Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

EPIDEMIOLOGICAL STUDIES OF EARLY EXERCISE AND MEASURES OF TRAINING AND RACING PERFORMANCE IN THOROUGHBRED RACEHORSES

A thesis submitted in partial fulfilment
of the requirements for the degree of
Doctor of Philosophy
in
Veterinary Epidemiology

Massey University, Palmerston North,
New Zealand

CHARLOTTE FRANCES BOLWELL

2011

ABSTRACT

This thesis includes a series of epidemiological studies conducted to quantify the exercise regimens of Thoroughbred yearlings during their sales preparation and 2- and 3-year-old race training. Additionally, this thesis aims to establish if there are associations between the exercise regimens and training and racing performance at two years of age.

Cross-sectional and cohort studies quantified the components of the exercise regimens used during sales preparation on stud farms in New Zealand. Exercise was a common practice during sales preparation. The type and amount of exercise was often tailored to individual horses. Overall, exercise varied by gender, the month of preparation, and between farms indicating that the exposure to exercise during sales preparation was not the same for all horses.

Survival analysis identified different horse and exercise risk factors for voluntary, involuntary, and musculoskeletal interruptions during training. Specifically, there were strong associations between increased total hand walking time and reduced chance of voluntary interruptions, and more time walking on a mechanical walker increased the risk of involuntary interruptions. Other horse and training factors, such as trainer, gender, age at the start of training, and the distance accumulated at canter and high speed, were associated with the time to interruptions during training.

Interruptions before the first trial were associated with an increased time to the first trial or race and a decreased chance of starting in a trial. Accumulating shorter distances and fewer events at high speed were both associated with a decreased chance of a trial or race start. Longer distances accumulated at high speed were associated with a decreased time to the first trial. No associations were found between the exercise accumulated during sales preparation and the time to the first trial during training. Overall, the exercise accumulated during sales preparation was associated with a measure of training performance, whilst the timing of interruptions and the accumulation of exercise during training have implications for reaching important training and racing milestones. The results of this thesis indicate that current exercise regimens could be modified to enhance the training and racing performance of Thoroughbred racehorses.

ACKNOWLEDGEMENTS

I am indebted to the many studmasters and trainers and their staff that gave up their valuable time to assist in this project and who recorded data with such interest and enthusiasm; without them this project would not have been possible. Thank you to all the people in the Thoroughbred industry who provided information or assisted in some way with this project, your help was greatly appreciated.

I would like to gratefully acknowledge New Zealand Racing Board as part of the Partnership for Excellence for funding the project and myself. I would like to thank Massey University and Education New Zealand for travel scholarships to attend conferences.

I am very grateful to my supervisors Professor Elwyn Firth, Dr Chris Rogers and Professor Nigel French for their advice, guidance and support. I would like to thank Elwyn for meeting with me in London and for giving me an amazing opportunity to live and work in New Zealand. I am grateful to Elwyn for his enthusiasm and encouragement, attention to detail, and for making me strive to produce the best work. I would like to thank Chris for always having an open door policy, for receiving my first drafts and for always sending me away with a unique drawing of an idea, problem or solution! I would like to thank Nigel for bringing his enthusiasm for epidemiology to my supervisory team, and for his guidance and advice during analysis and write-up.

I also thank Stuart Duggan and Georg Magerl at New Zealand Thoroughbred Racing for providing technical support and data extracts. I am very grateful to the New Zealand Thoroughbred Breeders' Association, New Zealand Equine Research Foundation, Allan Child at New Zealand Thoroughbred Racing and Justine Sclater at Waikato Breeders' Bloodline for their assistance in publishing information and findings from the project.

I am very grateful to Marije Blok and Audrey Burkard for their company and assistance when travelling around the country collecting data and for their friendship during their time in New Zealand. I would like to thank Marije, Nikita Stowers and Lauren Beanland for their help with data processing and entry. I would like to thank Bryan O'Leary for his assistance with designing the databases and his patience when answering all my questions. Thank you to Naomi Cogger and Nigel Perkins for their suggestions and advice on statistical analysis.

To Elwyn's Angels, Brielle, Jaz, Niki, Sarah T and Sarah R, thank you for making my working environment a fun, stimulating and challenging place to be. Thanks for reading drafts, helping with all my queries, problems and ideas and for supporting me through this process. Thanks also for your friendship, laughter, chocolate and bubbles; it has been a pleasure to work with you all over the last four years. A special thanks to all those who helped with reading drafts towards the end of the project, your thoughts and comments were invaluable. Birte, your knowledge of the English language is inspirational and I thank you for passing some of it on to me.

Thanks to all my family for their continued love and support over the last four years. Being so far away has been tough at times, so I thank Mum, Bill, Adam, Jake, Birte and Lucas for keeping in touch through regular Skype video chats, and to Dad, Patrick and other family and friends who have called, emailed, sent essential care packages of my favourite chocolate or made the long journey to visit us! Also, I want to thank my Kiwi friends who made it so easy to settle and feel at home and provided me with much needed fun, laughs and 'down time' from the PhD.

To Dan, thank you for agreeing to start a new adventure together in New Zealand, and for understanding when I then had to work all hours of the day, night and weekends! I thank you for your advice, love and support throughout this journey. I feel very lucky to have experienced this with you.

To my Mum: there are no words to describe how much I appreciate the sacrifices you have made for me and for your financial help that got me where I am today. Thank you for being there, for your encouragement, for supporting all my decisions and choices in life, and for making it so easy to follow my dreams to the other side of the world. This thesis is dedicated to you.

LIST OF PUBLICATIONS

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2010a) Management and exercise of Thoroughbred yearlings during preparation for yearling sales in North Island of New Zealand. *Proc. N. Z. Soc. Anim. Prod.* **70**, 157-161.

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2010b) Management and exercise of Thoroughbred yearlings during preparation for yearling sales. In: *Proceedings of the 18th International Conference of Racing Analysts and Veterinarians* Queenstown, New Zealand

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2010c) Identification of three distinct sub-populations of 2-year-old racehorses in training. In: *Proceedings of the 18th International Conference of Racing Analysts and Veterinarians* Queenstown, New Zealand.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011a) Risk factors for interruptions to training occurring before the first trial start of 2-year-old Thoroughbred racehorses. *N.Z. vet. J.* In Press.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011b) Exercise in Thoroughbred yearlings during sales preparation: A cohort study. *Equine vet. J.*, no.10.1111/j.2042-3306.2011.00370.x.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011c) Associations between yearling exercise and interruptions to race training in Thoroughbred racehorses. *Am. J. vet. Res.* In Press.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011d) The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses. *Pre. vet. Med.* Submitted.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

12s	12s/200m
13s	13s/200m
15s	15s/200m
BMC	Bone mineral content
CI	Confidence interval
CONDEX	Pasture plus exercise
DMD	Dorsometacarpal disease
GPS	Global positioning systems
HR	Hazard ratio
IQR	Interquartile range
LRS	Likelihood ratio statistic
MSI	Musculoskeletal injury
NH	National Hunt
NZB	New Zealand Bloodstock
NZTR	New Zealand Thoroughbred Racing
OR	Odds ratio
PASTEX	Pasture with no additional exercise
RR	Risk ratio
TAS	Training activity score

LIST OF TABLES

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

CHAPTER 8

LIST OF FIGURES

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

CHAPTER 8

CHAPTER 1

INTRODUCTION

BACKGROUND

Success of the Thoroughbred racing industries across the world relies on the production of horses that will race as 2-year-olds (flat racing) and continue to race for a number of seasons. However, over recent years there has been a steady decline in the size of the Thoroughbred foal crops and the number of starters and starts per horse across a number of racing jurisdictions (McCarthy 2009; Anon 2010a, 2011b, c), and New Zealand is no exception. There was a 10% decline in the number of foals born in New Zealand in 2004 compared to 2003, which resulted in a reduction in the number of 2- and 3-year-old starters in the 2006 and 2007 racing seasons (Anon 2008). Despite a number of initiatives to increase participation in the New Zealand racing industry, there was still a 2.6% and 1.7% decrease in both starts and average starts per horse, respectively, in 2009/10 compared to the 2008/09 season (Anon 2010b).

One of the largest threats to the Thoroughbred racing industry is the loss of horses from training and racing (wastage) due to either a lack of talent or musculoskeletal injury (MSI). A previous analysis of the supply chain in New Zealand Thoroughbred racing highlighted the loss of horses from the industry, estimating 57% of horses failed to race or 'reach their full potential' (McCarthy 2009). These losses are occurring not only during training and racing, but earlier in the career of the racehorse before entering training. Such losses have welfare implications for horses that are retired from racing due to poor performance or due to injury. Therefore, in order for the total number of annual starts to be maintained, either the number of horses available for racing or the number of lifetime starts per horse would need to increase, by reducing the number of horses failing to train and race.

One of the major causes of wastage within New Zealand, and worldwide, is musculoskeletal injury (Rossdale *et al.* 1985; Bailey *et al.* 1997b; Williams *et al.* 2001; Perkins *et al.* 2004b; Wilsher *et al.* 2006; Dyson *et al.* 2008). Several prospective epidemiological studies have quantified the wastage and risk factors relating to MSI in New Zealand (Perkins *et al.* 2004a, b, 2005a, b). Within a cohort of 1,571 horses in training, 35% left the industry as a result of voluntary (65%) or involuntary (35%) retirements and 78.8 % of the involuntary interruptions to training were due to MSI (Perkins *et al.* 2004b). These and other studies show that the amount and type of exercise accumulated during training is associated with both the risk of MSI during training and racing, as reviewed by Parkin (2008), and success during racing (Verheyen *et al.* 2009; Ely *et al.* 2010).

