Chapter 5: Profiling Australian two- and three-year-old Thoroughbred racehorses II: Training preparations

Abstract

AIM: To develop a profile of training preparations and examine factors that affect measure of performance in these preparations.

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. Training data were aggregated into units referred to as "preparations". A preparation ended when the horse left the stable for more than seven days. Univariable and multivariable analytical methods were used to examine the association between a range of independent variables and four preparation-level measures of performance: (i) the duration of preparations; (ii) length of time from the beginning of the preparation until the first start in a race or barrier trial; (iii) length of time from the first start until the end of the preparation and (iv) rate of starts in races or barrier trials.

RESULTS: During the study period, 451 horses and 14 trainers contributed 1, 272 preparations. Age, or age class, was conditionally associated with all outcomes. After adjusting for confounders, younger horses tended to have shorter preparations, took longer to start in a race or barrier trial, had a shorter interval from the first start to the end of the preparation and fewer starts per 100 training days. Musculoskeletal (MS) injury was not conditionally associated with any of the outcomes considered in this chapter.

CONCLUSION: Based on these results it would appear that MS injuries have limited impact on long term performance, although care must be taken in interpreting the results as they could be biased by a "healthy horse" effect. Age of the horse at the start of the preparation, or age class, accounted for some of the variability in all the outcomes considered in this chapter. In multivariable models, the number of previous preparations was significantly associated with all the outcome variables except for the time to first start in a preparation. Thus, some of the age effects observed in the unconditional analyses may have been confounded by previous exposure to training, as older horses are more likely to have trained previously.

5.1 Introduction

An understanding of "normal" training patterns provides information that trainers and owners can use to benchmark the performance of their horses. The information is also of great value in understanding the associations between training and management and the risk of injury. A study of horses racing in South-Eastern Queensland used multivariable techniques to describe factors associated with performance and length of racing career (More 1999). The study found that in comparison to horses that were performing poorly, well performing horses were more likely to be male, have started as 2-year-olds and had more starts in the preceding 12 months. Length of racing career was found to be associated with performance in the first year of racing, sex, date of birth and age at first start. However, as noted by the author, interpretation of the results was limited due to confounding from training-related factors, clustering at the level of the trainer and the health status of the horses.

Musculoskeletal (MS) injuries have been identified as the most commonly occurring 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). Analyses presented in the previous chapter showed horses that sustained a MS injury, prior to their first start, were 0.50 times less likely than horses that did not sustain an injury, to start in a race or barrier trial. While associations presented at the level of the horse are interesting horses frequently change trainers and owners, and as such it would be useful to describe the impact of MS injuries at the level of the preparations.

Perkins *et al.* (2004b) reported that after stratifying by age class and sex, the median duration of preparations after the first MS injury was less than those before the first MS injury (Perkins *et al.* 2004a). The associations presented by Perkins *et al.* (2004 a,b) provide valuable information about careers of racehorses in New Zealand. However, they must be interpreted with care because the analyses did not use multivariable techniques to adjust for potential confounders. Furthermore, the degree to which they can be extrapolated to other countries is limited. The aim of the current study was to describe the epidemiology of MS injuries in Australian two- and three-year-old

Thoroughbred racehorses. The chapter presents the results of multivariable analyses to determine factors associated with training preparations. Specifically, the analyses examined the impact of age, sex, racing season the horse was enrolled and MS injury.

5.2 Materials and methods

5.2.1 Study design

This was a 27-month longitudinal study that began in May 2000. The design, implementation and management of the study are described in Chapter 3. Briefly, 14 trainers were convenience sampled at metropolitan and provincial racetracks in New South Wales, Australia (n = 5). In the 2000/01 and 2001/02 racing seasons 323 and 128 two-year-olds, respectively, were enrolled. Horses were followed from enrolment until either the end of the study or they were lost to follow-up. A horse was classified as lost to follow-up if it was not in the training yards in the last month of the study.

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. Training information was collected using a standardised questionnaire. During the fortnightly visit, trainers were questioned about the injury status of all horses that had left the stable since the previous visit. If the 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. The trainer provided injury information, 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 (i.e. injuries such as stone bruises were excluded).

5.2.2 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.

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 in the official three-year-old racing season. Similarly, preparations and spell periods that began while the horse was a three-year-old were classified as belonging to the three-year-old racing season regardless of when they ended. Those preparations and spell periods that began when the horse was officially one-year-old were also classified as belonging to the two-year-old season.

5.2.3 Statistical analysis

Univariable and multivariable analytical methods were conducted to separately examine the association between a range of independent variables and four preparation level outcomes: (i) duration of preparation; (ii) length of time from the beginning of the preparation until the first start in an official barrier trial or race; (iii) length of time from the first start in an official barrier trial or race, until the end of the preparation; and (iv) rate of starts in a race or barrier trial.

The duration of the preparation was examined using standard methods of survival analysis (Hosmer and Lemeshow 1999, pp 27-112). In these calculations incomplete preparations were right censored. The Kaplan-Meier method was used to calculate the cumulative proportion of preparations that had not ended. The unconditional association between this measure and a number of variables was assessed using the log-rank (Mantel-Cox) statistic. The explanatory variables considered were age at the start of the preparation, racing season the horse was enrolled, sex, and MS injury status of the preparation. MS injury status was a binary variable with preparations classified as either before the incident MS injury or after the incident MS injury. Training preparations before the incident injury were all those preparations up to and including the preparation in which the incident MS injury occurred. Preparations at risk of subsequent MS injury included all those preparations that occurred once the horse returned to training, after the initial injury. Explanatory variables with $P<0.30$ were considered in a Cox-regression model. Variables for inclusion in the base model were selected using backward elimination and were 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 $P < 0.05$. To account for clustering at the level of the horse the base model was extended to include a frailty term coding for horse identity. All variables from the base model were retained in the final model even if after the inclusion of the frailty term $P > 0.05$. The proportional hazards assumption was tested, prior to the inclusion of the frailty term coding, by separately adding variables for the interaction of the log of survival-time and variable in the mode. The significance of the interaction term was assessed using the deviance ratio test: If $P > 0.05$ the interaction term was retained in the model.

Survival methods were also used to investigate the days from the start of the preparation until the first start in a race. When calculating the days from the beginning of the preparations until the first start in a race or barrier trial, a preparation was excluded if the horse started in a race on the first day of the preparation. In these calculations preparations that did not contain at least one start in an official barrier trial or race were right censored on the last day of the preparation. The cumulative proportion of preparations that had started in a race or barrier trial was estimated using the Kaplan-Meier method. The unconditional association between this measure and the explanatory variable (age at the start of the preparation, cohort, sex, and MS injury status) was assessed using the log-rank statistic. Variables with $P<0.30$ were considered in Cox-regression. The model was fitted in identical manner to the Cox-regression model investigating factors conditionally associated with the duration of a preparation.

For those preparations that included at least one start in an official barrier trial or race, the length of time from the first start to the end of the preparation was examined using survival analysis. In these calculations incomplete preparations were right-censored. The proportion of preparations that had ended after the first start, in a race or trial, was estimated using Kaplan-Meier methods. The unconditional association between this measure and the explanatory variables was assessed using the log-rank statistic. Variables associated with the length of time from first start in a race or barrier trial until the end of the preparation with $P<0.30$ were considered in a Cox-regression model. The model was fitted in an identical manner to the regression model used to investigate risk factors for the duration of preparations.

Number of starts in official barrier trials and races per 100 horse-training days were calculated and presented stratified by age class, sex, number of previous preparations, MS injury status of the preparation, and calendar month. Explanatory variables associated with rate of starts at $P<0.30$ were considered in a Poisson regression model. Variables were selected using backward elimination and were retained in the model if P remained less than 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. To account for clustering at the level of the horse the base model was extended to include a random effect coding for horse identity. All variables from the base model were retained in the final model even if after the inclusion of the random effect, coding for horse identity, $P > 0.05$.

Data analyses were conducted using SAS and R for Windows (version 2.0). The level of significance was set at $P < 0.05$.

5.3 Results

The data set comprised 1,272 preparations recorded in 451 horses. The cumulative proportion of preparations that had not ended in four, eight weeks and 12 weeks were 0.75 (95% CI = 0.72-0.77), 0.48 (95% CI = 0.45-0.51) and 0.29 (95 % CI =0.27-0.32), respectively (Figure 5.1). Unconditional association between a number of explanatory variables and the length of time to the end of the preparation are described in Table 5.1. Risk factors conditionally associated with the time to first start are presented in Table 5.2. In this population of horses the duration of the preparation was conditionally associated with age at the start of the preparation and with number of previous preparations. The racing season that a horse was enrolled in the study was a significant predictor of duration of preparation, prior to the inclusion of a term accounting for the clustering at the level of the horse, but became non-significant ($P = 0.23$) when a shared frailty term, coding for horse identity, was added to the model.

The cumulative proportion of preparations that had not started in a race or barrier trial eight, 10 and 12 weeks after the commencement of the preparation were 0.55 (95% CI = 0.52-0.59), 0.30 (95% CI = 0.27-0.34) and 0.13 (95 % CI =0.10-0.17), respectively (Figure 5.2). Table 5.3 describes the unconditional association between a number of independent variables and the length of time, from the beginning of the preparation, to the first start in a race or barrier trial. Risk factors for the length of time, from the beginning of the preparation, to the first start in a race or barrier trial are described in Table 5.4. After accounting for clustering at the level of the horse, age of the horse at the start of a preparation was the only significant predictor of length of time from the beginning of the preparation to the first start in an official barrier trial or race. Preparations where the horse was 24 to 27 months old were 1.79 (95% CI = 1.18-2.70) times more likely to start in a race or trial, than preparations that began when the horse was < 24 months old.

Subsequent to the first start in a race or barrier, the cumulative proportion of 589 preparations that had not ended at two weeks, four weeks and six weeks was 0.75 (95% CI = 0.72-0.79), 0.58 (95% CI = 0.54-0.62) and 0.38 (95 % CI =0.34-0.42), respectively (Figure 5.3). The unconditional association between a number of independent variables and the length of time from the first start in a preparation until the end of the preparation is detailed in Table 5.5. Table 5.6 describes the risk factors for the length of time from the first start, in a race or barrier trial, until the end of a preparation. In this population the number of previous preparations and age of the horse at the start of the preparation were significant predictors of length of time from the first start until the end of the preparation. The racing season that a horse was enrolled in the study was a significant predictor of this outcome prior to the inclusion of a term accounting for the clustering at the level of the horse, but became non-significant ($P = 0.06$) after the shared frailty term, coding for horse identity, was incorporated in the model.

The number of starts in races or barrier trials was 2.54/100 horse-training days (95% CI = 2.43-2.65). Unconditional association between a number of independent variables and the rate of starts in races or barrier trials is described in Table 5.7. Table 5.8 describes the risk factors for the rate of starts. After accounting for the other variables in the model, the age class of the horse was a significant predictor of the rate of start. The rate of starts was 1.33 times higher in three-year-olds than two-year-olds. In this population, the calendar month, racing season cohort and the number of previous preparations were all significantly associated with the rate of starts.

Table 5.1: Association between independent variables and the duration of preparations for 1, 272 preparations recorded in two- and three-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000, ordered according to the level of statistical significance.

Variable	Category	Preparations		Subsequent to the start of the preparation, the proportion of preparations that had not ended at			P[a]
		Total	Censored[b]	28 days	56 days	84 days	
Age at start of preparation[c]	< 24 months	213	0	0.52	0.20	0.07	<.0001
	24-27 months	322	0	0.73	0.39	0.16	
	28-31 months	294	9	0.82	0.56	0.34	
	≥ 32 months	393	28	0.86	0.70	0.52	
MSI[d] status of preparation	Before 1st MSI	894	14	0.71	0.42	0.23	<.0001
	After 1st MSI	378	23	0.84	0.63	0.43	
Number of previous preparations	None	451	1	0.62	0.29	0.10	<.0001
	1	365	5	0.80	0.50	0.29	
	≥ 2	456	31	0.84	0.66	0.48	
Racing season enrolled	2000/01	1031	32	0.75	0.51	0.32	<.0001
	2001/02	241	5	0.72	0.37	0.16	
Sex[e]	Female	665	16	0.78	0.51	0.31	0.34
	Male	579	21	0.73	0.46	0.28	

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

[b] In these calculations preparations classified as incomplete were right censored.

[c] Age was unknown for 50 preparations.

[d] Musculoskeletal injury.

[e] Sex was unknown for 28 preparations

Table 5.2: Risk factors conditionally associated with the cessation of a preparation in 1, 272[a] preparations recorded in two- and three-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000 (adjusted for potential clustering at the level of the horse).

Variable	**Category**	**Beta coefficient**	**Standard Error (Beta)**	**Adjusted Hazard Ratio (HR)**	**95% CI (HR)**	**P**
Age at start of preparation	< 24 months	0		1.00		<0.0001
	24-27 months	-0.51	0.11	0.60[b]	0.48 - 0.75	
	28-31 months	-0.78	0.13	0.46	0.36 - 0.59	
	≥ 32 months	-1.18	0.15	0.31	0.23 - 0.41	
Number of previous preparations	None	0		1.00		<0.0001
	1	-0.45	0.09	0.64	0.53-0.76	
	≥ 2	-0.82	0.12	0.44	0.35-0.56	
Racing season enrolled	2000/01	0		1.00		0.23
	2001/02	0.09	0.11	1.09	0.88-1.35	

[a] Data from 50 preparations were excluded because age was unknown.

[b] After accounting for the other variables in the model, preparations that began when the horse was 24-27 months old were 0.60 times less likely to end than those that began when the horse was < 24 months old.

Table 5.3: Association between a number of independent variables and the length of time from the commencement of a preparation to the first start in an official barrier trial or race for 1,274 preparations recorded in two- and three-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000, ordered according to the level of statistical significance.

