	
Ln(t)*Age at enrolment	Ln(t)* < 24 months	REF				0.002
	Ln(t)* ≥ 24 month	-0.45	0.15	0.64	0.48-0.85	

REF = Referent

[a] 64 horses were excluded from the analysis because they commenced training prior to enrolment (n = 33) or their age was unknown (n = 31).

[b]MSI = Musculoskeletal injury

[c] After accounting for all the other factors in the model, horses that had sustained a MSI were 0.5 times less likely to start in a race or barrier trial than horses that had not sustained an injury.

[d]ln(t)*Age at enrolment= interaction with the natural logarithm of survival time and age.

Table 4.8: Association between a number of independent variables and length of time to recovery (measured as start in an official barrier trial or race) after the first musculoskeletal injury (MSI) for 173 horses that returned to training during a 27-month period commencing in May 2000, ordered according to the level of statistical significance.

Variable	**Categorical**	**Number of horses**		**Subsequent to the 1st MSI, the proportion of horses that had not recovered at**			**P[a]**
		Total	**Censored[b]**	**6 months**	**9 months**	**12 months**	
Highest training intensity prior to MSI	< 890 m/minute	34	11	0.77	0.46	0.41	<0.0001
	≥ 890 m/minute[c]	75	18	0.43	0.26	0.21	
	Race pace[d]	64	11	0.28	0.11	0.02	
MSI involved only the 3rd metacarpal bone	Yes	92	20	0.33	0.21	0.13	0.02
	No	81	20	0.58	0.30	0.23	
Trainer	1	10	3	0.25	0.25	0.25	0.08
	2[e]	2	2	-	-	-	
	3[f]	0	0	-	-	-	
	4	11	6	0.37	0.19	0.19	
	5	22	0	0.14	0.14	0.00	
	6	37	10	0.52	0.33	0.33	
	7	5	0	0.20	0.20	0.20	
	8	14	0	0.36	0.14	0.14	
	9	5	1	0.60	0.30	0.00	
	10	5	0	0.80	0.80	0.20	
	11	19	6	0.45	0.27	0.27	
	12	26	5	0.49	0.16	0.16	
	13	13	5	0.85	0.45	0.34	
	14	4	2	0.67	0.67	0.00	

Variable	Categorical	Number of horses		Subsequent to the 1st MSI, the proportion of horses that had not recovered at			P[a]
		Total	Censored[b]	6 months	9 months	12 months	
Age at the time of MSI (months)	< 26	50	10	0.57	0.36	0.30	0.14
	26-27	58	11	0.42	0.24	0.13	
	28-31	41	11	0.39	0.15	0.10	
	> 31	24	8	0.34	0.16	0.16	
Sex[g]	Female	90	15	0.44	0.24	0.15	0.45
	Male	80	22	0.46	0.25	0.22	
Racing season enrolled	2000/01	145	27	0.43	0.25	0.18	0.53
	2001/02	28	13	0.54	0.22	0.22	
Age at enrolment (months)	< 22	33	8	0.49	0.24	0.07	0.86
	22-23	58	14	0.43	0.26	0.23	
	24-26	63	14	0.47	0.25	0.17	
	> 26	19	4	0.37	0.22	0.15	

[a] P value of logrank (Mantel-Cox statistic)

[b] In these calculations, horses that did not start in an official barrier trial or race before the end of the study were right censored either when they were lost to follow-up or the end of the study period, which ever came first.

[c] Horse had galloped at speeds ≥890 m/minute but had not started in a race or barrier trial.

[d] Started in an official barrier trial or race.

[e] No estimate available as all observations were censored.

[f] No estimate available as no horses in the data set from this trainer.

[g] Sex was unknown for 3 horses.

Table 4.9: Risk factors conditionally associated with recovery (measured as a start in an official barrier trial or race) from the first musculoskeletal injury, for 173 horses that returned to training during a 27-month period commencing in May 2000.