In agreement with the finding that exercise can influence the musculoskeletal system, the importance of early exercise in young children (Hind and Burrows 2007; Gunter et al. 2008), animals (Hiney et al. 2004) and horses (Barneveld and van Weeren 1999) has been demonstrated. In young horses, confinement typically imposed as part of modern management systems restricts exercise and leads to retarded development of the musculoskeletal system (Barneveld and van Weeren 1999; van Weeren *et al.* 2000); too much forced exercise in addition to a box regimen may be detrimental, compared to horses at pasture (Cherdchutham *et al.* 1999; Cornelissen *et al.* 1999; van de Lest *et al.* 2002). Further, providing a conditioning programme to young horses at pasture did not result in any adverse effects on the musculoskeletal system (Nugent *et al.* 2004; Doube *et al.* 2007; Moffat *et al.* 2008; Rogers *et al.* 2008b; Stanley *et al.* 2008; van Weeren *et al.* 2008; Brama *et al.* 2009) and some positive effects were observed (Dykgraaf *et al.* 2008; Nicholson and Firth 2010). Additionally, the conditioning program did not have any long-term negative effects on training and racing as 2- and 3-year-old horses (Rogers *et al.* 2008a). The recent advances in the area of early conditioning exercise in horses suggest that intervening earlier may allow a more proactive, rather than reactive, approach to reduce losses in the Thoroughbred racing industry. Despite this, information on how young horses are being managed, their exposure to exercise early in life, and the effects of early exercise on future training and racing performance is scant.

In order to establish whether early exercise is likely to have benefits to the training and racing campaigns of racehorses, epidemiological studies are required to study these associations at a population level. A critical review of the literature follows, which identifies gaps in the current knowledge, and provides a foundation to develop the aims and hypotheses for the chapters that follow.

LITERATURE REVIEW

This review describes the Thoroughbred racing industry in New Zealand and highlights the significant problem of wastage that occurs worldwide. Further, the main contribution to wastage is reviewed along with the substantial number of epidemiological studies that have contributed to the knowledge on risk factors for musculoskeletal injury (MSI). Finally, the effects of exercise during training on future performance, and the responses of the musculoskeletal system to exercise regimens before and during race training are reviewed.

New Zealand Thoroughbred breeding and racing industry

Based on the number of foals born in 2010, the New Zealand breeding industry (4,132 foals) was the 8th largest in the world behind countries such as the USA (26,578), Australia (17,191), Ireland (7,588) and Japan (7,104) (Fennessy 2010; Anon 2011d). In the 2009/10 breeding season there were approximately 7,098 registered broodmares of which 6,488 were covered by a stallion and produced approximately 4,300 foals (Anon 2010b). The breeding industry is sustained by the high export market, due to the high reputation of the New Zealand breeding industry for breeding top class Thoroughbreds (Fennessy 2010). In the 2008/09 Thoroughbred breeding season, over 1,500 horses with an estimated value of NZD 130 million were exported, most to Australia, Hong Kong and Singapore (McCarthy 2009; Anon 2010b; Fennessy 2010).

There are some 70 commercial stud farms and many smaller breeders across New Zealand, offering around 1,500 yearlings at the yearling sales series each year. New Zealand Bloodstock (NZB) manages all the commercial sales of Thoroughbred horses, from broodmares and weanlings, to yearlings and 2-year-olds within New Zealand. The yearling sales series consist of three types of sale, Premier, Select and Festival, and provides an opportunity for breeders to present their yearlings to both domestic and international buyers. The allocation of horses to each type of sale is determined by NZB and each horse is assessed on its pedigree, conformation, and ‘type’. The 2011 yearling sales saw international buyers, particularly from Australia, dominate the Premier sale (Anon 2011a), whereas the Select and Festival sales predominantly satisfied the domestic market. Overall, 1,050 yearlings were sold across the three sales in 2011, generating NZD 88,094,250 in turnover (Anon 2011a).

Both flat and jump racing in New Zealand is governed and managed by New Zealand Thoroughbred Racing (NZTR). NZTR are responsible for setting the trial and race dates throughout the racing season, which runs from 1st August to 31st July the following year. Further, NZTR maintain the New Zealand Thoroughbred Stud Book and racing database, and define the rules of racing within New Zealand. Stud book regulations state that both the mare and stallion must be registered so that the resultant foal can race or breed, and foals must be branded or micro-chipped. According to the rules of racing (Anon 2011e), the official birth date for all Thoroughbred horses in New Zealand is 1st August in the calendar year they were born, and no horses are allowed to race before age two.

Horses have an opportunity to practice for a race by starting in a trial, which is considered a competitive event but with no betting, but a trial is not compulsory for Thoroughbred racehorses before starting in a race. To enter trials and races, the rules of racing state that horses must be registered with a trainer that has either a Class A (sole livelihood from training), B (maximum six horses in training) or C (horse must be owned or part-owned by the trainer) licence, and the horse must be officially named (for racing) (Anon 2011e). This section does not provide an exhaustive review of the Thoroughbred racing industry or the rules of racing as it is beyond the scope of this thesis, and further detail was provided by Perkins *et al* (2005).

During the 2009/10 racing season 5,794 horses were trained by 370, 409 and 458 Class A, B and C trainers, respectively (Anon 2010b). In total, 3,068 races were run across 51 racetracks, of which 146 were classed are Group 1 or listed races (Anon 2010b). The top 30 training centres, based on total starts in 2009/10, were in the Northern (Waikato) and Central Districts (Manawatu) and the percentage of Class A trainers in those regions were 55.1% and 25%, respectively (Anon 2010b). Although in recent years there has been an increase in prize money, with over $58.4 million offered in the 2008/09 racing season, in the 2009/10 season prize money decreased to $49.6 million (Anon 2010b). Despite a number of initiatives to increase participation in the racing industry, there has been a 0.7%, 2.6%, 0.6% and 1.7% decrease in races, starts, individual starters and average starts per horse, respectively, in 2009/10 compared to the 2008/09 season (Anon 2010b). The ongoing success of the Thoroughbred racing industry relies on the production of horses for 2-year-old racing, that continue to race for a number of seasons, ensuring sufficient numbers of racehorses to optimise betting turnover and sustain the industry. One of the largest threats to the racing industry is the loss of horses from the training population as a result of wastage.

Wastage

A term that has been used to describe the losses that can occur at various stages in the life of a racehorse is ‘wastage’. Specifically, studies have defined wastage in the Thoroughbred racing industry by the number of training days lost, and death or retirement from racing due to injury or disease (Rossdale *et al.* 1985; Bailey *et al.* 1997b; Olivier *et al.* 1997). In other areas of the equine industry, such as eventing, wastage has been defined as failure to re-register a horse with British Eventing after its first year (O'Brien *et al.* 2005). However, it has been suggested that the term wastage may be too broad and imprecise (Parkin and Rossdale 2006) for describing the losses that can occur on the journey from stud farm, into training and racing. Whilst an alternative, ‘productivity’, has been proposed (Parkin and Rossdale 2006), it has not been widely used within the literature.

Wastage has been measured as the proportion of horses born that do not race before 4 years of age (Jeffcott *et al.* 1982) or the proportion of animals bred that do not race or ‘fail to reach their full potential’ (McCarthy 2009). Economically, wastage has been considered through lost stallion fees, keep of injured horses or those with reduced competitive ability, costs of diagnostic, medical or surgical procedures, all of which ultimately result in a lack of return on investment (Jeffcott *et al.* 1982; Perkins *et al.* 2004b; Rogers *et al.* 2008a).

A study conducted in the UK found at least 39% of 2-year-olds that were in training failed to enter races, and most (61%) of the veterinary problems were due to MSI (Wilsher *et al.* 2006). The study investigated the movement of 1022 Thoroughbred foals from birth to three years old, including whether the foal entered training, was destroyed or was waiting to race as a 3-year-old. Overall, 52% of the original foal crop entered training at two and 28% were exported. Information was obtained from trainers via a questionnaire and repeated telephone interviews, which may have resulted in recall bias. A strength of the study was that the compliance rate was 94%, reducing the impact of information bias from non-responders.

Another study (Yates *et al.* 2009) obtained a free text dataset from an international breeding operation based in the UK, in order to describe the reasons why foals failed to achieve different career stages. The authors used content analysis to extract data on 1044 foals recorded over a period of four years, from 2000-2004. Most (57%) horses entered training under the management of the breeding operation, which is similar to the 55% reported by Wilsher *et al* (2006). Of the 7% that died before entering training, 62% occurred after weaning and before entering training. Of the 69% of horses that sustained a veterinary problem (before training), 73% were due to MSI (excluding fractures). Although Yates *et al* (2009) reported a higher proportion of veterinary problems due to MSI than previously reported in the UK (Wilsher *et al.* 2006), the data were from one breeding operation that is likely to have had accurate reporting of problems as they were recorded for the farm's records. However, as the study considered reports from only one breeding operation, results are unlikely to be representative of the wider racehorse population. Additionally, as the data were not recorded for the purpose of a research project, the type and methods of recording data were reported to change over time often resulting in missing data, different terminology used and vagueness of veterinary reports; potentially resulting in under or overestimation of health problems reported.

McCarthy (2009) identified a similar problem in New Zealand, where 22% of horses studied were never registered with a trainer. The study aimed to analyse trends over consecutive foal crops using retrospective records to identify wastage in the supply chain, from birth to racing. An approximation of the supply chain, based on the analysis of the foal crops and data drawn from another study (Perkins 2005), indicated that 57% of horses failed to race or reach their full potential, described as any of the following: not registered with a trainer, retirement due to a physical event or poor performance, or suffered an injury that required a long break. Further approximation of the supply chain wastage identified just under half the horses in work would have sustained an injury that resulted in a long break or ended their career, and 31% would have been retired due to poor performance (McCarthy 2009). Similarly, Perkins *et al* (2004b) reported 64.9% of deaths or retirements from racing were due to voluntary retirements (no injury or condition that interfered with training), and 16.6 % of horses failed to start in at least one trial or race during the study period.

The study by McCarthy (2009) highlighted that, in agreement with other countries, the New Zealand racing industry is subject to losses before and after horses enter training that result in significant economic implications for the trainer, owner, and the wider racing industry, as well as welfare implications for horses that are retired from racing or are euthanised as a result of significant injury or poor performance. Little information is known about the reasons for losses before entering training in New Zealand. However, several studies worldwide have investigated the major cause of lost training days or retirements from racing.

Numerous studies in different countries and years have reported that most lost training days are due to lameness as a result of MSI. Table 1 shows the number of trainers, horses and the resulting percentage of training days lost due to lameness as reported by various studies.