Variable	Category	Preparations		Subsequent to the start of the preparation, the proportion of preparations that horses had not started in a barrier trial or race at			P[a]
		Total	Censored[b]	8 weeks	10 weeks	12 weeks	
Age at start of preparation [c]	<24 months	213	177	0.75	0.51	0.28	<0.0001
	24-27 months	322	197	0.58	0.37	0.17	
	28-31 months	294	132	0.57	0.25	0.08	
	>=32 months	393	128	0.45	0.24	0.10	
Number of previous preparations	None	448	340	0.67	0.42	0.19	<0.0001
	1	360	188	0.61	0.31	0.15	
	>=2	446	155	0.45	0.24	0.09	
Sex[e]	Female	660	325	0.75	0.42	0.16	0.0002
	Male	566	330	0.61	0.35	0.13	
Racing season enrolled	2000/01	894	534	0.52	0.28	0.12	0.003
	2001/02	378	149	0.75	0.42	0.16	
MSI[f] status of preparation	Before 1st MSI	884	534	0.59	0.33	0.13	0.28
	After 1st MSI	370	149	0.50	0.27	0.13	

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

[b] In these calculations preparations that did not contain a start were right censored at the end of the preparation.

[c] Age was unknown for 50 preparations.

[e] Sex was unknown for 28 preparations.

[f] Musculoskeletal injury.

Table 5.4: Risk factors conditionally associated with the a start in a race or barrier trial in 1, 272[a] preparations recorded in two- and three-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000 (adjusted for potential clustering at the level of the horse).

Variable	**Category**	**Beta coefficient**	**Standard Error (Beta)**	**Adjusted Hazard Ratio (HR)**	**95% CI (HR)**	**P**
Age at start of preparation	< 24 months	0		1.00		<0.0001
	24-27 months	0.58	0.21	1.79[b]	1.18-2.70	
	28-31 months	0.84	0.21	2.32	1.55-3.47	
	≥ 32 months	1.16	0.10	3.20	2.16-4.72	

[a] Data from 40 preparations were excluded because the age at the start of the preparation was unknown (n=22) or the horse started in a race on the first day of the preparation (n = 18).

[b] After accounting for the other variables in the model, preparations that began when the horse was 24-27 months old was 1.79 times more likely to include a start, in race or barrier trial, than preparations that began when the horse was < 24 months old

Table 5.5: Association between a number of independent variables and the length of time from the first start in a race or barrier trial to the end of the preparation, for 589 preparations recorded in two- and three-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000, ordered according to the level of statistical significance.

		Preparations		**Subsequent to the first start in a race or barrier trial, the proportion of preparations that had not ended at**			
Variable	**Category**	**Total**	**Censored[b]**	**2 weeks**	**4 weeks**	**6 weeks**	**P[a]**
Age at the start of the preparation	< 24 months	37	0	0.44	0.14	0.06	<.0001
	24-27 months	125	0	0.61	0.42	0.25	
	28-31 months	162	5	0.78	0.57	0.39	
	≥ 32 months	265	17	0.85	0.72	0.57	
Number of previous preparations	None	111	1	0.63	0.37	0.19	<.0001
	1	177	2	0.75	0.53	0.35	
	≥ 2	301	19	0.80	0.68	0.54	
Racing season enrolled	2000/01	512	19	0.77	0.61	0.45	<.0001
	2001/02	77	3	0.69	0.38	0.22	
MSI[c] status of preparation	Before 1st MSI	360	8	0.77	0.61	0.36	0.001
	After 1st MSI	229	14	0.69	0.38	0.52	
Sex	Female	340	8	0.91	0.78	0.42	0.81
	Male	249	14	0.89	0.73	0.42	

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

[b] In these calculations, preparations classified as incomplete (i.e. ended because data collection ended) were right censored.

[cd] Musculoskeletal injury.

Table 5.6: Risk factors conditionally associated with cessation of preparation, after the first start in a race or barrier trial, in 589 preparations recorded in two- and three-year-old Thoroughbred racehorses during a 27-month period commencing in May 2000 (adjusted for potential clustering at the horse level).

Variable	**Category**	**Beta**	**SE (Beta)**	**Hazard Ratio**	**95% CI**	**P**
Age at start of preparation	< 24 months	0		1.00		<0.0001
	24-27 months	-0.57	0.24	0.56[a]	0.35-0.88	
	28-31 months	-0.81	0.24	0.45	0.28-0.71	
	≥ 32 month	-1.33	0.25	0.27	0.16-0.44	
Number of previous preparations	0	0		1.00		<0.0001
	1	-0.11	0.13	0.90	0.68-1.19	
	≥2	-0.45	0.14	0.64	0.46-0.88	
Racing season enrolled	2000/01	0		1.00		0.06
	2001/02	0.21	0.14	1.34	0.99-1.82	

[a] After accounting for all the other factors in the model, preparations that began when the horse was 24-27 months were 0.56 times less likely to end after the first start in a race or barrier trial than preparations that began when the horse as < 24 months old.

Table 5.7: Association between a number of independent variables and the rate of starts, per 100 training days for 1, 986 starts in races and barrier trial in 78, 154 training days recorded in two- and three-year-old Thoroughbred horses during a 27-month period commencing in May 2000, ordered according to the level of statistical significance.

Variable	Category	Rate of starts	95% CI	P
Age class	2	2.08	1.96-2.2	<.0001
	3	3.57	3.33-3.81	
Racing season enrolled	2000/01	2.73	2.6-2.86	<.0001
	2001/02	1.49	1.27-1.71	
Month	Jan	2.44	2.08-2.8	
	Feb	3.01	2.59-3.43	
	Mar	2.97	2.58-3.36	
	Apr	2.93	2.53-3.33	
	May	2.61	2.24-2.98	
	Jun	2.89	2.5-3.28	
	Jul	2.36	1.98-2.74	
	Aug	2.53	2.1-2.96	
	Sep	2.77	2.32-3.22	
	Oct	1.67	1.34-2	
	Nov	2.09	1.73-2.45	
	Dec	2.02	1.68-2.36	
MSI status of preparation	Before 1st MSI[a]	2.29	2.16-2.42	<.0001
	After 1st MSI	2.97	2.77-3.17	
Number of previous preparations	None	1.37	1.2-1.54	<.0001
	2	2.31	2.11-2.51	
	≥ 2	3.3	3.11-3.49	
Sex	Female	2.73	2.57-2.89	0.002
	Male	2.38	2.22-2.54	

[a] Musculoskeletal injuries.

Table 5.8: Risk factors conditionally associated with the rate of starts, per 100 horse-training days for 1, 986 starts in races and barrier trial in 78, 154 training days recorded in two- and three-year-old Thoroughbred horses during a 27-month longitudinal study (adjusted for potential clustering at the horse level).

Variable	Category	Beta coefficient	SE (Beta)	Adjusted IRR[a]	95% CI (IRR)	P
Age class	2	0.00		1.00		<0.0001
	3	0.29	0.07	1.33	1.16-1.53	
Racing season enrolled	2000/01	0.00		1.00		0.0007
	2001/02	-0.46	0.13	0.63	0.48-0.82	
Month	Jan	0.00		1.00.		<0.0001
	Feb	0.25	0.1	1.28	1.06-1.55	
	Mar	0.32	0.09	1.38	1.14-1.66	
	Apr	0.4	0.11	1.5	1.21-1.84	
	May	-0.08	0.14	0.92	0.71-1.21	
	Jun	0.11	0.12	1.12	0.87-1.43	
	Jul	-0.11	0.12	0.9	0.71-1.14	
	Aug	0.22	0.11	1.25	1.01-1.55	
	Sep	0.28	0.11	1.33	1.08-1.63	
	Oct	-0.24	0.12	0.78	0.62-0.99	
	Nov	-0.06	0.11	0.95	0.76-1.17	
	Dec	-0.16	0.11	0.86	0.7-1.05	
Number of previous preparations	None	REF		1.00		
	2	0.44	0.08	1.55	1.33-1.81	
	≥ 2	0.66	0.09	1.94	1.62-2.32	

[a] Incidence rate ratio.

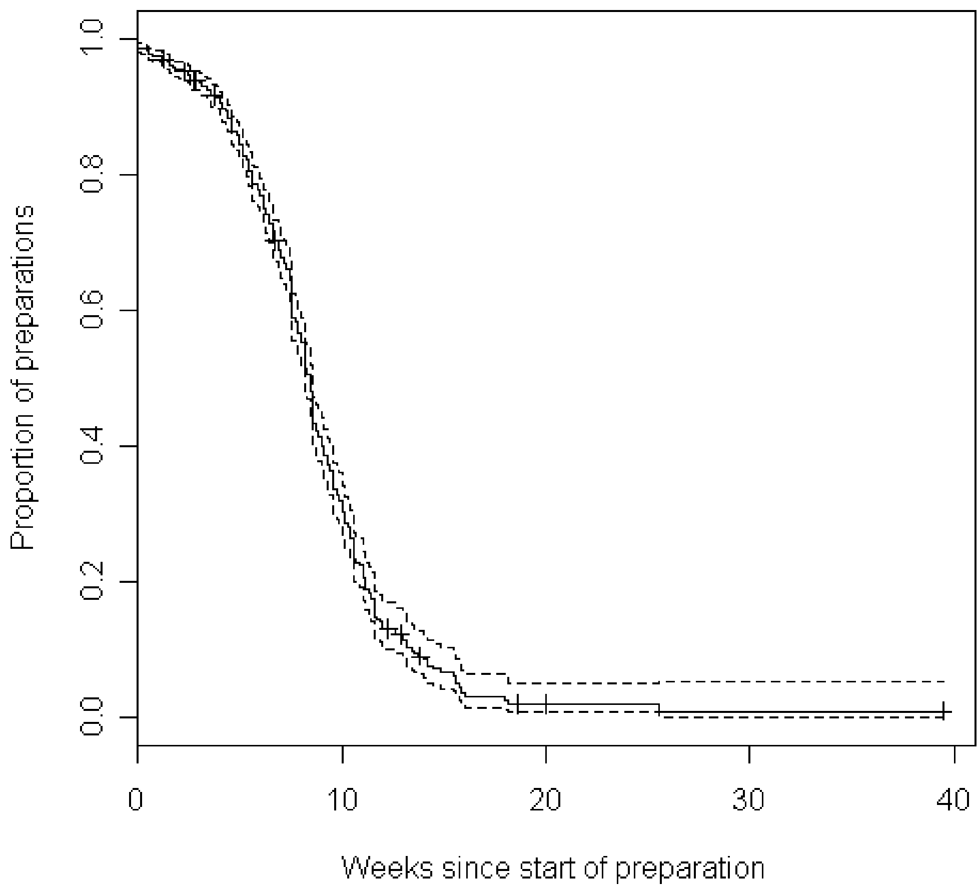

Figure 5.1: Kaplan-Meier survival curve of the proportion of 1,272 preparations in two- and three-year-old Thoroughbred racehorses that have not ended. Dashed lines represent 95% confidence intervals.

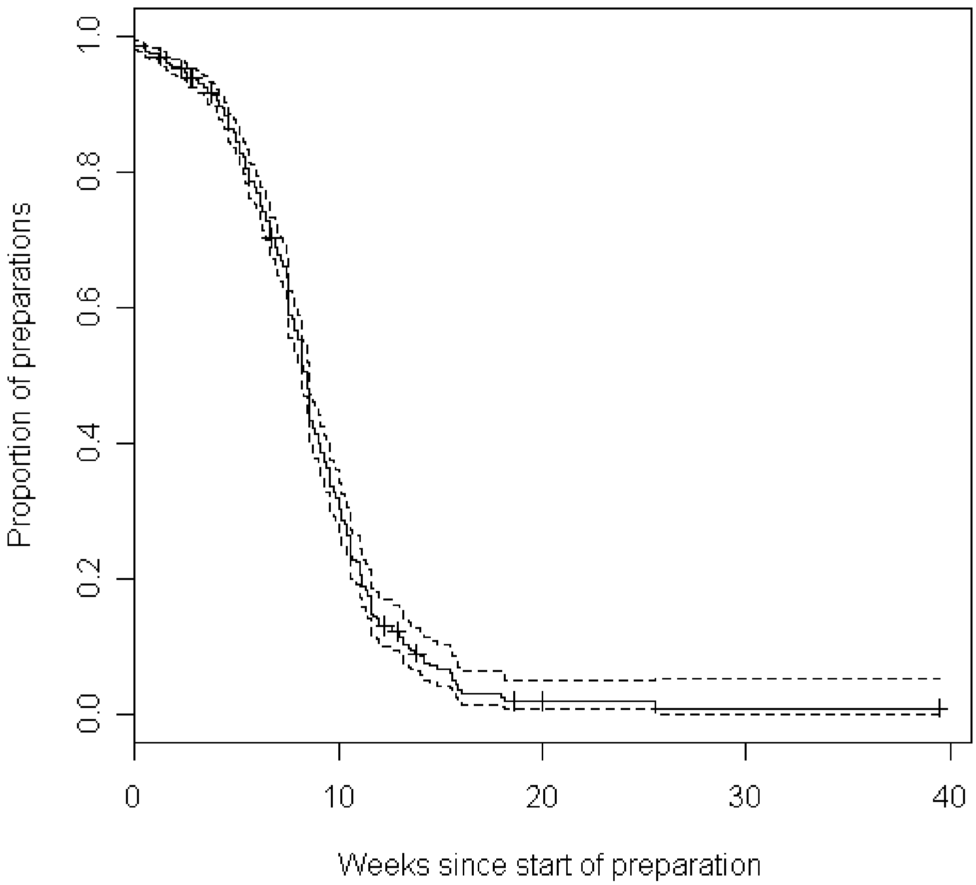

Figure 5.2: Kaplan-Meier survival curve for the proportion of 1,272 preparations, recorded in two- and three-year-old Thoroughbred racehorses that had not started in an official barrier trial or race. Dashed lines represent 95% confidence intervals.