Variable	Category	Beta coefficient	Standard error (Beta)	Adjusted Hazard Ratio (HR)	95% CI (HR)	P
Training intensity	< 890 m/minute	REF				<.0001
	≥ 890 m/minute	0.76	0.27	2.14[a]	1.25-3.65	
	Start	1.39	0.29	4.01	2.25-7.15	
Trainer	1	REF				0.07
	2	-0.48	0.61	0.62	0.19-2.04	
	3[b]	-	-	-	-	
	4[c]	-	-	-	-	
	5	-0.56	0.52	0.57	0.21-1.6	
	6	-1.01	0.51	0.36	0.13-0.99	
	7	-0.03	0.64	0.97	0.28-3.42	
	8	-0.57	0.53	0.56	0.2-1.61	
	9	-1.47	0.71	0.23	0.06-0.92	
	10	-0.75	0.64	0.47	0.13-1.67	
	11	-0.61	0.54	0.54	0.19-1.56	
	12	-1.26	0.53	0.28	0.1-0.81	
	13	-1.31	0.58	0.27	0.09-0.85	
	14	-1.77	0.86	0.17	0.03-0.93	

[a] After accounting for the effect of clustering due to trainer, horses that had trained at speeds ≥ 890 m/minute (but had not raced) were 2.14 times more likely to recover from MS injury than a horse that had trained at speed of <890 m/minute.

[b] No estimate available as all observations were censored.

[c] No estimate available as no horses in the data set from this trainer.

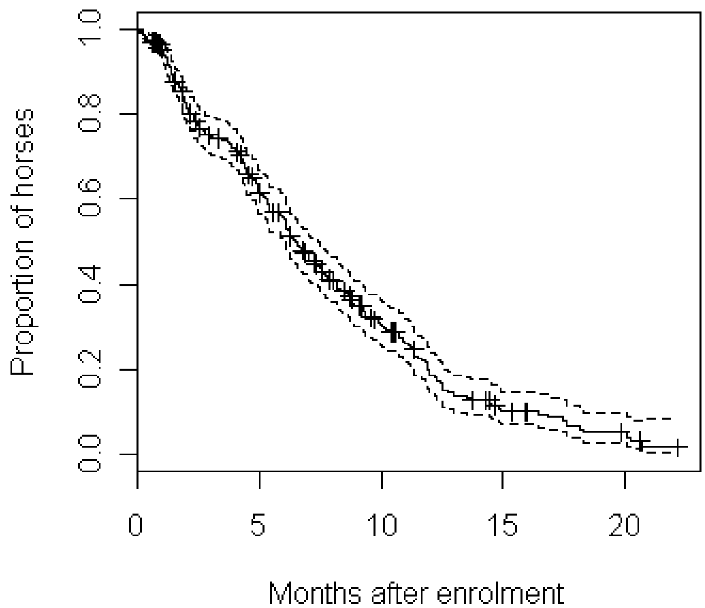

Figure 4.1: Kaplan Meier survival curve for the cumulative proportion of 418 horses that had not raced in the days, following enrolment in a longitudinal study. Dashed lines represent 95% confidence intervals.

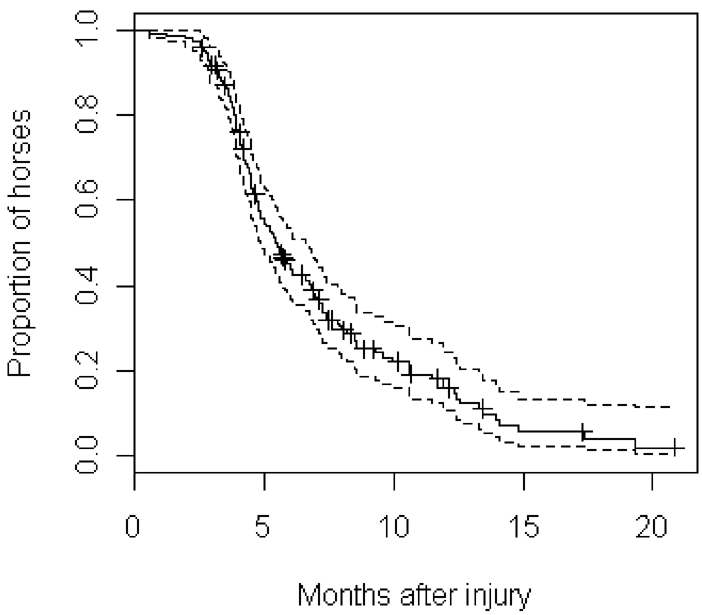

Figure 4.2: Kaplan Meier survival curve for the cumulative proportion of 173 horses that returned to training after sustaining an initial MS injury, and had not recovered from the initial musculoskeletal (MS) injury. Dashed lines represent 95% confidence intervals.