Table 1: The number of trainers, horses and percentage of lost training days due to musculoskeletal injury (MSI) reported in studies across several countries

Country	Year	Number of trainers	Number of horses	Percentage of lost training days due to MSI	Reference
United Kingdom	1985	6	581	68	(Rossdale *et al.* 1985)
Germany	1993	4	308	57	(Lindner and Dingerkus 1993)
South Africa	1997	6	579	72	(Olivier *et al.* 1997)
Australia	1999	24	169	56	(Bailey *et al.* 1999)
New Zealand	2004	20	1,571	79[a]	(Perkins *et al.* 2004b)
United Kingdom	2008	7	182	82	(Dyson *et al.* 2008)

[a] Percentage of involuntary interruptions

Two studies conducted in the UK (Rossdale *et al.* 1985; Dyson *et al.* 2008), with similar case definitions, number of trainers and horses, show that the percentage of training days lost due to MSI cases has changed little over the last 20 years. The slightly higher percentage reported by Dyson may be due to different data collection methods; data were collected routinely as part of a larger prospective cohort study (Dyson *et al.* 2008) compared to a questionnaire that was completed by the trainer, trainer's secretary or head lad (Rossdale *et al.* 1985), which could have resulted in potential recall bias and misclassification of outcome data. Furthermore, advances in the ability to detect MSI over recent years may have contributed to the notion that there has been little change in the percentage of training days lost due to MSI. A study in South Africa found a similar percentage of lost training days (Olivier *et al.* 1997) despite differences in the case definitions between these studies: Olivier *et al* (1997) classed any day where a horse was not sent to the training track to work as lost, whereas Dyson *et al* (2008) included days when a horse failed to train at slow canter or fast speed, and if a horse was retired from racing or died all subsequent days in that year were classed as lost.

In addition to the UK studies, Bailey *et al* (1999) and Perkins *et al* (2004b) (Table1) used a convenience sample of trainers, which may not have been representative of the whole population of racehorses within each country. In addition, both studies considered a horse to be a case if it had an injury that disrupted their training programme such as reducing the number of days training or preventing training altogether (Bailey *et al.* 1999), or resulting in a spell of >7 days in duration

(Perkins *et al.* 2004b). As a result, a horse with clinical signs that did not interfere with training was not considered a case, potentially underestimating the number of cases and training days lost, compared to the UK studies (Rossdale *et al.* 1985; Dyson *et al.* 2008). However, compared to Olivier *et al* (1997), where trainers were responsible for the diagnosis of injuries, the potential for misclassification of injury information was lower, since veterinarians were responsible for 54% of the diagnoses of injuries involving the musculoskeletal system (Perkins *et al.* 2004b).

Frequency of MSI during training and racing

Although the measurement of MSI varies within the literature, the standard measures adopted within epidemiological studies for the measure of risk of MSI occurrence during racing and training are ‘the number of events per 1,000 starts’ and ‘the number of events per 100 horse days (or months) in training’, respectively (Parkin 2008). As shown in Table 2, a number of outcomes have been used to describe the occurrence of injuries during training and racing, which have reported case definitions that vary from general to specific definitions that relate to structure involved.

Table 2: Outcomes used in studies describing the epidemiology of injuries in Thoroughbred racehorses during training and racing

Outcomes	References
Broad definitions	
Fatality	(Estberg *et al.* 1996b; Boden *et al.* 2005; Boden *et al.* 2006; Boden *et al.* 2007a, b)
Catastrophic musculoskeletal injury	(Estberg *et al.* 1996a; Estberg *et al.* 1998a; Estberg *et al.* 1998b; Cruz *et al.* 2007)
Musculoskeletal injury	(Peloso *et al.* 1994; Bailey *et al.* 1997a; Bailey *et al.* 1998; Cohen *et al.* 1999; Cohen *et al.* 2000; Perkins *et al.* 2005b; Cogger *et al.* 2006; Cogger *et al.* 2008a; Ramzan and Palmer)
Specific structures	
Tendon and/or ligament disease	(Ely *et al.* 2004; Perkins *et al.* 2005a; Lam *et al.* 2007a; Lam *et al.* 2007b; Ely *et al.* 2009)
Dorsal metacarpal disease	(Boston and Nunamaker 2000; Verheyen *et al.* 2005)
Fracture	(Ely *et al.* 2004; Parkin *et al.* 2004b, a; Parkin *et al.* 2004d; Verheyen *et al.* 2006a; Verheyen *et al.* 2006b; Ely *et al.* 2009)
Joint injury	(Reed *et al.* 2011)

The results from studies investigating the risk of fatality during racing are shown in Table 3. The variations seen in the risk of fatality between locations may reflect regional differences, or it may reflect differences in race tracks, management or training practices. However, in all studies there is an increased risk of fatality in jump races compared with flat races.

Table 3: Studies reporting the incidence of fatalities during flat and jump races, per 1,000 starts

		Fatalities per 1,000 starts	
Authors	**Location**	**Flat**	**Jump**
McKee (1995)	United Kingdom	0.8	4.9[a] & 6.7[b]
Wood *et al* (2002)	United Kingdom	0.9	5.6
Boden *et al* (2006)	Australia	0.4	8.3
Stephen *et al* (2003)	Virginia	-	3.4
Estberg *et al* (1996b)	California	1.7	-

[a]hurdle races, [b]steeplechase races.

Studies of MSI during racing in Australia found the rate of MSI to be 2.4 per 1,000 starts (Bailey *et al.* 1997a) and in a further study the rate of MSI to be 14.3, 6.3 and 0.6 per 1,000 starts in chase, hurdle and flat races, respectively (Bailey *et al.* 1998); in agreement with findings from studies in the UK (Williams *et al.* 2001; Wood *et al.* 2002). However, a number of case definitions for MSI were utilised across these studies, suggesting that the rates of MSI may not be directly comparable. Another study conducted in the UK (Parkin *et al.* 2004c), found the incidence of fatal distal limb fractures to be 0.72 per 1,000 starts; the incidence of fracture differed with race type, with the highest incidence being in National Hunt (NH) races. Furthermore, the rate of tendon injury has been reported to be higher in NH chases compared to flat races (9.12 per 1,000 starts, 0.78 per 1,000 starts respectively)(Williams *et al.* 2001). McKee (1995) found substantial prevalence of tendon injuries in all types of race (NH flat race (2.6%), steeplechase (3.9%) and flat (4.1%)), with the highest percentage (9.1%) occurring in hurdle races.

Musculoskeletal injury occurs not only during racing but also in training (Bathe 1994; Verheyen and Wood 2004; Verheyen *et al.* 2006b; Ely *et al.* 2009; Ramzan and Palmer 2011). During training, the incidence of MSI in a population of racehorses in New Zealand was found to be 1.91 per 1,000 training days (Perkins *et al.* 2004b). Within this population, fractures and tendon injuries accounted for respectively 42% and 41% of the exits from the study, and most (81.5%) of the MSI involved the forelimbs. Similarly, a study conducted in the UK found over half of the fractures that occurred involved the forelimbs (Verheyen and Wood 2004). The latter study, of 1,178 horses at 14 training establishments over a period of two years (Verheyen and

Wood 2004), showed an overall incidence of fracture of 1.2 per 100 horse months, which is similar to the incidence of fracture (1.1 per 100 horse months) reported in NH racehorses (Ely *et al.* 2009). Studies in Australia have found 'shin soreness' to be a common cause of wastage during training and racing (Buckingham and Jeffcott 1990; Bailey *et al.* 1997a; Bailey *et al.* 1998; Cogger *et al.* 2006; Wilsher *et al.* 2006). The incidence of DMD was found to be 1.87 per 100 horse months for horses in training in the UK (Verheyen *et al.* 2005). A recent study in the UK (Reed *et al.* 2011) quantified the occurrence of joint injuries diagnosed by a veterinarian in a cohort of 647 horses across 13 trainers, and reported an overall rate of 1.8 per 100 horse months.

In Hong Kong, tendon injuries were found to be the most important reason for retirement of Thoroughbreds from racing (Lam *et al.* 2007a). The study population was all horses stabled between 1992 and 2004 at the Hong Kong Jockey Club. The median racing population over this time was 1,286 horses, the average annual cumulative incidence of retirements due to tendon injury was 3.2%, and tendon injury accounted for 14% of all racing retirements (Lam *et al.* 2007a). Another study found that tendon injuries were the most common type of musculoskeletal injury, accounting for 46% of limb injuries occurring at racecourses in Britain (Williams *et al.* 2001). A pilot study of incidence rates of tendon injuries occurring in training for NH races found a total of 70 tendon injuries, of which 93% involved the superficial digital flexor tendon (Ely *et al.* 2004). The study consisted of four NH training yards with 477 horses in total. The overall incidence rate of tendon injury was 2.1 per 100 horse months (95% confidence interval (CI) 1.7-2.7). A later prospective study by the same group of authors (Ely *et al.* 2009), with more trainers and horses, reported a similar rate of 1.9 per 100 horse months (95% CI 1.7-2.2) for tendon injury.

Comparisons between the risk of different types of injury during training and racing have been made difficult as a result of variations in the study design, aim, case definitions, and countries, which are likely to reflect regional differences in terminology, management, training, and race tracks used. Despite this, these studies do demonstrate the importance of MSI to racing industries worldwide, and the need to use accepted and standard case definitions, and terminology, so that the results of future studies can be compared.

Epidemiological studies of risk factors for musculoskeletal injury during training and racing

The risk factors for MSI that have been identified at the race- and course-level include race distance (Peloso *et al.* 1994; Parkin *et al.* 2004a; Pinchbeck *et al.* 2004; Boden *et al.* 2007b), race class (Bailey *et al.* 1997a), number of runners and track surface (Hernandez *et al.* 2001; Williams *et al.* 2001; Parkin *et al.* 2004a; Boden *et al.* 2007b), and the racecourse (Estberg *et al.* 1998b; Boden *et al.* 2007b). Specifically, a study in the UK found longer races, those with more runners, and a firmer track surface were associated with an increased risk of fatal distal limb fracture (Parkin *et al.* 2004a). Similar results were reported by Boden *et al* (2007a), who found the odds of fatality increased with every extra 1km of race distance (Odds ratio (OR) = 1.45; 95% CI 1.05-2.01; P=0.025). However, it should be noted that several studies did not use multivariable analysis when assessing risk factors for MSI (Peloso *et al.* 1994; Wilson *et al.* 1996; Williams *et al.* 2001), removing the opportunity to adjust for effects of more than one variable at a time. Studies on race-level risk factors for MSI have identified a number of modifiable factors, which, in addition to other factors, have resulted in interventions aimed at reducing the occurrence of injuries during races. These include the reduction in the distance of some races at UK race courses and the introduction of more forgiving fences in jump races in Australia (Parkin 2008).