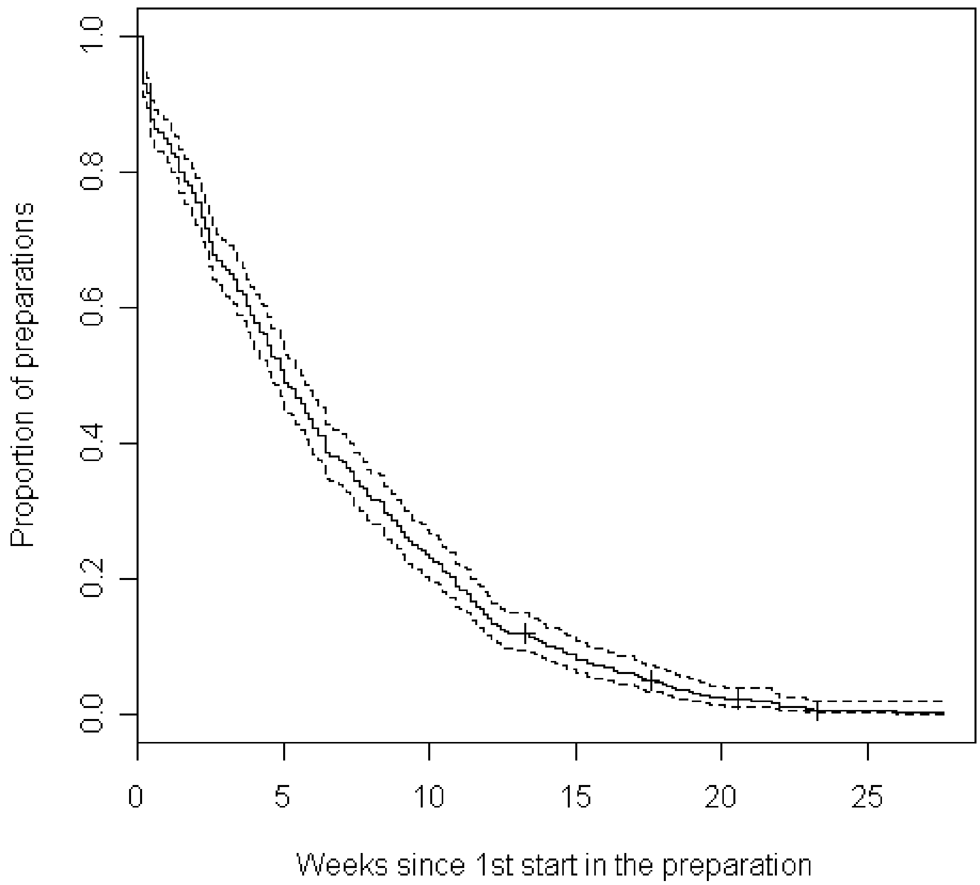

Figure 5.3: Kaplan-Meier survival curve of the proportion of 589 preparations in two- and three-year-old that had not ended, after the first start in an official barrier trial or race. Dashed lines represent 95% confidence intervals.

5.4 Discussion

This chapter describes patterns of training in preparations recorded in two- and three-year-old Thoroughbred racehorses. The profiles described in this chapter may not be representative of the Australian two- and three-year-old Thoroughbred population because trainers were sampled using non-random methods and a number of the selected trainers did not participate, or were removed from the study for failing to comply. While random sampling from all trainers in New South Wales, or even Australia, may have resulted in a more representative sample, it was considered to be impractical and likely to have resulted in low response rates and logistical difficulties.

It was not sensible to aggregate to racing season because horses move in and out of the stable several times during the racing season. Therefore, data were aggregated to the level of the preparation. Training data were also grouped as preparations because horses may change trainers and owners during a racing season. Therefore when trainers and owners are comparing the performance of their horse it is practical to compare performance at the preparation level. Focusing on performance within a preparation, whilst practically useful, creates a clustering as an individual horse could contribute more than one preparation. If this clustering was ignored it could result in regression models with standard errors that are too small and incorrect beta coefficients. In this analysis the clustering of preparations within horses was accounted for by the inclusion of frailty terms, or a random effect, that coded for horse identity.

The survival models were used to identify factors associated with three preparation-level measures of performance: (i) the duration of preparations (ii) length of time from the beginning of the preparation until the first start in a race or barrier trial and (iii) length of time from the first start until the end of the preparation. Survival methods were considered an appropriate for several reasons. Firstly, the end of preparations and the first start in a race are well defined events that are measured with minimal bias. The end and start dates for the preparation were thought to be measured with minimal bias because trainers routinely recorded this information as owners are charged for every day the horse is in the stable, irrespective of whether the horse was in training. Furthermore, the frequency of stable visits meant that even if the departure date was not recorded, it was generally possible for the person, completing the form, to recall when the horse departed. The first start in a race or trial was also recorded with minimal error as it could be confirmed by comparison with a commercial database. The second reason for selecting survival methods to analyse the data was that the start of the preparation and the first start in a race or barrier trial was a clearly identifiable 'beginning time' that was consistent across horses. The third reason for selecting survival methods was that the number of days since the start of the preparation and the first start in race or barrier trial was a meaningful metric for measuring time. Finally, survival methods were consider appropriate as they allowed data from preparations that did not include one or more starts to be included in the estimate of time to first start.

The data set comprised 1,272 preparations recorded in 451 horses. Approximately 50% (48%) of preparations had not ended eight weeks after the commencement of the preparation. A New Zealand study, using the same definition of a preparation, reported that the median duration of preparations, in horses of all ages, was 104 days (Perkins *et al.* 2004b). Differences between the two studies could be due to a variety of factors, including regional differences and differences in age structure of the study population.

The cumulative percentage of preparations that had started in a race or barrier trial eight weeks after the commencement of the preparation was 45%. The period of time from the commencement of the preparation to the first start in a trial or race, reported in this study, is less than the 11 weeks reported in a survey of NSW trainers as the time required to get a horse racing fit (Bailey *et al.* 1997b). One possible reason for the difference is that in the current study some horse may have undergone training away from the stable prior to the start of the preparation. Thus the length of time to first start is not equivalent to the length of time required to prepare a horse for a race. The length of time to first start in a race or barrier trial, reported in this study, is also lower than New Zealand research that reported the mean number of days from beginning of the preparation to the first start in two- and three-year-olds was 70 and 68 days (Perkins *et al.* 2004b). Care needs to be taken when comparing the current study and Perkins *et al.* due to differences in analytical methods. Specifically, the current study used Kaplan-Meier methods to determine the proportion of preparations that had experienced the event of interest. Thus all preparations could contribute information to the length of time to first start in race or barrier trial, regardless of whether a preparation did, or did not, experience the event. In contrast, Perkin *et al.* (2004b) reported the median time to first start, thus only in those preparations that included at least one start in a race or barrier trial contributed information.

In this study over 40% (42%) of preparations had ended within four weeks of the first start of the preparation and over 70% had ended with six weeks of the first start in a race or barrier trial. The only study reporting similar information is Perkins *et al.* (2005b) who found that the two- and three-year-olds the median number of days between successive starts, in the same preparation, was 20 and 19 days, respectively.

Overall, the rate of starts in races or barrier trials was 2.54/100 horse-training days, and in two- and three-year-olds the rate was 1.08/per 100 training days and 2.57/per 100 training days respectively. The rate of starts in two-year-olds is higher than that the rate of starts in two-year-olds reported by Perkins et al (1.22/ 100-training days, 95% CI = 0.68-1.22). This would seem to suggest that Australian two- year-olds are trained more intensely than New Zealand two-year-olds. However, the results should be interpreted with caution as they may be biased by a number of factors such as confounding and differences in study populations.

The MS injury status of the preparation was not found to be a risk factor for any of these measures of performance, suggesting that injuries that occur early in a horse's career do not have a long term impact on performance. Care needs to be taken when interpreting these results, as a "healthy horse" effect may have biased the findings. To illustrate, a horse that returns to training after the onset of MS injury is more likely to have suffered from a less severe injury. While the "healthy horse" effect cannot be discredited it is worth noting that 70% of injured horses returned to training after their incident MS injury (results presented in Chapter 4). The relationship between the MS injury status of the preparation and the outcomes considered in this chapter, could also have been biased because trainers failed to detect, or report, a MS injury. It was considered unlikely that the trainers in this study would fail to detect a MS injury as they were experienced, professional, and regularly used the services of a veterinarian.

Age of the horse at the start of the preparation or age class was a risk factor for all the measures of performance. After adjusting for confounders, younger horses tended to have shorter preparations, took longer to start in a race or barrier trial, had a shorter interval from the first start to the end of the preparation and fewer starts per 100 training days. This suggests that two-year-olds are trained less intensely than three-year-olds.

In multivariable models, the number of previous preparations was significantly associated with all the outcome variables except for the length of time from the beginning of the preparation to the first start in a race or barrier trial. Specifically, a higher number of prior preparations was associated with a longer duration of the preparation, a longer interval from the first start in a race or barrier trial to the end of the preparation and a higher the rate of race starts. Thus, some of the age effects observed in the unconditional analyses may have been confounded by previous exposure to training, as older horses are more likely to have trained previously. In order to examine the relationship between various outcomes, age and exposure to training it would be necessary to compare training of three-year-olds that trained as two-year-olds to those that did not train as two-year-olds. Unfortunately, this could not be done in the current study as all three-year-olds had trained as two-year-olds. Furthermore, it is the author's opinion, that in Australia it would be difficult to enrol a group of three-year-olds that had not had some previous exposure to training.

Sex was not a risk factor for any of the measures of performance. This suggests that male and female horses are trained in a similar manner. However, the results could be biased as the analysis did not differentiate between colts and geldings. Unfortunately, collecting information on the time that colts were gelded was difficult because it often occurred while the horse was spelling.

In the univariable analyses, the measures of performance differed between the racing season cohorts. However, after accounting for clustering at the level of the horse, the racing season that the horse was enrolled in was significantly associated only with the rate of starts/100 horse-training day. The differences between racing cohorts could have occurred for a number of reasons including the timing of races, and perceptions of the trainers and owners regarding the appropriate level of racing for the horses entering training that year. For example, the horse may be perceived as being suited to two-year-old racing, and the decision made to enter the horse in as many races as possible. Alternatively, the owners and/or trainers may perceive that the horse should not start until late in the two-year-old season or early in the three-year-old season.

The rate of starts varied between calendar months. Before adjusting for confounding the highest rate was recorded in February (3.01 starts/100 training-days) and the lowest rate was recorded in October (1.67 starts/100 training-days). After adjusting for confounders, the rate of starts was highest in August and September and lowest in October. This pattern is likely to reflect changes in the racing program. September has the first race for two-year-olds and therefore a large number of horses compete in timed barrier trials in August and September in an attempt to qualify for a place in this race. September is also the month of the spring racing carnival in Sydney. This carnival ends early in October when the major races move to Melbourne. It is at this stage that trainers will spell their older horses and start preparing their team of horses for the autumn carnival.

In conclusion, the analysis of training preparation provided some basic information about the manner in which horses are trained. Based on these results it would appear that MS injuries have limited impact on long term performance, although care must be taken in interpreting the results as they could be biased by a “healthy horse” effect. The analysis showed that younger horses tended to have shorter preparations, took longer to start in a race or barrier trial, had a shorter interval from the first start to the end of the preparation and fewer starts per 100 training days. This suggests that two-year-old horses are trained less intensely than three-year-old horses.

Chapter 6: Risk factors for musculoskeletal injuries involving the lower forelimb in the first training preparation with exposure to high-speed exercise

Abstract

AIM: To identify factors that influence the risk of MS injury involving the lower forelimb when horses are first exposed to high-speed (HS) exercise, that is gallop speed greater than or equal to 800 m/minute**.**

METHODS: Fourteen trainers were convenience sampled from those located at one of five racetracks in New South Wales, Australia. Two cohorts of two-year-old horses were enrolled in the study during the 2000/01 and 2001/02 racing seasons. 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. The first preparation for each horse that included exposure to HS exercise was selected for analyses. A preparation was classified as a case if it ended with a MS injury involving the lower forelimb from fetlock to carpal joint inclusive. Controls were those preparations that did not end in any MS injury. Multivariable logistic regression was used to determine the horse and training factors that altered the risk of MS injuries.

RESULTS: Thirty-eight percent (n = 133) of the 349 preparations included in the analysis ended with a MS injury involving the lower forelimb. The cumulative incidence of shin soreness, fetlock joint problems, carpal joint problems and soft tissue injuries was 23%, 7%, 6% and 3%, respectively. The odds of injury varied significantly between trainers with values ranging from 0.16 to 1.41. The odds of injury were highest in preparations where the highest gallop speed was greater than or equal to 890 m/minute, the cumulative exposure to HS exercise exceed 8,000 metres and the horse had previously sustained a MS injury.

CONCLUSIONS: The results demonstrated that increased exposure to HS exercise is a risk factor for MS injury. This supports the proposition that training injuries are caused by the accumulation of micro-damage. The significance of a variable coding for trainer indicates that there are a number of factors relating to training and management of racehorses that may be risk factors for MS injuries. These may include aspects of the training regimen such as the rate of increase in distance trained at HS or management issues.

6.1 Introduction

Musculoskeletal (MS) injuries are the most common health problem in Thoroughbred racehorses (Jeffcott *et al.* 1982, Rossdale *et al.* 1985, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey 1998). Both Bailey *et al.* (1999) and Perkins *et al.* (2004a) reported that incidence of MS injury is higher in two-year-olds. The current study also found that the incidence rate of MS injuries, in particular shin soreness, was higher in two-year-olds than three-year-olds. 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). These studies have been conducted in the UK and USA and differences in training and management mean that the results are not directly applicable to Australian conditions.

In Australia, Bailey *et al.* (1999) described the frequency and impact of MS injuries but did provide any multivariable analysis of the data. A survey of racetrack veterinarians and trainers found that the majority believed the commencement of fast work was associated with an increased risk of shin soreness (Buckingham and Jeffcott 1990). Another prospective study investigating risk factors for MS injuries concluded that horses commencing racing or "hard training" when skeletally immature, as measured by closure of the distal radial epiphysis, had a higher incidence of carpal problems and shin soreness (Mason and Bourke 1973). However, the authors did not define hard training and their analysis did not control for potential confounders.

The results of these studies suggest that the commencement of training at high-speed (HS) marks the onset of a period in which a horse is at increased risk of MS injury. The aim of this chapter was to identify those factors that influence the risk of MS injury when horses are first exposed to HS exercise.