4.4 Discussion

The chapter describes the incidence and impact of MS injuries at the level of the horse. The results presented in this chapter may not be representative of the general population of horses because trainers were sampled using non-random methods. Random sampling may have given in a more representative sample but it was felt that it would have resulted in low response rates and logistical difficulties with data collection.

The focus of the current study was those cases of MS injury that resulted in the horse leaving the stable for more than seven days. This differs from previous studies that included MS injuries that resulted in modified training (Rossdale 1989, Bailey *et al.* 1999). The definition used in previous studies was not applied in this study because it was felt that 'modified training' was subjective. In contrast, a horse being removed from the stable was a clearly defined event. All the trainers in the study trained at the racetracks and had a limited number of boxes. The trainers indicated a preference for removing horses that were not in training from the stable, although this was not quantitatively investigated. It is also worth noting that the severity of injury that would result in a horse ceasing training and thus being removed from the stable was likely to vary between trainers and should be considered as a reason for trainer effects in multi-variable models. Despite this limitation it was felt that defining a MS injury by removal from stable was more consistent that using modified training days.

Information relating to the nature of the MS injury was provided by the trainer and did not necessarily involve a veterinarian. It was felt that trainers were capable of detecting the presence or absence of a MS injury, especially an injury severe enough to result in the horse leaving the stable. However as the necessary diagnostic tests were not always conducted, it is possible that there was misclassification of the type of MS injury. For example an injury to the suspensory ligament may have been reported as swelling and/or heat in the fetlock joint with no known cause. Despite the potential for misclassification, it was considered preferential not to rely on confirmation by a veterinarian, as this may have resulted in an underestimation of MS injuries because common conditions such as shin soreness are often not seen by a veterinarian (Perkins *et al.* 2004a). MS injuries were primarily categorised on the anatomical location of the injury in an attempt to minimise the misclassification bias. However, the estimates for some injuries may still have been affected. In particular, tendon and ligament injuries may have been underestimated if they were misclassified as fetlock or carpal joint problems.

In this study the most common site of MS injury was the forelimb, in particular the lower forelimb. This is consistent with previous studies of horses in training conducted in Australia (Mason and Bourke 1973, Bailey *et al.* 1999), New Zealand (Perkins *et al.* 2004a) and UK (Rossdale 1989). The most common site of injury was the third metacarpal bone and the most common injury at the site was shin soreness. The results are consistent with previous research by Mason and Bourke (1973), Bailey *et al.* (1999) and Perkins *et al.* (2004a) but differ from a UK study that reported sore shins as the sixth most common cause of lameness behind muscular, feet, carpus, fetlocks and tendons (Rossdale 1989). The difference between the current study and Rossdale (1989) may be due to a number of factors such as regional differences, differences in case definition and study population. For example, the study population in the Rosedale included horses of all ages, while the current study was restricted to two- and three-year-olds.

The IR for shin soreness (2.51/1,000 horse-training days) was comparable to results in a previous Australian study that reported the IR for the first occurrence of shin soreness was 1.68 per 100-horse weeks, or 2.4 per 1,000 training-days (Bailey *et al.* 1999). In contrast, the IR for shin soreness in the current study was higher than the 4.4/100 horse-months reported in a recent UK study (Verheyen *et al.* 2005) and 1.19/1,000 horse-training days reported in a New Zealand study (Perkins *et al.* 2004a). The differences between the current study and the UK and New Zealand studies may be due to a number of factors, including different training practices, training surface and case-definitions.

The rate for the first MS injury was higher in two-year-old than in three-year-old horses: two-year-olds were 2.99 (95% CI = 1.87-4.79) times more likely than three-year-olds to sustain an incident MS injury. The IR for specific types of MS injuries were higher in two-year-olds than three-year-olds for all categories of injuries, except for tendon and ligament injuries, but the differences were only significant for injuries involving the third metacarpal bone. This is consistent with a study of New Zealand horses in training that reported the rate of shin soreness was highest in two-year-olds and decreased with increasing age, and that the IR for soft tissues injuries was highest in horses more than five years of age (Perkins *et al.* 2004a). This would seem to suggest that young horses are at increased risk of shin soreness and older horses are at increased risk of soft tissue injury. However, as the majority of horses commenced training as two-year-olds, the increased risk of shin soreness in this age group could be due to the onset of training. This hypothesis is supported by anecdotal evidence that older horses commencing training will also develop shin soreness (Buckingham and Jeffcott 1990). The increased risk of soft tissue injuries in older horses may be a true effect or be confounded by long term exposure to training, as older horses are likely to have been exposed to training for longer periods of time than younger horses.