Horse-level risk factors that have been associated with the risk of MSI include age (Bailey *et al.* 1997a; Cohen *et al.* 2000; Williams *et al.* 2001; Parkin *et al.* 2004d; Perkins *et al.* 2005b; Boden *et al.* 2007a; Lam *et al.* 2007b), gender (Boden *et al.* 2007a), dam age and parity (Verheyen *et al.* 2007), weight carried during the race (Pinchbeck *et al.* 2004; Takahashi *et al.* 2004), previous MSI during training (Perkins *et al.* 2004b), number of years racing (Parkin *et al.* 2004b; Parkin *et al.* 2004d), number of training preparations (Perkins *et al.* 2005b), intensity of exercise (Estberg *et al.* 1995; Estberg *et al.* 1996a; Estberg *et al.* 1998a; Hill *et al.* 2004; Parkin *et al.* 2004a; Perkins *et al.* 2005a, b; Verheyen *et al.* 2005; Verheyen *et al.* 2006a; Verheyen *et al.* 2006b), lay-up period (time off during training) (Carrier *et al.* 1998) and trainer (Perkins *et al.* 2005a; Verheyen *et al.* 2005; Cogger *et al.* 2006; Verheyen *et al.* 2006b).

Several studies have considered age as a risk factor, finding an association (Bailey *et al.* 1997a; Cohen *et al.* 2000; Williams *et al.* 2001; Parkin *et al.* 2004d; Perkins *et al.* 2005b, a; Boden *et al.* 2007a; Lam *et al.* 2007b) or, conversely, no association (Parkin *et al.* 2004b; Pinchbeck *et al.* 2004; Cogger *et al.* 2006; Verheyen *et al.* 2006a;

Cruz *et al.* 2007) between increasing age and an increased risk of MSI. It has been suggested that an association between age and the risk of MSI may be confounded by different levels of exposure to exercise and training (Perkins *et al.* 2005a).

A few studies have either matched cases and controls by gender (Estberg *et al.* 1996a), making it impossible to analyse the effects, or failed to find any significant associations (Verheyen *et al.* 2005; Cogger *et al.* 2006; Verheyen *et al.* 2006b; Lam *et al.* 2007b). In contrast, other studies found an increased risk of MSI associated with gender (Estberg *et al.* 1998b; Hernandez *et al.* 2001; Perkins *et al.* 2004b, 2005a; Boden *et al.* 2007b; Cruz *et al.* 2007). However, gender does not represent a modifiable risk factor for MSI, since the racing industry is unlikely to remove a particular gender from racing (Parkin 2008).

A factor that could be modified is the duration or timing of breaks occurring during training. Perkins *et al* (2005b) identified an increased risk of MSI for horses accumulating days at a training activity score (TAS) of 1 (spell/break from training) during a training preparation, but the association was no longer present after adjusting for other horse and training factors in the multivariable models. Other studies have shown an association between MSI and the timing and duration of lay-ups (Carrier *et al.* 1998; Anthenill *et al.* 2007). However, the definition of lay-up was classed as >60 days without an officially timed high speed or racing event, which differs from the classification of the TAS 1 utilised by Perkins *et al* (2005b). Despite associations between lay-ups or spells and MSI, there is little information on the risk factors. Whilst the conditions causing interruptions to training have been described and univariable associations between horse age and gender and the length of spells have been identified (Perkins *et al.* 2004b), there is a paucity of information on the risk factors for spells or interruptions to training. Many studies have instead focussed on potentially modifiable risk factors for outcomes such as MSI, which may lead to possible interventions to reduce the incidence of MSI.

Although many studies have shown an association between exercise and the risk of MSI during training and racing, results regarding the specific nature of the association were conflicting. The use of varied definitions and measurements of exercise intensity can make comparisons between studies difficult. The different time periods and measures of exercise that have been used in epidemiological studies of risk factors for MSI are shown in Table 4. Many studies have considered the distance or cumulative distance of exercise in 30 day periods, which is now considered to be the ideal observation period (Parkin 2007) that should be continued in future studies, in order to facilitate comparisons.

In many of the studies listed in Table 4, descriptive terms have been used for the type of exercise, such as canter, high speed, gallop or fast work. However, in many cases the speeds used to describe these terms vary between countries and racing sectors (Rogers and Firth 2004).

Table 4: Definitions of exercise intensity and time periods used in epidemiological studies of risk factors for MSI

Measure of exercise intensity	Authors
Distance at gallop per week	Boston and Nunamaker (2000) Parkin *et al* (2004b; 2004d)
Distance at canter in previous 30 days	Verheyen *et al* (2005; 2006b)
Distance at high speed in previous 30 days	Verheyen *et al* (2005; 2006b) Hill *et al* (2004) Cohen *et al* (2000)
Distance at high speed in previous 60 days	Hill *et al* (2004) Cogger *et al* (2008b) Cohen *et al* (2000)
Average distance trained at high speed	
Cumulative distance at canter since entering training	Verheyen *et al* (2005; 2006a)
Cumulative distance at high speed since entering training	Verheyen *et al* (2005; 2006a)
Percentage of training days that were fast	Cogger *et al* (2006)
Cumulative distance raced in previous 30 days before injury	Perkins *et al* (2005a, b)
Cumulative high speed in 60 days before race	Estberg *et al* (1995; 1998a)
Number of racing starts in previous 31-60 days before case event	Boden *et al* (2007a)

In addition, there were significant differences in the speeds of the descriptive terms, used within the industry to describe the workload; the speed differed with type or features of the track, the stage of training, and instruction to the rider. As a result, in an attempt to standardise measurement of exercise intensity the development of a cumulative workload index has been proposed, which is based on the product of speed and distance during training (Rogers and Firth 2004; Tabar-Rodriguez *et al.* 2009). Where possible, future studies should aim to collect specific measurements of speed and distance so that the cumulative exercise intensity may be more quantitatively described. The increasing uptake of GPS-based systems for the recording of speeds (Kingston *et al.* 2006; Fonseca *et al.* 2010) and distances travelled (Hampson and Pollitt 2008; Hampson *et al.* 2010) may mean that data capture and analysis will be easier in future studies.

A study conducted in the UK investigated the horse-level risk factors for fatal distal limb fracture, identified on any of the 59 racecourses in the UK (Parkin *et al.* 2004b). Univariable screening showed an increased risk of fracture during racing for horses doing no gallop work in training (per week) compared to those doing 2-7 furlongs (OR = 3.13; 95% CI 1.10-8.91; P=0.03). When distance galloped was modelled as a quadratic term, using multivariable conditional logistic regression, the risk of fracture was highest for those doing no gallop work, decreased for horses doing short distances of gallop, and levelling off for longer distances.

Early studies conducted in California investigated exercise history and the risk of fatal skeletal injury during racing (Estberg *et al.* 1996b). Results showed high total and high average daily rates of high speed exercise distance were associated with the risk of fatal skeletal injury. In particular, accumulating more than 35 furlongs of high speed exercise in a two-month period was associated with a 3.9 (95% CI 2.1-7.1) fold increase in risk, compared to accumulating only 25 furlongs. Cases were identified retrospectively and included horses that experienced a catastrophic racing fracture, during a nine-month period. Further research by Estberg and colleagues (1998a) showed an association between accumulation of high speed exercise distance and the risk of catastrophic musculoskeletal injury in racing or training. The study was a retrospective case-crossover design that had cases as a separate stratum so each case provided its own self-matched control information. A 60 day sliding window was used to identify hazard periods resulting from high speed distance accumulation that exceeded the 75th percentile; all other periods were considered to be non-hazard times at risk. Results showed a significantly increased risk of catastrophic MSI within 30 days following the rapid accumulation of high speed exercise distance (0.76-0.95 furlongs/day) (Risk ratio (RR) = 4.2; 95% CI 3.0-5.8). However, there may be some over/underestimation of the risk due to over/underestimation of the cut-offs used to define hazard periods.

A comparable study to that of Estberg *et al* (1996b) conducted in Kentucky, to determine the association between high speed exercise and the risk of MSI in racing thoroughbreds, found conflicting results (Cohen *et al.* 2000). Increased cumulative high speed exercise distance two months before the race was associated with a reduced odds of MSI, compared to uninjured controls (OR = 0.98; 95%CI 0.96-0.99; P=0.01). In addition, no high speed exercise in the month preceding the injury was associated with an increased risk of MSI, compared to uninjured controls (OR = 1.87; 95%CI 1.04-3.36; P=0.03). Horses, from four race tracks, that had suffered a MSI during the study period were eligible for inclusion within the study. Controls were healthy horses that were randomly selected from the same race as the case horse and were matched 2:1 on race (although this was not stated). In contrast to the studies conducted in California (Estberg *et al.* 1996b; Estberg *et al.* 1998a), this study reported that accumulation of high speed exercise was associated with a decreased risk of MSI. Whilst studies in the UK have reported a reduced risk of DMD with the accumulation of canter and high speed exercise, and of fracture with the accumulation of high speed exercise (Verheyen *et al.* 2005; Verheyen *et al.* 2006a), these studies investigated exercise accumulated since entering training. Therefore, these findings may not be comparable to the study by Cohen *et al* (2000), which reported distances accumulated during the 60 days before a race.

Studies in the UK have investigated the relationship between training-related risk factors and MSI sustained during training (Verheyen *et al.* 2005; Verheyen *et al.* 2006a; Verheyen *et al.* 2006b). Specifically, one study looked at the risk of fracture in Thoroughbred racehorses in training for flat racing (Verheyen *et al.* 2006a). A nested (within a larger cohort study), matched case-control study was conducted involving 13 trainers, which were selected through a convenience sample due to the level of cooperation needed. Daily training information was recorded by the trainers, or a member of staff, using either an electronic database or standardised paper forms. The trainers were visited every 4-6 weeks to collect the data and discuss any queries regarding the data, whilst information on injuries was obtained through the trainers' veterinary surgeon.