6.2 Materials and methods

6.2.1 Study design

Selection of trainers and horses was described in Chapter 3. In summary, 14 trainers were convenience sampled from those located at one of five racetracks in New South Wales

(NSW), Australia. The selected trainers were enrolled between May and November 2000. Data collection continued until 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 removed from the study for failing to comply were not included in analyses.

Two cohorts of two-year-old horses were enrolled in the study during the 2000/01 and 2001/02 racing seasons. Data were collected from the time of enrolment until either the end of the study or until the horse was lost to follow-up. A horse was considered lost to follow-up if it was not in training in the last month of the study (July 2002).

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. Information relating to speeds of the daily training and the type of training surface were collected using a questionnaire. The questionnaire was completed by the stable staff on a daily basis or at the time of the visit using stable records. No data were recorded when a horse was not in the stable.

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. The information 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 (i.e. injuries such as stone bruises were excluded).

6.2.2 Classification of study time

Horses 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. A preparation continued until the horse was lost to follow-up or left the stable for more than seven consecutive days. Those preparations that ended because the study ended or data collection at the stable was discontinued were defined as incomplete. The period between consecutive preparations was termed a spell-period or spell. If the spell did not end in a preparation, then it was termed incomplete.

Each training day was categorised based on the highest recorded exercise intensity on that day. The categories were, in increasing order of intensity:

- Rest- a training day in which the horse's only activity was a walk and/or swim or the horse was box rested.
- Slow-speed- a training day in which the horse's maximum speed did not exceed 800 m/minute
- Gallop- a training day in which the horse's maximum gallop speed was between 800 and 890 m/minute ("evens" or "3/4 pace") or ≥ 890 m/minute ("home on the bit") and the horse did not start in a race or barrier trial, and
- Start- Training day in which the horse started in a race or barrier trial.

6.2.3 Calculation of exposure to high speed exercise

HS exercise was defined as a gallop during training or a start in a race or barrier trial. Exposure to HS exercise during a preparation was quantified by summing the total distance galloped at HS. These values were determined for the whole preparation and the last and second-to-last weeks of the preparation. If there was more than one training day in the last or second-to-last week with missing training data, then the total distance galloped and percentage at fast speed were coded as missing values.

Exposure to HS exercise was also quantified by a categorical variable coding for the fastest gallop speed during the preparation. The categories were: 800 to 890 m/minute (i.e. "evens" or "3/4 pace); greater than or equal to 890 m/minute (i.e. "home on the bit") and race pace (gallop during a race or barrier trial). Binary variables were created to code for the presence or absence of a start in a race or barrier trial during the whole preparation and in the last and second to last week of the preparation. Other variables used to describe exposure to HS were the cumulative sum of days from:

- The start of the preparation until the first HS exercise day (slow speed interval) and
- The first HS exercise day until the end of the preparation (HS gallop interval).

In some preparations the duration of the slow speed interval was zero because the horse was exposed to HS exercise on the first day of the preparation.

6.2.4 Selection of cases and controls

The first preparation for each horse to include exposure to HS exercise was selected for analysis. Therefore, there was only one preparation per horse. Preparations were excluded from analysis if:

- The horse had trained at HS, as defined above, prior to enrolment in the study;
- The first training day involved a start in either an official barrier trial or race;
- The preparation was less than 14 days in duration;
- The preparation was classified as incomplete;
- More than 10% of the days in the preparation had missing training data, or
- The preparation ended because of a MS injury at an anatomical location other than the lower forelimb.

A case was defined as a preparation that ended with a MS injury involving the lower forelimb (fetlock joint to carpus inclusive) that was associated with training and not the result of accidental injury. If a horse sustained an injury but did not leave the stable, or left the stable for less than seven days, then the injury was not considered to have ended the preparation and was not classed as a case.

Controls were defined as all preparations that did not end with a MS injury as defined by the case definition.

6.2.5 Statistical analysis

MS injury data were categorised based on anatomical location as an injury involving the forelimb fetlock joint, carpal joint, third metacarpal bone or soft tissue. For each injury category, the cumulative incidence was calculated using total number of eligible horse preparations as the denominator (each horse only contributed one preparation to the analysis).

Nominal data were presented as counts or percentages (Table 6.1). All continuous variables were non-normally distributed and were summarized by minimum, maximum, median and percentiles (Table 6.2).

For each preparation, a binary outcome variable was generated to code for the presence or absence of MS injury at the end of the preparation. Separate, unmatched, logistic regression procedures were used to determine the association between MS injury status and each explanatory variable in each data set. Explanatory variables associated with the outcome at $P<0.30$ were included in a multivariable logistic regression model. A preliminary main effects model was built using a forward stepwise procedure in which variables were retained if P was less than 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. The linearity of the logit was assessed for all continuous variables by plotting regression coefficients against the mid-points of the quartiles (Hosmer and Lemeshow 2000, pp 97-8). A variable with evidence of a non-linear relationship were entered into the model as a categorical variable with two or more levels. All biologically plausible two-way interactions were considered for inclusion in the model. The base model was then extended to include a fixed effect coding for trainer identity. The significance of the interaction terms and the trainer identify were assessed by calculating the deviance test statistic. All variables from the base model were retained in the final model even if $P>0.05$ after the inclusion of the variable coding for trainer. The fit of the model with the fixed effect for trainer was assessed through the estimation of the Hosmer-Lemeshow goodness of fit statistic (Hosmer and Lemeshow 2000, pp 149-56). Model diagnostics involved evaluation of plots of the Pearson residuals, Hat matrix and Delta-Betas against predicted values (Allison 2001a pp 58-66, Dohoo *et al.* 2003, pp 357-67).

All analyses were completed using SAS (Version 8 for Windows).

6.3 Results

The complete data set contained 1,272 preparations and 451 horses. Whilst enrolled in the study 424 horses were exposed to HS exercise. Eight preparations were excluded because the horse trained at HS prior to enrolment in the study. A further 69 preparations were excluded because the preparation was incomplete (n = 1), horses started in a race or official barrier trial on the first day of the preparation (n = 2), the preparation was less than 14 days (n = 14), more than 10% of the training days had missing data (n = 42), or the preparation ended because of MS involving an anatomical location other than the lower forelimb (n = 10). Therefore, the final data set for the analysis consisted of 347 preparations.

Thirty-eight percent (n = 133) of the 347 preparations included in the analysis ended with a MS injury involving the front forelimb. The cumulative incidence of shin soreness, fetlock joint problems, carpal joint problems and soft tissue injuries was 23%, 7%, 6% and 3%, respectively.

The distribution of categorical and continuous variables is described in Table 6.1 and Table 6.2 respectively. Table 6.3 describes the univariable association between these variables and MS injury.

Table 6.4 describes the results of the multivariable logistic regression model to determine risk factors for lower forelimb MS injuries in horses. The odds of injury varied significantly between trainers with values ranging from 0.16 to 1.41. The odds of injury were highest in preparations where the maximum gallop speed was greater than ≥ 890 m/minute, the cumulative total of HS exercise was greater or equal to 8000 metres and a the horse had previously sustained a MS injury. The chi-squared test statistic of 6.4 with 8 degrees of freedom for the Hosmer-Lemeshow goodness-of fit test indicated that the model was a good fit for the data (P = 0.60). None of the observations had a chi-squared Pearson's residual with an absolute value greater than 3.

Table 6.1: Number and percentage of preparations in each category for categorical explanatory variables considered as risk factors for musculoskeletal injury (MSI) in the first preparation to included exposure to high-speed (HS) exercise. Data are derived from 347 preparations in two- and three-year-old Thoroughbred racehorses recorded during a 27-month longitudinal study.

Variable	Category	n	%
Age class	2-yr-old	338	97.4
	3-yr-old	9	2.6
Highest gallop speed	800 to 890 m/minute	160	46.1
	≥ 890 m/minute	106	30.5
	Race pace†	81	23.3
MSI previously	No	322	92.8
	Yes	25	7.2
Number of previous preparations	0	254	74.1
	≥ 1	93	25.9
Racing season enrolled	2000/01	257	74.1
	2001/02	90	25.9
Sex	Female	169	50.1
	Male	168	49.9
Start in the preparation	No	241	69.5
	Yes	106	30.5
Start in the last week of the preparation	No	282	77.8
	Yes	65	22.2
Start in 2nd last week of preparation	No	194	69.5
	Yes	35	30.5
Trainer	1	3	0.9
	2	8	2.3
	3	28	8.1
	4	35	10.1
	5	62	17.6
	6	10	3.2
	7	25	7.2
	8	9	2.6
	9	9	2.6
	10	30	8.6
	11	78	22.5
	12	17	4.9
	13	17	4.9
	14	16	4.6

† Gallop during a barrier trial or race.

Table 6.2: Number of preparations and minimum (min), maximum (max) and percentiles for continuous variables considered as risk factors for musculoskeletal injuries (MSI) in the first preparation to include exposure to high-speed (HS) exercise. Data are derived from 347 preparations recorded in two- and three-year-old Thoroughbred racehorse during a 27-month longitudinal study.

				Percentile			
Variable	Unit	n	min	25th	50th	75th	Max
Age at the start of the preparation†	month	329	19.9	23.44	25.7	28.66	44.62
Age at the start of the two-year-old racing season†	month	329	17.44	21.21	22.1	22.85	23.97
Age when enrolled in the study†	month	329	18.75	22.56	24.43	26.82	35.77
Average distance galloped at HS in the HS interval††	metre/day	347	16	160	208	258	640
Duration of the slow-speed interval†††	days	347	0	7	17	26	70
Duration of the HS interval	days	347	1	13	24	35	74
Duration of the preparation	days	347	14	32	47	67	175
Total distance galloped at HS during the preparation	metre	347	400	3000	5500	8300	34400
Total distance galloped at HS in the last week	metre	321	0	600	1200	1800	4700
Total distance galloped at HS in the second-to-last week	metre	340	0	600	1400	1800	4200

† Date of birth unknown for 18 horses.
†† Interval from the 1st exposure to HS exercise until the end of the preparation.
††† Interval from the start of the preparation to the first day the horse was exposed to HS exercise.

Table 6.3: Association between a number of independent variables and musculoskeletal injury (MSI) involving the lower forelimb in first training preparation where horses were exposed to high-speed (HS) exercise for 347 training preparations recorded in two- and three-year-old Thoroughbred racehorses during a 27 month longitudinal study, ordered according to level of statistical significance.

Variable	Category	Beta	Standard error (Beta)	Unadjusted odds ratio (OR)	95% CI (OR)	P-value
Trainer	1	REF				0.0003
	2	-0.13	1.15	0.5[a]	0.04-6.68	
	3	-0.53	0.77	0.33	0.05-2.18	
	4	-0.02	0.4	0.56	0.16-1.94	
	5	0.51	0.35	0.94	0.29-3.08	
	6	0.97	0.3	1.5	0.5-4.54	
	7	0.16	0.62	0.67	0.14-3.3	
	8	-0.38	0.44	0.39	0.11-1.45	
	9	-0.13	0.68	0.5	0.09-2.73	
	10	-0.13	0.68	0.5	0.09-2.73	
	11	0.43	0.38	0.88	0.26-2.95	
	12	-1.04	0.33	0.2	0.06-0.63	
	13	1.17	0.5	1.83	0.45-7.41	
	14	-1.45	0.72	0.13	0.02-0.78	
Highest gallop speed during the preparation	800 to 890 m/minute	REF				0.0006
	≥ 890 m/minute	0.43	0.16	3.34	1.78-6.26	
	Race pace[b]	0.34	0.17	3.04	1.56-5.94	
Duration of preparation (days)		0.01	0.004	1.01	1.01-1.02	0.0009
Duration of the HS interval (days)[c]		0.02	0.007	1.02	1.01-1.04	0.001
Previous MSI	No	REF				0.001
	Yes	1.54	0.46	4.67	1.9-11.52	
Total distance gallop at high speed during the preparation (per 200 meters)		0.01	0.01	1.01	1-1.02	0.01
Average distance trained at gallop-speed in the HS interval (200 meters/day)		0.59	0.24	1.8	1.13-2.88	0.01
Distance galloped in the 2nd to last week of the preparation (per 200 meters)		0.05	0.03	1.06	1-1.11	0.04
Duration of the slow speed interval (days)[d]		0.02	0.01	1.02	1-1.03	0.05

Variable	Category	Beta	Standard error (Beta)	Unadjusted odds ratio (OR)	95% CI (OR)	P-value
Cohort	2000/01	REF				0.07
	2001/02	-0.24	0.13	0.79	0.61-1.02	
Number of previous preparations	0	REF				0.1
	≥ 1	-0.05	0.03	0.95	0.9-1.01	
Difference in distance galloped between last and second to last week (meters)	< 0	REF				0.12
	0 to 199	0.25	0.25	0.99	0.5-1.96	
	200 to 400	-0.14	0.27	0.67	0.32-1.4	
	> 400	-0.37	0.2	0.53	0.31-0.92	
Start during the preparation	No	REF				0.27
	Yes	-0.03	0.03	0.97	0.91-1.03	
Age at the start of the preparation (months)		0.03	0.03	1.03	0.97-1.1	0.28
Sex	Female	REF				0.29
	Male	0.24	0.22	1.27	0.82-1.97	
Start in the last week of the preparation	No	REF				
	Yes	0.14	0.14	1.32	0.76-2.27	0.33
Age at the start of the 2-yr-old racing season (months)		-0.1	0.11	0.9	0.72-1.12	0.36
Distance galloped in the last week of the preparation (per 200 meters)		0.02	0.02	1.02	0.97-1.07	0.54
Age when enrolled in the study (months)		-0.01	0.04	0.99	0.93-1.06	0.79
Start in the 2nd to last week of the preparation	No	REF				0.94
	Yes	-0.01	0.18	0.97	0.47-2	

REF = Reference

[a] Without accounting for any other factors the odds of MSI was 0.5 times less in horses trained by trainer 2 than in horses trained by trainer 1.

[b]Gallop during a barrier trial or race.