Sex was only associated with increased risk of injury involving the third metacarpal bone. The comparison of IRR indicated that males were 1.6 times more likely than females to sustain an initial injury involving the third metacarpal bone. These differences between male and female horses may represent a true increased risk in male horses. However, the finding may also be due to differences in exposure to training variables.

Survival methods were used to investigate the length of time to first start in a race or barrier trial and the length of time to recovery. Factors influencing the length of time to first start were investigated as it represents the time taken before owners have an opportunity to receive a return on their investment. Similarly, length of time to recovery after a MS injury was chosen as it also has economic implications. For both the time to first start and the time to recovery, the interval was the cumulative sum of both spell and training days as many owners incur cost regardless of whether the horse is spelling or training. However, costs associated with spelling are generally lower than those incurred when training.

This study found that approximately 80% (78%) of horses started in a race or barrier trial within 12 months of enrolling in the study. As data collection began in May 2000, well before the commencement of the two-year-old racing season, the enrolment date for the majority of horses is the same date that they commenced training at a racetrack. While it was unlikely that horsed would have trained at the stable prior to enrolment some of the horses may have undergone training away from the stable prior to enrolment. Previous work by Bailey *et al.* (1999) has shown that Australian two-year-old Thoroughbred horses spent 7.5% of their time in pre-training. The potential impact of this on the estimates presented in this study could not be described as data were not collected when horses were away from the stable. However, it is likely to vary between trainers and should be considered as a reason for the significant differences between trainers in the multivariable model.

The multivariable model showed that horses that sustained a MS injury were 0.5 times less likely to race than those that did not sustain a MS injury. This represents a substantial increase in costs to the owner in form of lost opportunity to race, additional training and adjistment fees and any expenses associated with diagnosis and treatment of the injury. Further research should therefore focus on understanding those factors associated with the onset of the first MS injury, irrespective of the type of injury. Analyses presented in Chapter 5 will investigate the long term impact of MS injury on training preparations, and the analysis presented in Chapter 7 will examined risk factors for the first MS injury. The significant variation between trainers, after adjusting for the presence of a MS injury, suggests that factors other than the presence of MS injury play a role in the horses not starting in races. These may include management decisions to commence training but to delay the commencement of racing for a variety of reasons. It is also possible that time to first start is delayed due to the presence of health problems other than MS injury, such as respiratory disease. The relationship between age at enrolment and the time to first start was complicated by the incorporation of interaction term for this variable and survival time. This term was included because the age at enrolment violated the proportional hazard assumption. Violation of the proportional hazard assumption can be handled by stratifying the nonproportional, partitioning of the time axis, choosing a different model or modelling non-proportionality with time-dependent covariates (Therneau and Grambsch 2001, pp145-147). The latter was chosen in this study.

Seventy percent of the 248 horses that sustained a MS injury returned to training, of which the cumulative proportion of horses that had started in a race or barrier trial six months after the initial injury was 55%. Time to recovery was significantly associated with the intensity of exercise prior to the onset of MS injury: horses that had started in a race, prior to the MS injury, were nearly four times more likely to recover from injury than those horses that sustained a MS injury when they had not galloped at speeds greater than 890 m/minute. This finding may be a true association or it may be biased because those horses that sustain a MS injury at lower speed may differ from horses that raced in a number of factors, including poor conformation. The presence of these variables may make the horse more likely to sustain another MS injury and thereby delay recovery. Another possible bias is owners and/or trainers may decide to spell a horse that sustained a MS injury at slower speeds for longer than one that received a MS injury at higher speeds because they believe that the horse is “skeletally immature”.

To conclude, this study describes training and racing patterns in young Australian racehorses and supports findings both in Australia and other countries that the most common MS injury in two- and three-year-old Thoroughbred racehorses was shin soreness. Overall, the rate of injury was higher in two-year-olds than three-year-olds due mostly to a higher incidence of shin soreness in two-year-olds. The current study also showed that MS injury impacts negatively on the length of time to first start in a race or barrier trial. Time to recovery, as measured by a start in a race or barrier trial, was shortest in horses that had galloped at speed ≥ 890 m/minute or started in a race or barrier trial. To the author’s knowledge, the impact of MS injuries on the length time to first start and the length time for recovery following a MS injury have not previously been reported for MS injuries that occur during training. This information may prove useful in estimating the economic cost of MS injuries.