Multivariable analysis showed a strong interaction (P=0.002) between distances exercised at canter and gallop; horses that had exercised more than 44km at canter and 6km at gallop in a 30-day period were at an increased risk of fracture. The risk of pelvic and tibial fractures increased with increasing canter distance, but decreased in horses doing more than 50 km in a 30 day period (OR=1.17; 95% CI 1.05-1.31; P=0.001) (Verheyen *et al.* 2006b). A cohort study was also conducted on a subset of the study population (Verheyen *et al.* 2006a), which used data from 8 of the 13 trainers whose horses started training as yearlings; as these horses had no previous training experience, it allowed the identification of risk factors associated with only those training regimes imposed. When adjusted for daily exercise, accumulation of canter exercise since entering training was associated with an increased risk of fracture (P=0.01), the accumulation of high-speed exercise had a protective effect on the risk of fracture (P<0.001). These results suggest that increasing canter exercise is not sufficient for inducing an adaptive response, so the bone is not adequately prepared to withstand the forces experienced during racing.

Further work within this population of racehorses investigated the risk of dorsometacarpal disease (DMD) (Verheyen *et al.* 2005). A case was any horse diagnosed with DMD, based only on clinical signs. The diagnosis was usually made by the trainer, potentially resulting in misclassification or lack of inclusion of cases due to a lack of expertise. However, the authors stated that this condition was well recognised by trainers, reducing potential misdiagnosis. A Cox proportional hazards regression was used to identify associations between the activity performed and the time to developing DMD. As the data consisted of daily observations, exercise variables were allowed included as time-dependent covariates that varied over time and proportional hazards were no longer assumed; weekly average distances were measured as fixed variables. In addition, trainer was included as a shared frailty term to account for any potential correlation between horses within the same training yard. The risk of DMD varied significantly between trainers in both multivariable models (P=0.003, P=0.008). There was a statistically significant association between increasing distances worked at canter (Hazard Ratio (HR) = 1.05; 95% CI 1.02-1.07; P<0.001) and high speed (HR = 1.09; 95% CI 1.0-1.1; P<0.001) during one month and the risk of DMD. In addition, there was an interaction between daily high speed and canter exercise, suggesting that on high speed days canter exercise should be reduced.

A study conducted in Australia considered risk factors for developing MSI during training (Cogger *et al.* 2006). The longitudinal, cohort study included 274 2-and 3-year-old Thoroughbred horses from a convenience sample of 14 training yards. Interviews with the trainer and completed data forms were used to record injury and exercise information; yards were visited every two weeks, with the aim of reducing recall bias. A case was a MSI that ended a training preparation, which began when a horse entered a participating stable and ended if it left for more than seven days. Some misclassification of cases or controls may have occurred as the trainers were responsible for the diagnosis of MSI. Analysis involved multivariable logistic regression and included trainer as a fixed effect in the final model to adjust for between trainer variability. The risk of MSI increased when the average distance trained at speeds greater than 800m/min increased, and with the percentage of days spent in fast training that were fast; no confidence intervals or P-values were reported. Although the authors justified their chosen analysis, the study design was a prospective cohort and other techniques such as Poisson regression or survival analysis could have been used.

A case-control study was conducted in New Zealand with the aim of investigating risk factors for MSI during training (Perkins *et al.* 2005b). Twenty trainers were recruited into the study, based on their willingness to participate, and thus it is doubtful that the sample would have been representative of the entire racing population in New Zealand. Exercise and injury information were collected via monthly visits to yards using a questionnaire. The definition for a case preparation was any training preparation when a MSI involving the forelimb was diagnosed, and complete preparations were selected as controls for analysis. Exercise intensity was measured as a continuous variable that represented the cumulative distance raced in the last 30 days of the preparation. Multivariable analysis showed that as the cumulative distance raced increased, the likelihood of MSI decreased with cumulative distance up to 13 furlongs, levelled and then began to increase again as cumulative distance raced increased up to 55 furlongs. However, it should be noted that the confidence intervals were wider as cumulative distance increased (from 43-55 furlongs), indicating a greater uncertainty in prediction at longer distances. The authors hypothesised that the relationship between cumulative distance raced and MSI may be an effect of MSI, resulting in a survival bias as injured horses had their preparations cut short. However, the authors suggested that a survival bias was unlikely given the increase in risk with longer distances raced. It is important to note that such studies use race distance as an approximation of the high speed exercise history and do not take into account exposure to high speed exercise during training.

A form of survival bias known as the ‘healthy worker effect’ has been in observed in studies in humans (Arrighi and Hertz-Picciotto 1994) and, similarly, a ‘healthy horse effect’ has been previously described. Whilst a ‘healthy horse effect’ is likely, it is also plausible that the risk factors for MSI are multifactorial and as such, may change with the development of specific injuries (Parkin 2008). Similarly, the risk of injury may change throughout the course of a training programme, as found in previously untrained young horses (Verheyen *et al.* 2006a). As a result, policy changes and specific recommendations to trainers on the amount and type of exercise may be difficult, and it has been suggested that training interventions to reduce injury will need to be put in place and assessed in order to observe potential reductions in MSI (Parkin 2008).

Exercise and future racing performance

Whilst recommendations for changes to exercise programmes could be made to trainers in order to reduce the incidence of MSI, the horses’ performance during training and racing should not be compromised as a result of any modifications. Given the demonstrated associations between exercise during training and racing and the risk MSI, the number of studies investigating the effect of exercise on future performance is reasonably limited and this area has only recently started to be investigated. Associations between the exercise distance accumulated during training and the prize money won, starting in a race, and winning a race have been reported in studies of both flat and NH racehorses in the UK (Verheyen *et al.* 2009; Ely *et al.* 2010).

Verheyen *et al* (2009) reported that the high speed distance accumulated in the 30-day period before a race was associated with increased odds of winning a race (P=0.004) and winning prize money (P<0.001), after adjusting for horse and trainer effects. The effect of high speed exercise was also adjusted for the significant (P=0.006) association between the distance raced in the 30 days before a race and the odds of winning a race. The mixed effects linear regression models indicated a significant (P=0.003) interaction between the distance cantered and galloped and the amount of prize money won. Additionally, the results indicated that 22% of the variation in prize money was due to horse effects that were not accounted for by the other variables in the model.

A study of NH horses (Ely *et al.* 2010) investigated outcomes specific to jump racing in addition to the same outcome variables as Verheyen *et al* (2009), allowing comparisons of the two studies. In contrast to Verheyen *et al* (2009), an association between the canter distance accumulated in a 30 day period before a race and winning a race or winning prize money in NH horses was observed (Ely *et al.* 2010). Apart from this finding, the other associations between high speed exercise accumulated in a 30 day period, trainer effects, and horse effects on performance were similar to those reported in flat racehorses.

The use of multiple outcomes in these studies highlights that there is not one consistent measure for assessing racing performance. However, by using a number of binary outcomes the performance of all horses can be measured, as opposed to using continuous measures of prize money where only those horses capable of earning money are included. Variables for prize money are skewed by a large number of horses earning zero prize money, which results in the exclusion of these horses (Verheyen *et al.* 2009) and leads to a biased sub-set of the wider racehorse population.

Exercise and future training performance

To add to the variation in measures of racing performance, a horse's progress or performance during training can be assessed. A cross-sectional survey of New Zealand Thoroughbred racehorse trainers identified the milestones trainers used to assess the progress of a horse during training (Bolwell *et al.* 2010). Of the 55 trainers surveyed, 35% and 40% used the first gallop and the first trial, respectively, to decide if an individual horse should continue training. Although these findings may not be applicable to all racehorse trainers in New Zealand or other countries, the outcome of time to first barrier start or race has been utilised in studies of training and racing performance in Australia (Bailey *et al.* 1999; Cogger *et al.* 2008b).

The effect of gender and foaling period on the time to the first race has been investigated (Bailey *et al.* 1999), although no associations between these exposures and the outcome were observed. Unlike the studies in the UK (Verheyen *et al.* 2009; Ely *et al.* 2010), this study utilised retrospective race records and could not have adjusted for the exercise distance accumulated during training. Similarly, the study did not adjust for trainer, which is likely to have an effect, as the trainer will make decisions regarding the best races to enter and when to do so. A study of New Zealand trainers indicated that training practices and decisions differed with the geographical location of the trainer and the number of horses the trainer had in work (Bolwell *et al.* 2010). Additionally, some trainers may be influenced by the owners of the horses, particularly if the trainers are highly dependent on outside clients (Boyle *et al.* 2007). Further, the population studied by Bailey *et al* (1999) could be considered an elite population of horses as they were from the premier sale in Australia, which may not be representative of the wider population of racehorses.

In contrast to Bailey *et al* (1999), Cogger *et al* (2008b) conducted a prospective cohort study of Australian racehorses in training which allowed the use of survival analysis of time to the first race, or barrier start within each training preparation; this included censored horses that did not experience the event. Although univariable analysis indicated an association between the age at first start of a preparation, number of previous training preparations, gender, and racing season with the outcome, age at first start was the only significant association after adjusting for the other variables in the model. Horses that were 24-27 months old at the start of a training preparation were 1.79 (95% CI 1.18-2.70) times more likely to start in a barrier trial or race than horses that were <24 months old. The difference in these results compared to those of Bailey *et al* (1999) may be attributed to the different time periods, as Bailey *et al* (1999) used the time from the first possible start for 2-year-olds. Additionally, the authors note that the effects of age can be complicated by the training history of the horse (Cogger *et al.* 2008b). Whilst the study did not investigate exposure to specific exercise distances accumulated during training, the number of previous preparations was included as a measure of previous exercise intensity. In addition to assessing the factors that affect performance during training, the age at the start of training, gender and performance during racing have been associated with longer-term measures of performance, such as career duration (Bailey *et al.* 1999; More 1999).