[c]Interval from the 1st HS exercise day until the end of the preparation.

[d]Interval from the start of the preparation to the first day the horse galloped at HS.

Table 6.4: Risk factors conditionally associated with lower limb musculoskeletal injury (MSI) in the first preparation to include exposure to high speed (HS) exercise for 347 training preparations in two- and three-year-old Thoroughbred racehorses recorded during a 27 month longitudinal study.

Variable	Category	Beta coefficient	Standard error (Beat)	Adjusted odds ratio (OR)	95% CI (OR)	P
Highest gallop speed in the preparation	800-890 m/minute	REF				0.02
	>890 m/minute	0.54	0.19	2.19[a]	0.95-5.03	
	Race pace[b]	-0.3	0.28	0.94	0.32-2.78	
MS injury in previous preparation	No	REF				0.02
	Yes	1.24	0.53	3.45	1.23-9.67	
Total distance galloped at HS in the preparation (meters)	< 2999	REF				0.04
	3000 to 5999	-0.08	0.22	1.73	0.78-3.84	
	6000 to 7899	-0.1	0.27	1.69	0.63-4.54	
	≥ 8000	0.81	0.29	4.19	1.47-11.95	
Trainer	1	REF				0.005
	2	0.64	1.18	1.3	0.09-19.29	
	3	-0.71	0.78	0.34	0.05-2.26	
	4	0.12	0.42	0.77	0.2-2.9	
	5	0.34	0.38	0.96	0.28-3.33	
	6	0.78	0.31	1.49	0.45-4.89	
	7	0.39	0.65	1	0.18-5.5	
	8	-0.41	0.47	0.45	0.11-1.82	
	9	-0.17	0.69	0.58	0.1-3.32	
	10	-0.23	0.73	0.54	0.09-3.36	
	11	0.62	0.41	1.27	0.34-4.73	
	12	-1.05	0.34	0.24	0.07-0.79	
	13	0.73	0.57	1.41	0.3-6.58	
	14	-1.44	0.76	0.16	0.02-1.08	

REF = Reference

[a] After accounting for the other variables in the model, the odds of MSI in horses that had galloped at speeds greater than or equal to 890 m/minute (but not start in a race of barrier trial) was 2.19 times higher than horses whose fast gallop speed did not exceed 890 m/minute.

[b]Gallop during a barrier trial or race

6.4 Discussion

This chapter presents the results of a multivariable logistic model to determine risk factors for MS injury when Thoroughbred horses are first exposed to HS exercise. The analysis focused on the preparation in which a horse was first exposed to HS because the commencement of training at high speed has been suggested as a risk factor for MS injuries, in particular shin soreness (Buckingham and Jeffcott 1990). It was considered unlikely that preparations from horses previously exposed to HS exercise were included in the analysis for two reasons. Firstly, the majority of horses were enrolled in the study during their first training session. Secondly, commencement of HS exercise is an important milestone in training of a young racehorse and thus trainers could be reasonably expected to recall if the horse had been exposed to these speeds prior to enrolment.

Preparations were excluded when more than 10% of the training days had missing data. This was because the exposure to HS exercise would have been underestimated and the estimates of the duration of the slow and HS gallop intervals were more likely to be biased. Similarly, variables for the last and second-to-last week were also coded as missing if there was more than one training day in the week with missing data as the estimate of exposure to HS exercise were likely to have been underestimated. Exclusion of these preparations may have biased the results as analysis presented in Chapter 3 has shown that the missing values were clustered within study month and trainers.

Injury information during the course of the study was provided by the trainer and did not always involve a veterinarian. It was considered unlikely that the trainers would fail to identify a horse with an injury severe enough to require the horse being spelled because all trainers were experienced, professional, and regularly used the services of a veterinarian. Although, it possible that the trainer would not detect a mild injury, or detect the injury and continue training the horse, until such time as it was severe enough to impact on performance. Therefore, the severity of injury that resulted in a horse being spelled would vary between trainers.

Should a MS injury be detected it was considered unlikely that the injury would not have been reported as trainers were specifically questioned about the injury status of all horses that left the stable. Therefore, it is considered unlikely that there would have misclassification of the injury status of a preparation. Therefore, it is unlikely that a case was misclassified as a control or vice versa. However, as the necessarily diagnostic procedures were not always conducted, the type of MS injury may have been incorrect. For example, a ligament sprain may have been classified as a fetlock injury.

The outcome in this analysis was the presence or absence of MS injury affecting structures in the lower forelimb that resulted in the horse leaving the stable for a period of more than seven days. Therefore, the results of this analysis are not directly comparable to those for more severe MS injuries.

A logistic regression model was used because the outcome of interest was a binary variable, MS injury or no MS injury. A useful measure of association from a logistic regression model is the odds ratio (Hosmer and Lemeshow 2000, p 68). In a multivariable model, the odds ratio for a particular exposure represents the value after adjusting for the other variables in the model. If the outcome of interest affects less than 5% of the population then the odds ratio can be interpreted as an estimate of relative risk (Callas *et al.* 1998). In this analysis, 38% of the horses sustained a MS injury. The odds ratio is likely to be an overestimate of the relative risk. It is also important to note that the results may not be applicable to the population of horses in Australia as the trainers were not randomly sampled and a number of the selected trainers did not participate or were removed from the study for failing to comply.

When using a logistic model it was necessary to describe exposure at the level of the preparation. In an attempt to capture the dynamic nature of training, the training in the last and second to last week of the preparation were included as co-variates. The decision was made to use one week intervals rather than 30-or 60-day windows used in previous studies (Estberg *et al.* 1995, Estberg *et al.* 1996a, Estberg *et al.* 1997, Estberg *et al.* 1998a) because use of the 30- and 60-day window would have resulted in the exclusion of 76 and 230 preparations, respectively. A better approach may have been to use survival models with time-changing covariates (Singer and Willett 2003, pp544-55), thereby allowing the dynamic nature of training to be captured.

There was clustering of horses within trainers. In other words, there was the potential that horses trained by one trainer may be more similar than those trained by another. In logistic regression models, clustering may alter both the variance and the parameter estimates (McDermott *et al.* 1994). In this analysis clustering was accounted for by the inclusion of a fixed effect coding for trainer identity. The significance of the trainer effect suggests that factors related to trainer, and not included in the model, may be risk factors for MS injuries. These factors may relate to other aspects of the training regimen, such as the rate of increase in distance trained at speeds >800 m/minute. Management issues, including the level of veterinary and farrier involvement (Ross and Kaneene 1996b), may also be involved. The trainer effects may also reflect differences between trainers in data quality as both the rate of incorrect entries and missing data varied significantly between trainers.

In the present study, exposure to training was quantified using a number of variables that described training over the whole preparation and in the last 14 days of the preparation. In the model, the odds of MS injury increased as the total distance trained a high speed increased. This supports the hypothesis that training injuries are caused by the accumulation of micro damage incurred during high speed exercise (Lanyon 1990, Brunker *et al.* 1999, pp 6-9).

The results suggested that different gallop speeds may be associated with a different risk of MS injury. Horses that galloped at speeds greater than 890 m/minutes were at increased risk compared to those fast gallop speeds was between 800 and 890 m/minute. In contrast, horses that raced were at the same risk as horses that galloped at speeds between 800 and 890 m/minutes. These results may be explained by a “healthy horse” effect. Essentially, horses that start in a race or barrier trial have remained in training longer and went onto race because they did not sustain a MS injury. In other words, the reason a horse that galloped at ≥890 m/minutes did not start in a race or trial was because it sustained a MS injury. The results may also have been biased as research has indicated that subjective gait does not correlate well to actual recorded speed (Rogers and Firth 2004). Therefore, future studies may wish to collect training data that included actual speeds. Collection and analysis of such data may facilitate the design of training programs that allowed horses to be exposure to HS exercise in a safe way.

The results of the analysis showed that horses that had previously sustained a MS injury were at increased risk of injury. This is supported by research that found pre-existing subclinical or mild suspensory apparatus injury was a risk factor for all types of MS injuries and suspensory apparatus injury (Hill *et al.* 2001).

In this analysis the effect of age was investigated using age in months at the commencement of training, at the start of the two-year-old season or at the start of the preparation. Age class (two- or three-year-olds) was not considered as a covariate in the multivariable model as only nine preparations were recorded in the three-year-old racing season. When incorporated in the preliminary main effects model, none of the variables coding for age were significant association with the outcome variable (results not presented). This suggests that delaying the age, in months, at which a horse is first exposed to HS exercise does not alter the risk of a MS injury. The results are supported by Wilson *et al.* (1996) who found that two-year-olds with their first start early in the two-year-olds season were at no greater risk of MS injury than those horses with their first start at the end of the season (Wilson *et al.* 1996).

Sex was also not significantly associated with MS injury in the univariable screening and when included in the preliminary main effect model (results not present). This is supported by other studies investigating risk factors for suspensory apparatus injuries (Hill *et al.* 2001), racing injuries (Mohammed *et al.* 1991, Bailey *et al.* 1997a, Bailey *et al.* 1998) and pelvic and tibial stress fractures (Verheyen *et al.* 2003). However, compared to females males have been shown to be more likely to suffer a fatal injury (Carrier *et al.* 1998, Estberg *et al.* 1998b, Hernandez *et al.* 2001). The difference between the current study and those that found sex was a risk factor may reflect differences in outcomes. In the current study, the outcome was mild to moderate MS injuries whilst the other studies investigated risk factors for fatal fractures.

To conclude, this analysis focused on the first preparation to include exposure to HS exercise because commencement of training at high speed has been suggested as a risk factor for MS injuries, in particular shin soreness (Buckingham and Jeffcott 1990). The results suggested that changing the age at which horses were first exposed to HS exercise did not alter the risk of injury. The multivariable model demonstrated that exposure to HS exercise, in particular gallop speeds greater than 890 m/minute, was a risk factor for MS injury. The significance of the fixed effect for trainer in the model indicated that there are a number of factors relating to training and management of racehorses that may be risk factors for MS injuries. These may include aspects of the training regimen, such as the rate of increase in distance trained at speeds HS or management issues.

Chapter 7: Risk factors for first musculoskeletal injury in two- and three-year-old Thoroughbred racehorses

Abstract

AIM: To investigate risk factors for the incident MS injury in two- and three-year-old Thoroughbred racehorses.

METHODS: Data were collected during a 27 month longitudinal study and included 391 horses. A Cox regression model within a competing risk framework was used to investigate risk factors for shin soreness, injuries in the forelimb joint injuries and other forms of lameness. Explanatory variables considered of importance *a priori* were added to a Cox regression model. The explanatory variables included both time dependent training variables and non-time dependent covariates. Non-time dependent variables were sex, cohort and age at the time of enrolment. A shared frailty term coding for trainer was included account for potential clustering.

RESULTS: The hazard of both shin soreness and joint injuries was association with weekly distance trained at high-speed (HS). However, the magnitude did differ between the event types. There was no significant association between HS exercise and forms of lameness other than shin soreness and joint injures. For each of the injury types there was no significant association between hazard of injury and number of rest days, per week. Furthermore, the presence of a start in an official barrier trial or race, in the preceding week, did not significantly alter the hazard for any of the injury types. The hazard of shin soreness was 1.77 times higher in male horses than female horses. In contrast, there was trend towards the hazard of lameness being less in males than females ($P = 0.06$), while the hazard of joint injuries did not differ significantly between male and female horses ($P = 0.77$). Horses aged ≥ 24 months at the enrolment in the study were 46% less likely to sustain a joint injury than those < 24 months at the time of enrolment. There no association between age at the commencement of training and the hazard of either shin soreness or lameness.

CONCLUSION: The results showed that exposure to HS exercise increased the risk of both shins soreness and joint injuries. These results support a hypothesis that these injuries are the result support a hypothesis that theses injuries are due to failure of the bone to adapt to the accumulation of loading cycles over a short period of time.

7.1 Introduction

Musculoskeletal (MS) injuries have been identified as a common health problem in Thoroughbred racehorses (Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Perkins *et al.* 2004a, Perkins *et al.* 2004b). Analyses presented in this thesis showed that the horses that sustained a MS injury were 0.5 times less likely to start in a race or barrier trial, than a horse that did not sustain a MS injury (Chapter 4). Furthermore, the results presented in Chapter 6 showed that the odds of MS injury was 3.45 times higher for horses that had previously suffer a MS injury than in horses, than one that had not. Given, the substantial cost of injuries, every attempt should be made to understand the risk factors for the incident MS injury. A better understanding of these risk factors could contribute to the design of strategies that reduce the occurrence and/or impact of MS injuries.

Previous studies have identified exposure to high-speed (HS) exercise as a risk factor for fatal MS injury(Estberg *et al.* 1995, Estberg *et al.* 1996a, Estberg *et al.* 1997, Estberg *et al.* 1998a). There have been a small number of studies, in the UK and USA, 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). Due to differences in training and management the results are not directly applicable to Australian conditions. The results of previous studies, and those presented in Chapter 6, may also be limited as they do not describe the dynamic nature of training. For example, in Chapter 6 exposure to high-speed exercise was quantified by the cumulative sum of high-speed exercise during the preparation. An alternative approach may be to use a counting process form of the Cox regression model which would allow time-dependent covariates to be incorporated into statistical models (Singer and Willett 2003, pp 545-551). Thus, allowing the dynamic nature of training to be captured in statistical models.

The aim of this chapter was investigate risk factors for the first MS injury using the Cox regression model with time-dependent covariates. 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.

7.2 Materials and methods

7.2.1 Study design

This was a longitudinal study of the epidemiology of MS injuries in two- and three-year-old Thoroughbred racehorses. The design, implementation and management of the study were described in Chapter 3. Briefly, over a 27-month period daily training and injury records were collected at fortnightly intervals from 14 trainers located at one of five racetracks in New South Wales, Australia. The selected trainers were convenience sampled based on the location of stable, expected number of enrolled horses and willingness to participate in the study. Trainers enrolled all horses eligible to race as two-year-olds in the 2000/01 racing season. Nine of the trainers also enrolled all horses eligible to race as two-year-olds in the 2001/02 racing season.

Trainers were visited at fortnightly intervals to enrol eligible horses and to collect training and injury data for those horses present at the stable. Training information was collected using a standardised questionnaire. During the fortnightly visit, trainers were questioned about the injury status of all horses that had left the stable since the previous visit. The trainer provided injury information, and a veterinarian may or may not have been involved in the diagnosis. A problem involving the musculoskeletal system was only classified as an injury if it resulted in the horse leaving the stable for more than seven days and was the result of training.

Training and injury data were manually entered into a customized database (Microsoft Access, 2000). If no training data were recorded on the questionnaire then the data was classified as missing. 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 ™).

7.2.2 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 not in 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 from the stable, of more than seven days. The preparation continued until the horse was lost to follow-up or left the stable for more than seven consecutive days. The period between consecutive preparations was termed a "spell-period" or "spell".

The training days were categorised based on the highest intensity of training on that day. The activities were, in order of increasing intensity of exercise:

- Rest- a training day in which the horse's only activity was a walk and/or swim or the horse was box rested.
- Slow-speed- a training day in which the horse's maximum speed did not exceed 800 m/minute
- Gallop- a training day in which the horse's maximum gallop speed was between 800 and 890 m/minute ("evens" or "3/4 pace") or ≥ 890 m/minute ("home on the bit") and the horse did not start in a race or barrier trial, and
- Start- Training day in which the horse started in a race or barrier trial.

7.2.3 Calculation of exposure to training related variable

Variables were created that quantified the horse's exposure weekly exposure to HS exercise, rest days and starts in races and barrier trials. HS exercise was defined as a gallop or a start in a race or barrier trial. For each day in the preparation, exposure to high-speed exercise was quantified by summing the total distance galloped at HS in the previous seven days. The weekly distance trained at high speed was then categorized as 0, 1 to 999 metres, 1000 to 1999 metres or ≥ 2000 metres. Similarly, exposure to rest days was quantified by summing the total number of rest days in the same seven day window and the variable categorized as: 0, 1 or > 1. The third training related variable was a binary variable that was coded one if the horse had a started in a race or barrier trial in previous week, and zero if it did not. The training variables were coded as missing if there was more than one training day in the last seven day window that had missing data or if the cumulative sum of training days in the current preparation was less than 14. The value for each of the variables was then lagged by seven days. To illustrate, consider an individual horse on day 21 of a training preparation. The calculated value for weekly exposure to HS exercise would be estimated by summing the daily distances trained at HS from day *7* to day 14. The same approach was taken for estimation of weekly number of rest days and exposure to race or trial starts.

7.2.4 Statistical analysis

Survival analysis methods were used to investigate risk factors for MS injuries. For horses that sustained a MS injury, the time to event was the period of time from enrolment until the onset of the first or incident MS injury. All data collected after the first MS injury were excluded from the analysis. Horses that did not sustain a MS injury contributed data from enrolment until they were lost to follow-up or until the end of the study.

An event was defined as the first occurrence, for an individual horse, of a MS injury that resulted in the horse leaving the stable for more than seven days. MS injures were classified as shin soreness, joint injury and lameness. Shin soreness was defined as a MS injury that was localised to the dorsal surface of the third metacarpal bone. A joint injuries was defined as an MS injuries that involved swelling and/or heat in either the carpal joint or fetlock joints. The category lameness included all MS injuries that did not meet the case definition for either shin soreness or fetlock injuries.

The data set was arranged in counting process method, that is each horse was represented by a “set” of observations. In this analysis, each day was treated as a single observation. Each row of data, or day, contained variables coding for the start and stop date for the interval, status at the end of the interval, horse’s identity, and explanatory variables. When a horse was not in the stable it was considered not at risk of MS injury. Thus spell periods were identified in the data set as gap periods and excluded from the analysis. Observations with missing values caused discontinuous intervals in the risk period and were excluded from the analysis. An example of the data set is shown in Figure 7.1.

A competing risk framework was used to determine risk factors for each of the event types described above (Singer and Willett 2003, Pp 588-595). In this framework, all injuries are competing to end a horse’s preparation, therefore horses that suffer one type of injury are no longer at risk of another type of MS injury. For example, a horse that suffers from shin soreness is removed from the risk sets for joint injuries and lameness.

Conceptually, the occurrence of an event acts as a form of censoring. Therefore, the data can be analysed by the inclusion of a censoring variable for each event type as shown in Figure 7.1.

Explanatory variables consider of importance *a priori* were added to a Cox regression model. The explanatory variables included both time dependent and non-time dependent covariates. The time-dependent variables were training-related variables described above. Non-time dependent variables were sex, cohort (i.e. racing season the horse was enrolled) and a categorical variable coding for age at the time of enrolment (<24 months, ≥ 24 months). The age at enrolment was calculated by subtracting the date of birth from the date the horse was enrolled in the study. A shared frailty term coding for trainer was included in the model to account for potential clustering of horses under the care of the same trainer (Dohoo *et al.* 2003, p 453).

The proportional hazard assumptions were tested for each of the non-time dependent variables by application of a statistical test using generalised linear regression to test for a non-zero slop of the scaled Schoenfeld residuals against time (Dohoo *et al.* 2003, p 436). The proportional hazard assumption was not tested for time-dependent variables as the value for each of the variables changes with time thereby violating the proportion hazards assumption (Allison 2001b, p 154).

All analyses were performed using R for Windows (version 2.0). Tied events were handled using an Efron approximation (Allison 2001b, p 127).

Horse Id	Start	Stop	MSI	Shin	Joint	Other	Age	Sex	High
84	13	14	0	0	0	0	23	Female	0
84	14	15	0	0	0	0	23	Female	200
84	15	16	0	0	0	0	23	Female	200
84	16	17	0	0	0	0	23	Female	400
84	117	118	0	0	0	0	23	Female	0
84	118	119	1	1	0	0	23	Female	400
85	13	14	0	0	0	0	25	Male	0
85	15	16	0	0	0	0	25	Male	200
85	16	17	0	0	0	0	25	Male	200
85	18	19	0	0	0	0	25	Male	400
85	20	21	0	0	0	0	25	Male	400
85	79	80	0	0	0	0	25	Male	1000
85	80	81	1	0	1	0	25	Male	1000

MSI = Censoring variable for all musculoskeletal injuries
Shin = Censoring variable for injuries classified as shin soreness
Joint = Censoring variable for injuries classified as joint injuries
Other = Censoring variable for all injuries classified as other
Age = Age in months at enrolment
Sex = Male or female
High = Weekly distance trained at High-speed, lagged by seven days.

Figure 7.1: Example of a counting process data set for horse 84 that suffered an episode of shin soreness and horse 85 that sustained a joint injury. The start and stop times for the first observation for both horses were 13 and 14, respectively, because all the training variables for days less than 14 days were coded as missing. Horse 84 was enrolled for 119 days and was spelled from day 17 to 103. The second horse was enrolled for 81 days and was spelled from day 19 to 64.

7.3 Results

The complete data set contained data from 451 horses trained by 14 trainers. Data from 53 horses was excluded because the horses sustained a MS injury prior to enrolment (n = 13) or the duration of follow-up was less than 14 days or the duration of each of their training preparations was <14 days (n = 40). The remaining data set comprised of 398 horses trained by 14 trainers of which 192 horses sustained a MS injury; 101, 62 and 29, respectively, suffered from shin soreness, joint injuries and lameness.

Table 7.1 describes the results when the event of interest was defined as any MS injury and horses lost to follow-up were treated as censored. In this model, there was a significant association between exposure to high-speed exercise and hazard of injury (P<0.0001). In addition, the hazard of injury in horses that commenced training at ≥ 24 months of age was less than in those that commenced training at < 24 months (HR = 0.68, 95% CI = 0.50-0.92; P = 0.01). The hazard ratios for each event type are shown in Table 7.2.

Table 7.1: Multivariable counting process form of a Cox regression model for the number of training days until the first occurrence of musculoskeletal (MS) injury with hazard ratios (HR), 95% confidence intervals (CI) for the HR and P-value.

Variable	Category	HR	95% CI	P
Weekly distance trained at HS[a] (m)	0	REF		<0.0001
	1 to 999	3	1.85-4.88	
	1000 to 1999	3.77	2.41-5.89	
	≥ 2000	4.9	2.93-8.2	
Weekly number of rest days	0	REF		0.05
	1	1.21	0.52-2.82	
	>1	1.77	0.74-4.24	
Start in a race or barrier trial in the previous week	No	REF		0.7
	Yes	1.02	0.66-1.58	
Racing season enrolled	2000/01	REF		0.24
	2001/02	0.89	0.73-1.09	
Sex	Female	REF		0.49
	Male	1.15	0.85-1.56	
Age at the time of enrolment	<24 month	REF		0.01
	≥24 month	0.68	0.5-0.92	
Trainer				<0.0001

[a]High-speed

Table 7.2: Multivariable counting process form of a competing risk Cox regression model for the number of training days until the first occurrence of musculoskeletal (MS) injury with hazard ratios (HR), 95% confidence intervals (CI) for the HR and P-values for each event type.

		Shin soreness			Joint injuries			Lameness [a]		
Variable	Category	HR	95% CI	P-value	HR	95% CI	P-value	HR	95% CI	P-value
Weekly distance trained at HS[b] (m)	0	REF		<0.0001	REF		0.0036	REF		0.12
	1 to 999	4.06	1.82-9.02		2.21	1.05-4.64		3.35	1.02-10.94	
	1000 to 1999	7.11	3.42-14.78		1.94	0.94-3.99		2.15	0.67-6.88	
	≥ 2000	6.92	3.02-15.84		4.13	1.86-9.18		3.17	0.9-11.15	
Weekly number of rest days	0	REF		0.12	REF		0.37	REF		0.88
	1	0.93	0.29-3.03		2.82	0.37-21.28		0.42	0.09-2.01	
	>1	1.9	0.58-6.2		2.47	0.31-19.54		0.42	0.08-2.27	
Start in a race or barrier trial in the previous week	No	REF		0.75	REF		0.87	REF		0.74
	Yes	0.93	0.51-1.67		1.14	0.49-2.69		1.17	0.4-3.41	
Racing season enrolled	2000/01	REF		0.37	REF		0.57	REF		0.37
	2000/01	0.89	0.68-1.16		0.93	0.66-1.3		0.83	0.48-1.44	
Sex	Female	REF		0.01	REF		0.77	REF		0.06
	Male	1.77	1.19-2.64		0.96	0.57-1.63		0.44	0.19-1.03	
Age at the time of enrolment	<24 month	REF		0.31	REF		0.03	REF		0.43
	≥ 24 month	0.8	0.52-1.23		0.54	0.31-0.92		0.72	0.32-1.59	
Trainer				0.27			<0.0001			0.0004

[a] Lameness other than shin soreness and joint injuries
[b] High speed

7.4 Discussion

This chapter focused on understanding the risk factors for the first MS injury that resulted in the horse leaving the stable for a period of more than seven days. It was considered important to focus on the first injury because the first injury may be 'clinically' mild, it is associated with substantial economic cost. Thus every attempt should be made to understand the risk factors for the incident MS injury. An alternative approach may have been to consider the first occurrence of each type of MS injury, separately, and include a time changing covariate for previous injury (of another type). This approach has merit and may be considered in subsequent analyses. However, the author felt it was also important to better understand the risk factors associated with the incident MS injury.

Survival methods were considered an appropriate method for a number of reasons. Firstly, the incident MS injury was a well defined event as the horses were typically enrolled in the study when they first started training and injury records were available for those that had previously been in training. Therefore, horses that had previously sustained an injury could be excluded from the analysis. Secondly, the commencement of training was a clearly identifiable 'beginning time' that was consistent across horses. Thirdly, the number of days since the commencement of training was a meaningful metric for measuring time.

The results described in this chapter may not be representative of the Australian two- and three-year-old Thoroughbred population because trainers were sampled using non-random methods and a number of the selected trainers did not participate or were removed from the study for failing to comply. Random sampling from all metropolitan and provincial trainers may have resulted in a more representative sample. However, it was considered to be impractical and likely to have resulted in low response rates and logistical difficulties with data collection.

The injuries were diagnosed by a trainer and a veterinarian may or may not have been involved. It was considered unlikely that the trainers would fail to identify a horse with an injury severe enough to require the horse being spelled because all trainers were experienced, professional, and regularly used the services of a veterinarian. Although, it is possible that a trainer may decided to continue training for a period of time after the injury was identified and as such the severity of injury that resulted in a horse being spelled would vary between trainers. Should an injury have been identified it was considered unlikely that the injury would not have been reported as trainers were specifically questioned about the injury status of all horses that left the stable. However, as diagnostic procedures were not always conducted, the type of MS injury may have been incorrect. For example in the analysis presented in this chapter a ligament sprain is classified as lameness but if the diagnostic procedures were not conducted it could be incorrectly classified as a joint injury.

A competing risk approach was applied in this analysis because there are many different types of MS injuries that can occur when a horse is in training and racing. When using this framework MS injuries are “competing” to end the horses’ training preparation (Singer and Willett 2003, pp 586-95) and the onset of one injury meant that the horse was no longer at risk of other MS injuries (Allison 2001b, pp 185-210). In interpreting the survivor functions, there is an assumption that the occurrence of one event should be, after adjusting for all the predictors in model, be non-informative of all other events (Singer and Willett 2003, pp 590-1). This assumption influenced the categorisation of event types in preparation for this analysis. Shin soreness is a common and well defined condition that was considered non-informative of other types of MS injuries. Injuries involving the fetlock and carpal joint were aggregated into one category because it was thought that horses that experience a carpal joint problem may be more likely to experience a fetlock joint injury. The event category “lameness” was created because of the low numbers of animals in the remaining injury categories and because one type of lameness may have an influence on the risk of another type of injury, thereby violating the non-informative assumption. However, it is possible that the assumption of non-informative censoring was violated and this could have resulted in bias estimates of risk (Allison 2001b, 13-14). Unfortunately, the magnitude and direction of the bias caused by informative censoring is difficult to determine and there are no statistical tests suitable for assessment of this form of potential bias.