The studies discussed above indicate some variation in the measurement of training and racing performance, which may limit comparisons between studies, and highlights the issue of what constitutes ‘success’ or performance in Thoroughbred racing. However, the results indicated that regardless of the measure of performance used, the workload of horses during training was associated with both performance and the risk of MSI. Therefore, future studies investigating horse or trainer-level variables and indicators of training and racing performance or the risk of MSI should aim to adjust for the potential confounding effects of exercise accumulated during training.

Exercise and the development of the musculoskeletal system

During race training

Detailed reviews on how different musculoskeletal tissues of the horse develop in response to exercise at an age when race training commences have been conducted (Smith *et al.* 1999; Firth 2006; Smith and Goodship 2008), and a full review of the literature in this area is beyond the scope of the thesis. Therefore, the most pertinent findings of the musculoskeletal responses to exercise during training are presented.

The rate of adaption of the musculoskeletal system varies with the type of tissue, age and the exercise regimen applied (Firth and Rogers 2005b; Firth 2006; Murray *et al.* 2007; Smith and Goodship 2008). The tissues responds when the exercise is above the ‘normal’ level, which results in increased strain and adaptive changes in the tissues (Firth 2006). Bone is known to be highly responsive to exercise and it adapts quickly by increasing mineral content, mineral density, organ size and strength indices, which withstand the increased loads applied (Firth and Rogers 2005b; Firth 2006). A study in New Zealand compared the effects of training 2-year-old Thoroughbreds six days a week for 13 weeks on the musculoskeletal tissues with a group of untrained horses that were kept in pasture yards (Firth *et al.* 2004). In the trained horses there was a significant effect on the size and strength of the bone compared to untrained horses (Firth *et al.* 2005).

Firth and Rogers (2005b) reported that bone apparently responded most to the training exercise in the 2-year-old horses, compared to cartilage or tendon. Although it was concluded that an adaptive response to training occurred in cartilage (Firth and Rogers 2005a), it was the tissue most likely to develop abnormalities as a result of the training (Brama *et al.* 2000a; Firth 2006). Furthermore, degenerative changes were observed in the articular cartilage of both trained and untrained horses (Firth and Rogers 2005b). Whilst it was clear that cartilage responded to exercise, the best opportunity for improving the tissue quality of cartilage may be very early in life due to a known limited capacity for repair (Brama *et al.* 2000a; Brama *et al.* 2000b).

It has been previously reported that immature tendon had the ability to adapt as a result of training, whereas tendon appeared to lose its ability to adapt after skeletal maturity (2 years and older) (Smith *et al.* 1999; Smith and Goodship 2008), leading to degeneration (Patterson-Kane *et al.* 1997a; Patterson-Kane *et al.* 1997b; Birch *et al.* 1999). Additionally, tendons appear to function very close to their physiological limits at high speed, with a narrow safety margin (Goodship 1993; Patterson-Kane and Firth 2009). The lack of response of energy-storing tendons to training may make them more susceptible to future injury (Firth 2006; Patterson-Kane and Firth 2009). Smith *et al* (2008) concluded that too much exercise during growth could have a negative effect on tendons, but there may be an optimal time for training that benefits the development of tendons.

Overall, it is clear from the studies mentioned above that there is a variable response of different tissues to exercise and a certain amount of exercise is required to initiate appropriate adaptation of the musculoskeletal tissues. However, there is still a question of the amount of exercise that is required, and the optimal time for such exercise, to ensure the tissue are enhanced and in a positive, rather than detrimental, manner.

Before race training

In agreement with the findings that exercise during race training can influence the musculoskeletal system, recent studies have suggested the importance of early exercise in young animals (Knowles and Broom 1990; Hiney *et al.* 2004; Warden *et al.* 2007) and horses (Barneveld and van Weeren 1999; Rogers *et al.* 2008a) to the development of the musculoskeletal system.

Within many sports, coaches and administrators have recognised the benefits of developing the appropriate skills early in life, during growth and maturation. Studies in humans have shown that exercise whilst young may have some beneficial effects to the development of bone, reducing the risk of MSI in later life (Hind and Burrows 2007). Cohort studies that have been used to assess the bone mineral density of young competitive athletes compared with recreational sports players (Nordstrom *et al.* 2005), identified significantly ($P<0.001$) larger bone mineral density in active and retired athletes, five years after baseline measurements, compared with recreational players. However, a selection bias towards more successful athletes and less successful recreational players may have resulted in an overestimate of the effect of exercise in this study, as authors do not state which population controls were selected or how.

A number of studies that have investigated the relationship between early weight-bearing exercise and bone health, employ cross-sectional, prospective and retrospective designs (Hind and Burrows 2007; McKay and Smith 2008) that suffer from bias as a result of poor study and exercise compliance, failing to take account of previous exercise, error in recall of exercise, injury and lifestyle in previous years, and in some cases from the techniques used to determine the changes in bone (Hind and Burrows 2007). Establishing a causal association between early exercise in humans and reduced MSI in later life is likely to prove difficult since prospective studies will need to be over a large number of years (a human lifetime) (McKay and Smith 2008), which is not feasible. Short-term randomised controlled trials, however, can be used to assess if exercise induced changes during childhood remain in early adulthood.

A systematic review of such studies found some of them to be at a low risk of bias, and concluded that interventions of weight-bearing exercise in boys and girls resulted in positive skeletal effects (Hind and Burrows 2007). Similarly, Gunter *et al* (2008) conducted a randomised, controlled, intervention trial that showed short-term exercise in early childhood resulted in a significant ($P<0.05$) increase in hip bone mineral content (BMC) compared to controls, and these differences were maintained after eight years of follow-up. A multivariable, random effects model was used to adjust for confounders (namely maturity) and account for repeated measures within individuals.

Although the long-term effects of exercise cannot be easily studied in humans, rodents and animals with a shorter lifespan provide a better model. Similar results have been shown in animal studies using rodents (Warden *et al.* 2007). After a 7-week programme of exercise, there was a significant ($P<0.05$) difference in the measures of bone quantity (bone mineral content and density) in the exercised forelimbs compared to non-exercised forelimbs. Although the differences in bone quantity did not remain after detraining, there were significant differences in bone strength ($P<0.01$) and fatigue life ($P<0.05$) between exercised and non-exercised forelimbs after de-training (92 weeks). The authors suggest that early exercise may result in lifelong benefits to bone strength and reduced fracture risk in later life. Similarly, daily wheel running of 6-12km/d for 3 months in hamsters resulted in a protective effect against cartilage degeneration (Otterness *et al.* 1998). Studies using guinea pigs and dogs have reported similar results (Helminen *et al.* 2000).

Studies in other animals have considered the effects of a lack of exercise associated with different environments and management systems. Specifically, studies in pigs have shown that confinement results in significant negative changes in parameters that contribute to bone strength, compared with pigs that did moderate exercise (Marchant and Broom 1996; Weiler *et al.* 2006). Similarly, reduced bone strength was seen in hens kept in battery cages compared with other housing systems due to a lack of wing movement (Knowles and Broom 1990), and a recent study concluded that restriction of exercise in hens had significant effects on the skeleton (Shipov *et al.* 2010).

A study using 18 bull calves investigated the effects of three different management systems: 1) confined to tie stalls; 2) confined to tie stalls with an exercise regimen imposed and 3) group housed in a 8.5m x 7.3m pen (Hiney *et al.* 2004). The exercise regimen consisted of 5 days a week running for a total of 164m, at a speed of 4m/s, for a total of 6 weeks. The exercise regimen in the confined calves resulted in an overall increase in bone mineral density (P=0.001). Short periods of high intensity exercise were shown to be beneficial to the bone of growing animals in this study, with the authors concluding that if animals are to have their natural movement limited during growth they should be supplemented with an exercise regimen (Hiney *et al.* 2004). In contrast to the latter study where no negative effects of confinement were seen, box stall confinement in young horses resulted in retardation in development of the musculoskeletal system (Nielsen *et al.* 1997; Barneveld and van Weeren 1999; Hoekstra *et al.* 1999; van Weeren *et al.* 2000; Rietbroek *et al.* 2007).

The effect of early exercise in the horse was studied in a group of 43 Dutch Warmblood foals (van Weeren and Barneveld 1999). One-week-old foals were randomly assigned into three groups consisting of those kept in stalls (3x3.5m), stalls plus an exercise regimen, and those kept at pasture for 24 hours a day. The exercise regimen consisted of gallop sprints of 40m/day; initially horses experienced 12 sprints that were increased to 16, 24 then 32 and 16 on alternate days, six days a week for five months. Foals were weaned at five months and matched for sex and sire; eight weanlings were euthanised whilst the rest remained together in a loose box with access to pasture until age 11 months. Results showed the bone mineral density of the third carpal bone was higher in the exercise group compared with the stalled (P<0.001) and pasture (P=0.01) groups at five months (Firth *et al.* 1999). At five months the cartilage of the stalled group appeared to be retarded in development, but at 11 months this finding was no longer evident (van den Hoogen *et al.* 1999). Additionally, the cross-sectional area of the bone was highest in the pasture and exercised groups compared with the stalled group; a lack of exercise in stalled horses led to a delay in the development of the bone (Cornelissen *et al.* 1999). These results suggest that withholding exercise early in life can have long-term effects on the development of the musculoskeletal system in horses.

An early study considered the effect of imposing exercise on young horses (Ruab *et al.* 1989). Nineteen Quarter Horse and Thoroughbred foals (average 147 days old) were matched for age, sex, and breed and randomly allocated into an exercise or non-exercise group. The foals were exercised 5 days/week at a speed of 3.6m/s and at increasing distances from 0.43km/day to 4.35km/day, for 72 days. The authors stated that exercise led to a greater increase in bone mineral density and circumference of the bone. However, there was no significant difference in the circumference of the bone and there was a trend (P=0.06) for a difference in the bone mineral density, between the two groups. A possible explanation for these findings is the housing of the foals during the study. Foals in both groups were kept in pairs in pens during the day and box stalls during the night. The access to exercise in the pens may have been enough to induce a response so that little difference was seen between the two groups. As discussed by Firth (2004), there are a number of methods to determine the response of bone to exercise, and the lack of differences observed by Raub *et al* (1989) could be due to the methodology used to measure bone density.