The results did not include graphical displays of survivor and cumulative hazard functions as the models contained time-varying explanatory variables. The inclusion of such terms makes generation and interpretation of these graphical displays difficult.

Therefore it is recommended that results be restricted to numerical summaries (Singer and Willett 2003, p 551).

In this chapter the multivariable model was not "built". Rather explanatory variables were determined *a priori* and remained in the final model even if P>0.05. This approach was taken because Singer and Willet (2003, p 592) advised against the development of different models for each event type. Rather, the explanatory variables should be the same in each model. The advantage of fitting the same explanatory variables to the each event type is that it allows more meaningful comparison of risk factors across event types. However, this approach may have resulted in confounders being excluded from the analysis. Model diagnostics were not performed as the use of a counting process form and inclusion of a frailty term made interpretation of model diagnostics difficult. In the absences of model diagnostics, it is suggested that the results be interpreted with caution.

Each of the models included a shared frailty term coding for trainer to account for correlations between horses trained by the same trainer (Dohoo *et al.* 2003, p 453). Despite multiple observations per horse, there was no clustering at the horse level as an individual horse only contributed one observation to a particular day in the data set and because each horse was only eligible to contribute one event – the incident injury (Therneau and Grambsch 2001, pp 145-7)). If the models were extended in the future to allow horses to contribute multiple events to the data set, then it may be necessary to account for clustering at the level of the horse, for example through the incorporation of frailty terms.

Exposure to training was quantified by determining the cumulative sum of various activities in a seven day window. The size of this window differs from previous studies that have used both 30- (Verheyen *et al.* 2003) and 60-day (Estberg *et al.* 1995, Estberg *et al.* 1996a, Estberg *et al.* 1997, Estberg *et al.* 1998a) exposure windows. The smaller windows were used in this study for two reasons. Firstly, the injuries considered in this analysis were low grade injuries and it was hypothesised that exposure to high speed exercise over shorter time intervals was an important risk factor. Secondly, use of larger windows, in particular the 60-day window, would have resulted in the exclusion of large amounts of data as more than 50% of preparations were less than 60 days in duration.

The training variables were lagged because their value may have been dependent on the injury status of the horse. For example, a horse with a MS injury may be rested in a box prior to removal from the stable for a number of reasons, such as the need for intensive medical treatment. The decision to lag training variables by seven days was arbitrary and it is important to note that for some injuries training may have been modified for more than seven days before the horse is removed from the stables. In other instances horses may have been removed from the stable as soon as the MS injury was detected and as such some relevant exposure information has been lost. Despite these issues, it is the author's opinion that the inclusion of the seven day lag strengthens the argument that the association between covariates and the outcome is causal.

Comparison of the three different models suggested that there were some commonalities in the pathogenesis of shin soreness, joint injuries and other forms of lameness. However, there was variation in the relationship between explanatory variables and each of the outcomes. The results relating to the category of lameness may have been biased towards the null by the small number of events (n = 29). The heterogeneous nature of the event category may also have biased the results, most probably towards the null (Hyams 1998, Viikari-Juntura and Riihimaki 1999). To illustrate, the risk factors for lameness originating in the shoulder could be very different to the risk factors for hind limb lameness. Due to the bias the interpretation and implications of the results for the category lameness will not be discussed further.

The results showed that, compared to female horses, male horses were at 1.77 times more risk of shin soreness. This increased risk could represent a true difference or be confounded by factors such as body size and shape or differences in training factors. For example, one trainer in the study reported cantering male horses "twice around the sand to keep the weight off them." In contrast, the risk of joint injuries did not differ between male and female horses.

Age at the time of enrolment in the study was identified as a risk factor for joint injuries but not for shin soreness. The results indicated that horses enrolled in the study at ≥ 24 months were 0.54 times less likely than horses that were enrolled at < 24 months to sustain a joint injury. Owing to the design of the study, enrolment corresponded to the commencement of training. Hence, these results suggest that the incidence of joint injuries may be reduced if horses do not commence training until they are two-years of age. However, further research is required as there has been some suggestion that training at a young age may aid in the bone development (Smith *et al.* 1999).

The hazard of forelimb joint injuries was significantly associated with weekly distance trained at high-speed. The results, showed that compared to horses that were not exposure to high-speed exercise, the hazard of joint injury was 4.13 times higher in horses that had accumulated ≥ 2000 meters of high-speed exercise in a seven day period. Therefore, limiting the exposure to high-speed exercise should reduce the incidence of joint injuries in two- and three-year-old Thoroughbred racehorses.

The hazard of shin soreness was also associated with the weekly distance trained at high-speed. Compared to horses that had not been exposed to high-speed the hazard of shin soreness was 4.06 (95% CI = 1.82-9.02), 7.11 (95% CI = 3.42-14.78) and 6.92 (95% CI = 3.02-15.84) times higher, respectively, in horses that had accumulated between 1 and 999 metres, between 1000 and 1999 metres and ≥ 2000 metres. The results of the current study and Verheyen *et al.* (2005) support a hypothesis that shin soreness is due to failure of the bone to adapt to the accumulation of loading cycles over a short period of time (i.e. one to four weeks).

It is worth noting that results of this study and Verheyen *et al.* (2005) contradict Boston and Nunamaker (2000) who reported a protective effect of exposure to speeds ≥ 900 m/minute. Verheyen *et al.* (2005) suggest the most likely reason for this is that Boston and Nunamaker 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. This is supported by results presented in their paper that showed 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 a moving window of one week, two-weeks and one month, the risk of dorsometcarpal disease increased as the distance trained at high-speed increase. Other possible reasons for the difference between the current study and Verheyen *et al.* (2005) and Boston and Nunamaker include methodological differences. In the current study and work reported by Verheyen *et al.* (2005), all the data was collected prospectively. In contrast, 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.

Thoroughbred racehorses are unlikely to compete successfully unless exposed to high-speed exercise. Therefore, future research should focus on identification of ways in which high-speed exercise can safely be introduced into a training period. For example are frequent short HS gallops safer than fewer longer gallops? The results of Verheyen *et al.* (2005) also indicated that distances trained at canter may be risk factors for MS injuries. Therefore studies should collect information relating to distances trained at slower speeds. Ideally, this information would be collected using less subjective measures than in the current study, as the results of studies in New Zealand have suggested that use of subjective gait as a true measure of speed may be problematic (Rogers and Firth 2004). Recent advances in microelectronics and GPS technology mean that similar systems could be implemented in other countries with relative ease. Finally, it is important that the studies are repeated in a number of countries because differences in “typical” training and management strategies make it difficult to extrapolate the results.

In conclusion, the results showed that exposure to high speed exercise increased the risk of both shins soreness and joint injuries. These results support a hypothesis that these injuries are the result of cumulative exposure to high-speed exercise that results in accelerated remodelling. Unfortunately, it is not possible to prepare Thoroughbred racehorses for racing without exposure to high-speed exercise. Therefore, future research should focus on developing strategies that could reduce the risk associated with exposure to high-speed exercise. Development of such strategies may reduce the incidence of shin soreness and joint injuries.

Chapter 8: General Discussion

8.1 Frequency and impact of MS injuries

The results of the study confirmed previous research that has shown that MS injuries in Thoroughbred racehorses are a common and recurrent problem (Rossdale 1989, Kobluk *et al.* 1990b, Lindner and Dingerkus 1993, Bailey *et al.* 1999, Perkins *et al.* 2004a, Perkins *et al.* 2004b). During the study period 428 MS injuries were recorded in association with 395 preparations in 248 Thoroughbred racehorses. The most common site of MS injury was the forelimb, in particular the lower forelimb, and the most common type of injury was shin soreness. This is consistent with the results of previous research by Mason and Bourke (1973), Bailey *et al.* (1999) and Perkins *et al.* (2004a) but differs from a UK study that reported sore shins as the sixth most common case of lameness behind muscular, feet, carpus, fetlocks and tendons (Rossdale 1989). The differences between the current study and Rossdale (1989) may be due to a number of factors, such as regional differences and differences in case definition and age structure in the study population.

The rate of MS injuries was highest in two-year-old Thoroughbred with two-year-olds 2.99 (95% CI = 1.87-4.79) times more likely than three-year-olds to sustain an MS injury. The IR for specific types of MS injury was 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 ($P = 0.06$). 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 a true effect, but could also be confounded by the effect of long term exposure to training, as older horses have generally been in training for longer periods of time than younger horses.

The IR did not vary between male and females, except for shin soreness. 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.

The impact of MS injuries was measured using two horse-level measures of performance: (i) time to first start and (ii) time to recovery (measured as started in a race or barrier trial). In addition to advancing understanding on the epidemiology of MS injuries, these measures provide information that would be useful in estimating the economic impact of MS injuries. To the authors knowledge such values have not been reported previously.

The cumulative proportion of horses that had started in a race or barrier trial in the 12 months following enrolment in the study was approximately 78%. Presence of a MS injury prior to the first start, was a significant predictor of length of time to first start. After adjusting for confounders, horses that sustained a MS injury were 0.5 times less likely to start in a race than those horses 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.

Seventy percent of the 248 horses that sustained a MS injury returned to training after their first MS injury, of which 45% had started in a trial or race six months after their initial injury. 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 be biased because those horses that sustained a MS injury at lower speed may differ from horses that raced in a number of factors, such as 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 that 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'.

8.2 Training preparations

An understanding of "normal" training patterns provides information that trainers and owners can use to benchmark the performance of their horses. The information is also of great value in understanding the associations between training and management and the risk of injury. The profiles described in this thesis may not be representative of the Australian two- and three-year-old Thoroughbred population because trainers were sampled using non-random methods and a number of the selected trainers did not participate, or were removed from the study for failing to comply.

The data set comprised 1,272 preparations recorded in 451 horses: 83, 113, 118, 90, 34 and 13 horses had one, two, three, four, five and six preparations respectively. Approximately 50% (48%) of preparations had not ended eight weeks after the commencement of the preparation. A New Zealand study, using the same definition of a preparation, reported that the median duration of preparations, in horses of all ages, was 104 days (Perkins *et al.* 2004b). Differences between the two studies could be due to a variety of factors, including regional differences and differences in age structure of the study population.

The cumulative percentage of preparations that had started in a race or barrier trial eight weeks after the commencement of the preparation was 45%. The period of time from the commencement of the preparation to the first start in a trial or race, reported in this study, is less than the 11 weeks reported in a survey of NSW trainers as the time required to get a horse racing fit (Bailey *et al.* 1997b). One possible reason for the difference is that in the current study some horses may have undergone training away from the stable prior to the start of the preparation. Thus the length of time to first start is not equivalent to the length of time required to prepare a horse for a race. The length of time to first start in a race or barrier trial, reported in this study, is also lower than New Zealand research that reported the mean number of days from beginning of the preparation to the first start in two- and three-year-olds was 70 and 68 days (Perkins *et al.* 2004b). Care needs to be taken when comparing the current study and Perkins et al. due to differences in analytical methods.

Overall, the rate of starts in races or barrier trials was 2.54/100 horse-training days, and in two- and three-year-olds the rate was 1.08/per 100 training days and 2.57/per 100 training days respectively. The rate of starts in two-year-olds is higher than that the rate of starts in two-year-olds reported by Perkins et al (1.22/ 100-training days, 95% CI = 0.68-1.22). This would seem to suggest that Australian two- year-olds are trained more intensely than New Zealand two-year-olds. However, the results should be interpreted with caution as they may be biased by a number of factors such as confounding and differences in study populations.

The MS injury status of the preparation was not found to be a risk conditionally associated with any of these measures of performance. This suggests injuries that occur early in a horse's career do not have a long term impact on performance. However, care needs to be taken when interpreting these results, as a "healthy horse" effect may have biased the findings. While, the "healthy horse" effect cannot be discredited it is worth noting that 70% of injured horses returned to training after their incident MS.

Age of the horse at the start of the preparation or age class was a risk factor for all the measures of performance. After adjusting for confounders, younger horses tended to have shorter preparations, took longer to start in a race or barrier trial, had a shorter interval from the first start to the end of the preparation and fewer starts per 100 training days. This suggests that two-year-olds are trained less intensely than three-year-olds.

In multivariable models, the number of previous preparations was significantly associated with all the outcome variables except for the length of time from the beginning of the preparation to the first start in a race or barrier trial. Specifically, a higher number of prior preparations was associated with a longer duration of the preparation, a longer interval from the first start in a race or barrier trial to the end of the preparation and a higher the rate of race starts. Thus, some of the age effects observed in the unconditional analyses may have been confounded by previous exposure to training, as older horses are more likely to have trained previously.

Sex was not a risk factor for any of the measures of performance, suggesting that male and female horses are trained in a similar manner. However, the results could be biased as the analysis did not differentiate between colts and geldings. Unfortunately, collecting information on the time that colts were gelded was difficult because it often occurred while the horse was spelling away from the stable.

8.3 Risk factors for MS injuries

Logistic and survival models were used to investigate risk factors for MS injuries. The results of both models may not be representative of the Australian two- and three-year-old Thoroughbred population as trainers were sampled using non-random methods and a number of the selected trainers did not participate or were removed from the study for failing to comply. Furthermore, the results presented in the analysis should not be extrapolated to horses older than three-years of age because the risk factors for horses with increased exposure to training may differ.

A logistic model was used to determine risk factors for MS injury when Thoroughbred horses are first exposed to high speed exercise. The analysis focused on the preparation in which a horse was first exposed to high-speed exercise because this has been suggested as a risk factor for MS injuries, in particular shin soreness (Buckingham and Jeffcott 1990). In this analysis 38% of the horses sustained a MS injury. Therefore the odds ratio may be an over estimation of the relative risk (Callas *et al.* 1998).

The survival model used a competing risk approach to identify risk factors for shin soreness, forelimb joint injuries and other forms of lameness. Survival methods were considered a appropriate for a number of reasons. Firstly, the first MS injury was well defined because the horses were typically enrolled in the study when they first started training, and injury records were available for those that had previously been in training. Therefore, horses that had previously sustained an injury could be excluded from the analysis. Secondly, the commencement of training was a clearly identifiable ‘beginning time’ that was consistent across horses. Thirdly, the number of days since the commencement of training was a meaningful metric for measuring time.