In contrast, other studies have found exercise superimposed on a box regimen to be detrimental to the development of the musculoskeletal system (van Weeren *et al.* 2000; van de Lest *et al.* 2002). In the Dutch Warmblood study (van Weeren and Barneveld 1999), the exercise in the trained group had a detrimental effect on the matrix of the superficial digital flexor tendon that resulted in reduced tissue quality at 11 months (Cherdchutham *et al.* 1999). Additionally, the viability of the cartilage was reduced in the trained group compared to the other groups at 11 months, resulting in poor cartilage response to stimulation (van den Hoogen *et al.* 1999). As a result, the exercise regimen in addition to box rest had long-term negative effects on the cartilage that led to a reduced capacity for repair and a potentially increased susceptibility to injury (van den Hoogen *et al.* 1999; van Weeren and Barneveld 1999).

Overall, it was concluded that access to free exercise at pasture was superior for the conditioning of the musculoskeletal system (Barneveld and van Weeren 1999; van Weeren *et al.* 2000). Similarly, providing foals with regular access to free exercise at pasture has been suggested as a modifiable practice that could be implemented on farms, to improve orthopaedic health (Lepeule *et al.* 2009). Likewise, Bell and others (2001) suggested that there may be benefits to keeping weanlings (average 19 weeks of age) at pasture for a minimum of 12 hours a day, since it may be enough to prevent a reduction in bone mineral content as a result of being in stalls.

A recent behavioural study investigated the level of activity performed by foals in three different management options (Kurvers *et al.* 2006). The study population consisted of 59 Warmblood foals aged from 0-16 weeks. The foals were randomly allocated into three different groups: 1) a foal and dam; 2) 2-5 foals and dams; 3) >10 foals and mares. These groups were also subdivided into those that were at pasture for 24 hrs/day and those that were stabled at night. Global satellite positioning, a handheld computer and video recording were used to quantify the behaviours and activity level of the foals. The highest workload was in the first month which was almost twice that of the fourth month. Foals stabled at night spent more time cantering ($P<0.001$) and trotting ($P=0.04$) whilst at pasture than the group at pasture for 24 hours a day; the authors suggest that this may be compensatory as they are not able to perform these activities at night. The foals at pasture for 24 hrs/day were found to have a similar level of activity as semi-feral foals, which may therefore be comparable to the natural situation.

As a result of the effects of confinement, conditioning exercise and pasture exercise on the development of the musculoskeletal system previously observed in foals, and the worldwide problem of MSI, a Global Equine Research Alliance was created (McIlwraith 2000). The aim of the Alliance was to reduce the incidence of injury in the equine athlete using a conditioning programme to modify the tissues in young horses. Subsequently, a large intervention study was set up to investigate the effect of a conditioning exercise regimen in addition to free exercise at pasture (Rogers *et al.* 2008b). The study consisted of 33 Thoroughbred foals that were matched for sex and sire, and randomly allocated to two groups: 1) pasture with no additional exercise (PASTEX) and 2) pasture plus exercise (CONDEX). The CONDEX group received a 16-18 month exercise programme that started from an average age of three weeks. The conditioning regimen was split into three phases (Table 5) and the exercise took place on an oval track, five days/week over a distance of 1030m. At age 18 months, 20 foals entered phase 2 of the study, whilst six foals from each group were euthanised.

Table 5: Description of exercise velocity and phases used in the conditioning programme by Rogers *et al* (2008)

Phase	Description	Base velocity m/s
1A	Birth to weaning	5.36 ± 0.89
1B	Weaning to 1st sprint	7.25 ± 1.75
1C	1st sprint to end phase 1	9.62 ± 0.71; 12.52 ± 3.39[a]
2	Broken, trained and raced as 2-year-olds	n/a
3	Trained and raced as 3-year-olds	n/a

[a]Sprint velocity over 129m

Results showed an absence of clinical signs of MSI in either of the two groups (Rogers *et al.* 2008b). There was no indication of any surface damage to the joints of the exercise foals (van Weeren *et al.* 2008). In addition, there appeared to be an advancement in the normal maturation of cartilage in the CONDEX group (van Weeren *et al.* 2008; Brama *et al.* 2009), which did not appear to be detrimental (Nugent *et al.* 2004; Doube *et al.* 2007), and there was some indication of positive effects (Dykgraaf *et al.* 2008). Although cartilage lesions were detected in both groups of horses, more lesions were detected in the PASTEX group but the study had low power to detect a significant difference between the two groups (Kim *et al.* 2009). Overall, these findings provided further support for a lack of negative effects of the early conditioning programme on cartilage. Additionally, there was no evidence of negative effects of exercise in tendons (Moffat *et al.* 2008; Stanley *et al.* 2008), and there was an increase in bone strength in the radius and tibia of horses from the CONDEX group (Nicholson and Firth 2010). Kawcak *et al* (2010) concluded that the early conditioning programme did not induce musculoskeletal damage and may have been beneficial as a lower prevalence of joint lesions were observed in the CONDEX group compared to the PASTEX group.

During phase 2 and 3 of the study the horses were trained by a licensed trainer who was blinded to the previous study group of the horse (Rogers *et al.* 2008a). However, as a result of the conditioning exercise, the trainer may have been able to visually distinguish which group the horses were from. The workload of the horses, time and distance, were recorded daily. There was a low incidence of MSI in both groups; although Kaplan-Meier survival analysis indicated that horses in the PASTEX group tended to show clinical signs earlier than horses in the CONDEX group, numbers were too low to draw specific conclusions. Additionally, there was no difference in the workload required to reached specific milestones, or fitness, but CONDEX horses performed significantly ($P<0.05$) more pre-race training sessions than PASTEX horses. The lack of significant positive findings may be due to a respiratory outbreak that resulted in a reduced workload for half the PASTEX horses and over half the CONDEX horses (Rogers *et al.* 2008a). Further, the results may indicate that the conditioning exercise was not strenuous enough to induce significant responses; the authors state that potential wastage as a result of injury was a concern for the sample size and also for animal welfare, which prevented the use of a more strenuous regimen. Overall, the early conditioning did not have a negative effect on the 2- and 3-year-old racing careers of the horses, and previously conditioned horses appeared to tolerate the workload of race training better than the non-conditioned horses (Rogers *et al.* 2010).

Industry practices and management of young Thoroughbred horses

Whilst the modifications of the tissues due to a conditioning programme in young foals have been described, information on how young Thoroughbred horses are being managed in the industry and the protocols for exercise before the commencement of race training is scant. In the USA, Gibbs and Cohen (2001) conducted a survey of the management of weanlings and yearlings on 58 randomly selected Thoroughbred and Quarter horse stud farms. The survey related to a whole calendar year of operation on the farm, which may have resulted in some recall bias. The results showed over half the farms kept weanlings and yearlings at pasture for 24 hrs/day with access to unlimited free exercise. Controlled exercise for yearlings was conducted on 64% of farms, with half of the farms surveyed using a scheduled exercise programme when the yearlings were 14-16 months old to prepare the yearlings for sale. One third of the farms used a mechanical walker and 52% of the farms exercised yearlings every other day.

The study conducted in the USA (Gibbs and Cohen 2001), is currently the only one to specifically report on the management and exercise of Thoroughbred yearlings at stud farms. Cross-sectional surveys have previously been used to obtain baseline data on the general management and, more specifically, weanling management on stud farms in New Zealand. Rogers *et al* (2007) described the general stallion, broodmare and young stock management on 22 stud farms selected from the 2004 New Zealand Stallion Register. The survey identified that a yearling preparation took place on stud farms before the annual sales, with an average duration of a 13 (range 6-20) weeks. However, the study focussed on general stud farm management and did not aim to report what management and exercise practices constitute yearling sales preparation.

In a later survey (Stowers *et al.* 2009), 46 commercial stud farms were surveyed on the feeding and management practices of Thoroughbred weanlings in the North Island of New Zealand. Although this survey included commercial stud farms, the definition varied slightly from Rogers (2007), with Stowers *et al* (2009) defining commercial farms as those that had >5 yearlings catalogued for the yearling sales in 2008. The results of the survey indicated that 10% of farms were exercising weanlings, a smaller percentage compared to the 26% of farms reported by Gibbs and Cohen (2001). Furthermore, unlike the survey of stud farms in the USA (Gibbs and Cohen 2001), Stowers *et al* (2009) did not report on the type or amount of exercise given to weanlings. Overall, the previous cross-sectional surveys of stud farm management in New Zealand have served to provide baseline information on foal and weanling management, but no such information exists for yearlings on stud farms in New Zealand. Additionally, there is a distinct lack of information on the current industry practices and exercise regimens for yearlings during a sales preparation.

Summary

This review of the literature highlighted that exercise, and the interruptions to exercise during training, are associated with the risk of MSI and future performance in Thoroughbred racehorses. However, there is a lack of information on the effect of interruptions on future performance. The increasing evidence for the benefits of exercise to the development of the musculoskeletal system brings into question the contentious view, held by some, that the training and racing young horses, specifically 2-year-olds, may be harmful and a cause for concern for the welfare of these horses.

A recent series of studies supports the hypothesis that conditioning exercise in young horses, before the commencement of race training, does not have harmful or negative effects on the development of the musculoskeletal tissues. Furthermore, it appears that stimulating the musculoskeletal tissues earlier in life may have long-term effects, potentially extending into the time when horses commence race training.

However, the literature review highlighted a lack of information on the effects of early conditioning regimens on the future performance of Thoroughbred racehorses. This gap in the knowledge is exacerbated by limited information on the management practices of young horses, and the components of the exercise regimens utilised in the Thoroughbred industry. Furthermore, there is a need for racing authorities to address the falling Thoroughbred populations and wastage in the supply chain, which is threatening the sustainability and success of the racing industries. Therefore, there is a requirement for epidemiological studies at a population level to identify ways to improve productivity, address the issue of wastage in the supply chain and improve equine welfare. This has led to the construction of aims and hypotheses based on the gaps in scientific knowledge, for a set of linked epidemiological studies to provide information that may assist the Thoroughbred industry in future planning and management.

AIMS AND HYPOTHESES

This thesis aims to provide an original contribution to knowledge on the effects of early exercise on future training and racing performance. This may allow the development or modification of exercise regimens that could enhance training and racing performance of Thoroughbred racehorses and optimise equine welfare.