In both the survival and logistic model there was clustering of horses within trainers. In other words, there was the potential that horses trained by one trainer may be more similar than those trained by another. Clustering may alter both the variance and the parameter estimates (McDermott *et al.* 1994). In the logistic model, clustering was accounted for by the inclusion of a fixed effect coding for trainer identity. In the survival model clustering was accounted for by including a shared-frailty term coding for trainer identity. Inclusion of such a term is analogous to the inclusion of a random effect coding for trainer (Dohoo *et al.* 2003, p 453).

Despite aggregating data to the level of the preparation, neither of the analyses presented in chapters 6 and 7 of this thesis had clustering at the level of the horse. In Chapter 6 only one preparation was selected per horse, thus there was only one observation per horse. While there were multiple observations per horses in the survival analysis presented in Chapter 7, this did not result in clustering at the level of the horse because an individual horse only contributed one observation to a particular day in the data set and only incident injuries were considered (Therneau and Grambsch 2001, p 145-7). If the survival model were extended in the future to allow horses to contribute multiple events to the data set, then it may be necessary to account for clustering at the level of the horse.

8.3.1 Exposure to high-speed exercise at ≥800 /minute

In the first fast preparation, the odds of MS injury involving structures in the lower forelimb increased as the total distance trained at high speed increased. The results presented in Chapter 6 also showed that the risk of MS injury varied depending on the maximum gallop speed in the preparation. This suggested that the risk associated with cumulative exercise at speeds between 800 and 890 m/minute, ≥890 m/minute and starts may differ. This was not explored further in this thesis.

The hazard of forelimb joint injuries was significantly associated with cumulative distance trained at high-speed. The results showed that compared to horses that were not exposure to high-speed exercise, the hazard of joint injury was 4.13 times higher in horses that had accumulated ≥ 2000 meters of high-speed exercise in a seven day period. Therefore, limiting the exposure to high-speed exercise should reduce the incidence of joint injuries in two- and three-year-old Thoroughbred racehorses.

The hazard of shin soreness was also associated with the weekly distance trained at high-speed. Compared to horses that had not been exposed to high-speed the hazard of shin soreness was 4.06 (95% CI = 1.82-9.02), 7.11 (95% CI = 3.42-14.78) and 6.92

(95% CI = 3.02-15.84) times higher, respectively, in horses with a weekly distance trained at HS between 1 and 999 metres, between 1000 and 1999 metres and ≥ 2000 metres. This is supported by Verheyen et al. (2005) who found that that the hazard of shin soreness increased 1.17 (95% CI: 1.09-1.25) times, with each furlong increase, in the weekly distance galloped at HS. The results of the current study and Verheyen et al. (2005) support a hypothesis that shin soreness is due to excessive exposure to HS speed exercise over a short period of one to four weeks. The excessive bone loading causes accelerated bone remodelling.

8.3.2 Previous MS injury

In the survival analysis, the event of interest was the first or incident MS injury of a particular type. Therefore the impact of previous MS injury was not investigated in these analyses. The results of logistic regression showed that horses that had previously sustained a MS injury were at increased risk of injury. This finding supports a previous finding that pre-existing subclinical or mild suspensory apparatus injury were a risk factor for all types of MS injuries and suspensory apparatus injury (Hill *et al.* 2001).

8.3.3 Age

There were conflicting results regarding the association between age and risk of injury. In the multivariable logistic analysis of risk factors for MS injury involving the forelimb in the first training preparation to include exposure to high-speed exercise, the effect of age was investigated using age, in months, at the commencement of training, at either the start of the two-year-old season or at the start of the preparation. In the multivariable logistic model, there was no significant association between age and the outcome variable. This suggests that delaying the age, in months, at which a horse was first exposed to HS exercise did not alter the risk of a MS injury. The results were consistent with those reported by Wilson *et al.* (1996) who found that two-year-olds with their first start early in the two-year-olds season were at no greater risk of MS injury than those horses with their first start at the end of the season.

In the competing risk survival model, age at the time of enrolment in the study was identified as a risk factor for joint injuries but not for shin soreness. The results indicated that horses enrolled in the study at ≥ 24 months were 0.54 times less likely than horses that were enrolled at < 24 months to sustain a joint injury. Owing to the design of the study enrolment corresponded to the commencement of training. Hence these results suggest that the incidence of joint injuries may be reduced if horses do not commence training until they are ≥ 24 months.

8.3.4 Sex

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 males and females were also reported in the survival model with males at 1.77 times more risk of shin soreness than females. This may represent a true biological difference. Alternatively, the results could be biased by confounders such as body size and shape or differences in training not included in this model. For example, one trainer in the study reported cantering male horses “twice around the sand to keep the weight off them.” The risk of fetlock joint and carpal joint problems did not differ between male and female horses.

8.4 Future research

The results of the current study and those of Bailey (1999) and Mason and Bourke (1973) have contributed to our understanding of the frequency and impact of MS injuries in Australian two- and three-year-old Thoroughbred racehorses. However, there is a distinct lack of information regarding the epidemiology of MS injuries in older horses. Results from Perkins *et al.* (2004 a,b) indicated that the type of MS injuries and impact of these injuries on training varies between age groups. It is the authors’ opinion that funding agencies in Australia should prioritise research that will describe the frequency and impact of MS injuries in horses more than three years old. A better understanding of the frequency and impact of MS injuries across all age groups will allow resources to be targeted to those injuries that result in the greatest cost to the industry.

In Australia epidemiological investigation of training-related risk factors for injuries is hampered by an inability to collect an individual horses’ daily training in an accurate and cost effective manner. In the current study, despite fortnightly visits and use of a standardised form, 8% of training days had missing training data and 3% of the 1,986 starts in the races or barrier trials were incorrectly recorded. Future studies would be advanced if the Thoroughbred racing industry centrally recorded daily training. Daily training is currently recorded by the Hong Kong Jockey club and recent advances in microelectronics and GPS technology mean that such systems could be implemented in other locations with relative ease.

The results of this and other studies have found that exposure to HS exercise is a risk of injury. However, it is not practical to train horses without exposing them to HS exercise as they are unlikely to compete successfully. Therefore, research needs should focus on developing strategies to lower the risk of MS injury when horses are exposed to high-speed exercise. For example, research could investigate the relationship between high-speed exercise, distance trained at canter and MS injury as studies have shown that distance trained at a canter, in association with HS exercise, may be a risk factor for shin soreness (Verheyen *et al.* 2005) and pelvic and tibial stress factures (Verheyen *et al.* 2003). Other research questions that could be considered include:

- Are frequent short HS gallops lower in risk than fewer longer HS gallops?
- Is the risk of MS injury reduced if horses legs are iced after HS gallops? and
- What is the relationship between rate that distance trained at HS increases and risk of MS injury?

Future studies should also investigate the relationship between track factors, training factors and risk of MS injury. The first step would be to develop appropriate techniques for monitoring the physical characteristics of training tracks. These techniques could be developed by monitoring surface hardness and moisture content at multiple locations on training tracks both at the beginning and end of track for an extended period of time (e.g. three months). It would also be advisable to collect data on number of horses that used the track each morning, daily rain fall and temperature as these may influence surface hardness and moisture content.

Finally, it is import that researchers and funding agencies appreciate that the only way that findings of these and other studies will reduce the risk of MS injury is if the recommendations are adopted by industry. It is the authors' opinion that to date industry adoption of research findings has been poor. One possible reason for this is that impact of recommendations on cost and/or racing performance has not been presented to industry stakeholders. However, there are likely to be many other reasons. Therefore, funding bodies, and researchers, should endeavour to understand the barriers to the adoption of research.

8.5 Conclusion

The results of this study support previous research that found MS injuries are both a common and recurrent problem in Thoroughbred racehorses. The results presented in Chapter 4 showed that horses that sustain a MS injury are 0.5 times less likely to start in a race or barrier trial, than those that do not sustain a MS injury. The analysis of training preparations suggested it would appear that MS injuries have limited impact on long term performance, although care must be taken in interpreting the results as they could be biased by a "healthy horse" effect. The analysis of training preparations also found that: younger horses tended to have shorter preparations, took longer to start in a race or barrier trial, had a shorter interval from the first start to the end of the preparation and fewer starts per 100 training days. This suggests that two-year-old horses are trained less intensely than three-year-old horses. The number of previous preparations was also significantly associated with all the outcome variables except for the length of time from the beginning of the preparation to the first start in a race or barrier trials. Thus, some of the age effects observed in the unconditional analyses may have been confounded by previous exposure to training, as older horses are more likely to have trained previously.

When investigating risk factors for MS injury the results of the current study the results HS exercise was a consistently associated with an increased risk of injury. However, it is not practical to train horses without exposing them to HS exercise as they are unlikely to compete successfully. Thus, researchers should focus on developing strategies to lower the risk of MS injury when horses are exposed to high-speed exercise. Finally, it is import for researchers, and funding agencies, to remember that injuries will only be reduced if the recommendations are adopted by the industry. Therefore, funding bodies, and researchers, should endeavour to understand the barriers to the adoption of research and use this information to develop extension programs.

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Appendix

A.1: Number and percentage of horses lost to follow-up[a] for 323 Thoroughbred two-year-olds enrolled in a longitudinal study during the 2000/01 racing season, by trainer, musculoskeletal injury (MSI) status on the horse's last recorded training day and reason for loss to follow up.

Trainer	MSI status	Reason lost to follow-up					Total number of horses lost to follow-up	% of horses
		Trainer lost to follow-up	Horse changed trainer	Death	Unknown			
					Last training day < 6 months before the end of the study	Last training day ≥ 6 months before the end of the study		
1	None	0	7	0	4	4	15	83
	MSI	0	3	0	2	2	7	39
2	None	4	0	0	0	0	4	100
	MSI	1	0	0	0	0	1	25
3	None	8	0	0	0	0	8	100
	MSI	2	0	0	0	0	2	25
4	None	29	3	0	0	0	32	100
	MSI	3	0	0	0	0	3	9
5	None	0	13	0	18	4	35	85
	MSI	0	3	0	4	2	9	22
6	None	0	15	1	10	21	47	78
	MSI	0	6	0	5	12	23	38
7	None	0	1	0	3	0	4	57
	MSI	0	0	0	0	0	0	0
8	None	0	1	0	6	6	13	68
	MSI	0	1	0	0	0	1	5

Trainer	MSI status	Reason lost to follow-up					Total number of horses lost to follow-up	% of horses
		Trainer lost to follow-up	Horse changed trainer	Death	Unknown			
					Last training day < 6 months before the end of the study	Last training day ≥ 6 months before the end of the study		
9	None	0	5	0	4	2	11	92
	MSI	0	1	0	0	0	1	8
10	None	0	4	0	3	0	7	64
	MSI	0	0	0	2	0	2	18
11	None	0	8	0	6	5	19	79
	MSI	0	5	0	3	5	13	54
12	None	0	5	0	24	16	45	65
	MSI	0	2	0	7	6	15	22
13	None	1	3	0	3	1	8	89
	MSI	0	3	0	3	1	7	78
14	None	0	0	0	5	1	6	67
	MSI	0	0	0	1	1	2	22
Total	None	**42**	**65**	**1**	**86**	**60**	**254**	**79**
	MSI	**6**	**24**	**0**	**27**	**29**	**86**	**27**

[a] A horse was classified as lost to follow-up if it was not in the stable in the last month of the study (i.e. July 2003).

A.2: Number and percentage of horses lost to follow-up[a] for 128 Thoroughbred two-year-olds enrolled in a longitudinal study during the 2001/02 racing season, by trainer, musculoskeletal injury (MSI) status on the horse's last recorded training day and reason for loss to follow up.

Trainer	**Injury status when lost to follow-up**	**Reason lost to follow-up**			**Total number of horses lost to follow-up**	**% of horses**
		Horse changed trainer	**Unknown**			
			Last training day < 6 months before the end of the study	**Last training day ≥ 6 months before the end of the study**		
6	None	0	5	1	6	35
	MSI	0	2	0	2	12
7	None	1	5	0	6	67
	MSI	1	2	0	3	33
8	None	0	12	2	14	70
	MSI	0	4	1	5	25
9	None	0	3	0	3	33
	MSI	0	3	0	3	33
10	None	0	3	0	3	75
	MSI	0	1	0	1	25
11	None	0	4	1	5	38
	MSI	0	2	0	2	15
12	None	0	19	4	23	74
	MSI	0	7	0	7	23
13	None	0	4	0	4	36
	MSI	0	2	0	2	18
14	None	0	6	2	8	57
	MSI	0	1	1	2	14
Total	**None**	**1**	**61**	**10**	**72**	56
	MSI	**1**	**24**	**2**	**27**	21

[a] A horse was classified as lost to follow-up if it was not in the stable in the last month of the study (i.e. July 2003).

A.3: Number of horses and complete and incomplete preparations in a cohort of two-year-olds enrolled in a longitudinal study during the 2000/01 racing season, by trainer

Trainer	Horses	Preparations	
		Complete	Incomplete[a]
1	18	47	3
2	4	8	2
3	8	13	1
4	32	81	6
5	41	135	3
6	60	190	5
7	7	24	3
8	19	80	3
9	12	31	0
10	11	34	1
11	24	76	1
12	69	225	3
13	9	21	1
14	9	34	0
All	**323**	**999**	**32**

[a] A preparation was classified as incomplete if it ended because the study ended or the trainer was lost to follow-up.

A.4: Number of horses and complete and incomplete preparations in a cohort of two-year-olds enrolled in a longitudinal study during the 2001/02 racing season, by trainer

Trainer	Horses	Preparations	
		Complete	Incomplete[a]
6	17	34	0
7	9	16	1
8	20	36	1
9	9	14	0
10	4	8	0
11	13	26	0
12	31	50	2
13	11	26	1
14	14	26	0
All	**128**	**236**	**5**

[a] A preparation was classified as incomplete if it ended because the study ended or the trainer was lost to follow-up.