The scope of the thesis was limited to quantifying the exercise regimens utilised on New Zealand stud farms during preparation of Thoroughbred yearlings for sale and during 2- and 3-year-old race training, and to identifying if there was an association between the exercise regimens and training and racing performance in the two-year-old year. Therefore, the specific aims and hypotheses addressed in this thesis are as follows:

Chapter 2 aims to describe the time to the first interruption during training as a 2-year-old, and identify horse and training risk factors for voluntary and musculoskeletal injury interruptions occurring before the first trial.

- **Hypothesis:** horse and exercise variables will be associated with the risk of each type of interruption.

Chapter 3 aims to investigate the effect of an interruption to training occurring before the first trial on the time to starting in a trial or a race.

- **Hypothesis**: interruptions during training before the first trial will be associated with the time to the first trial or race.

Chapter 4 documents baseline data collected via a cross-sectional survey on the management and early exercise of young Thoroughbred horses at stud farms on the North Island of New Zealand.

Chapter 5 describes the exercise, and health problems, of a cohort of Thoroughbred yearlings during preparation for sales, and to identify variations in exercise between and within farms.

Chapter 6 aims to determine the fate of horses after the yearling sales, quantify the loss of horses from sales preparation through to the end of the 2-year-old racing season and to compare the cohort of yearlings in the study population with the whole foal crop in the same year (2007).

Chapter 7 aims to investigate the effect of exercise during sales preparation on the risk of interruptions during training for a cohort of Thoroughbred racehorses.

- **Hypothesis:** total hand walking and walker exercise time will be associated with interruptions occurring before the first trial.

Chapter 8 aims to investigate the effect of early exercise in Thoroughbred yearlings on an index of training performance, the time to the first trial.

- **Hypothesis:** total hand walking and walker exercise time during yearling preparation will be associated with the time to the first trial.

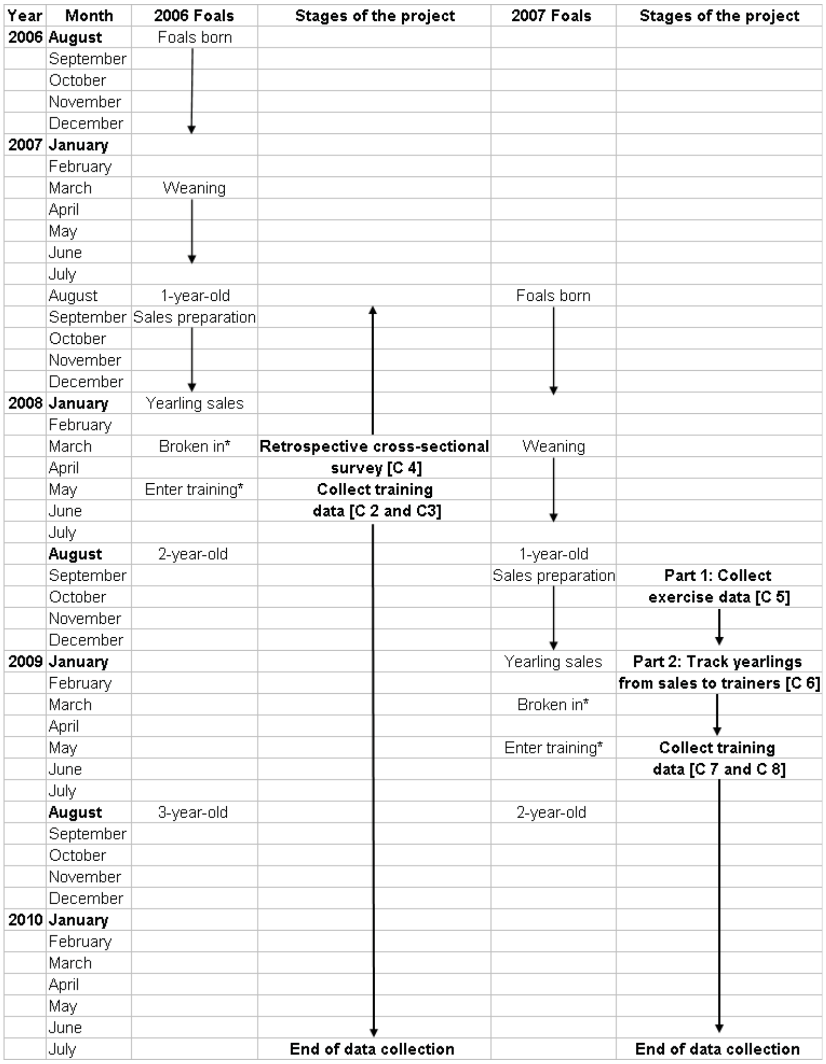
PRELUDE

The aims of this thesis were addressed through the application of a retrospective cross-sectional survey, and prospective cohort studies on commercial properties throughout New Zealand. These studies resulted in a collection of manuscripts that have been submitted for peer-reviewed publication, and comprise five of the nine chapters in this thesis.

Chapter 1 outlines the background to the problem, consists of a full review of the literature and states the aims and hypotheses investigated. **Chapter 2** reports on the methodology of a prospective study that followed a cohort of 2-year-old Thoroughbred racehorses over two racing seasons, to quantify the exercise performed during training and investigate interruptions to training that occur before the first trial. Competing risks analysis was used to investigate horse and training risk factors associated with interruptions to training. To expand on the findings reported in Chapter 2, **Chapter 3** reports on the results of a survival analysis used to identify the effects of interruptions on the time from entering training to the first trial and race start.

The previous chapters provide information on the exercise during training, whilst **Chapter 4** provides baseline information on the management and provision of exercise during a sales preparation, obtained using a cross-sectional survey of Thoroughbred stud farms in New Zealand. Based on Chapter 4, a prospective cohort study was designed to allow individual Thoroughbred yearlings to be followed through the sales preparation at the stud farm (Part 1) and into training as 2-year-olds (Part 2). **Chapter 5** reports on the collection of these daily exercise records during the sales preparation and describes the type and amount of exercise and the health problems observed during the preparation. **Chapter 6** describes the fate of the yearlings after the sales, providing comparisons with the whole foal crop, and documents the loss to follow-up that occurred as the horses progressed from the sales to entering training. **Chapter 7** describes the recruitment of trainers to the prospective study and how the training data were recorded. **Chapter 7** and **Chapter 8** investigate the effects of the early exercise regimens described in Chapter 6 on the training performance of the yearlings as 2-year-olds. Expanding on Chapters 2 and 3, **Chapter 7** investigates the time from entering training to the first interruption, whilst **Chapter 8** focuses on the time from entering training to the first trial. Finally, **Chapter 9** provides a general discussion, conclusions and industry implications of the pertinent findings from all the chapters.

This style of thesis can result in repetition of the introduction and methods in some of the chapters. Therefore, the references for each chapter are presented at the end of each chapter, and the references alluded to in Chapters 1 and 9 are presented in the bibliography at the end of the thesis. The format of the manuscripts published in various journals has been standardised to the thesis style to provide consistency. A prelude is provided before each chapter to provide a link between the other sections of the thesis, facilitating the flow of the thesis. Figure 1 presents an overview of the stages from birth to racing for a Thoroughbred racehorse in New Zealand and the relationship to the studies presented in Chapters 2-8.



Year	Month	2006 Foals	Stages of the project	2007 Foals	Stages of the project
2006	**August**	Foals born			
	September				
	October				
	November				
	December				
2007	**January**				
	February				
	March	Weaning			
	April				
	May				
	June				
	July				
	August	1-year-old		Foals born	
	September	Sales preparation			
	October				
	November				
	December				
2008	**January**	Yearling sales			
	February				
	March	Broken in*	**Retrospective cross-sectional**	Weaning	
	April		**survey [C 4]**		
	May	Enter training*	**Collect training**		
	June		**data [C 2 and C3]**		
	July				
	August	2-year-old		1-year-old	
	September			Sales preparation	**Part 1: Collect**
	October				**exercise data [C 5]**
	November				
	December				
2009	**January**			Yearling sales	**Part 2: Track yearlings**
	February				**from sales to trainers [C 6]**
	March			Broken in*	
	April				
	May			Enter training*	**Collect training**
	June				**data [C 7 and C 8]**
	July				
	August	3-year-old		2-year-old	
	September				
	October				
	November				
	December				
2010	**January**				
	February				
	March				
	April				
	May				
	June				
	July		**End of data collection**		**End of data collection**

Figure 1: An overview of the stages from birth to racing for a Thoroughbred racehorse in New Zealand and the relationship to the studies presented in this thesis. C=Chapter. *Average start time, some horses may enter later than this.

PRELUDE TO CHAPTER 2

Before the effects of early exercise on training programmes can be measured, it is important to quantify the exercise that occurs during training and the effect of this on interruptions to training.

Chapter 2 reports on following a cohort of 2-year-old Thoroughbred racehorses over two racing seasons. The study utilises a competing risks analysis to examine the horse and training risk factors for two types of interruptions occurring before the first trial.

Supplementary information providing an example of the forms used to record the data, data collection methods, and statistical analysis is presented in the appendix for this chapter. A manuscript based on Chapter 2 is in press with New Zealand Veterinary Journal.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011) Risk factors for interruptions to training occurring before the first trial start of 2-year-old Thoroughbred racehorses.

CHAPTER 2

RISK FACTORS FOR INTERRUPTIONS TO TRAINING OCCURRING BEFORE THE FIRST TRIAL START OF 2-YEAR-OLD THOROUGHBRED RACEHORSES

ABSTRACT

Aim

There is currently little information on the reasons for Thoroughbred racehorses failing to train due to non-health events. The aim of this study was to investigate the time to the first interruption during training and to identify horse and training risk factors for two types of interruptions occurring before the first trial.

Methods

A prospective cohort study was used to collect data on the training activity of 2-year-old racehorses, from 14 trainers, followed for two racing seasons (2008/09 and 2009/10). Daily training data such as, distances worked at canter (>15 seconds/200m), three measures of high speed exercise (15, 13, and <12 seconds/200m) and reasons why horses were not working, were recorded for each horse. Competing risks survival analysis was used to investigate effects of training exercise on the risk of a voluntary (no known condition or disease present), or musculoskeletal injury (due to the presence of a condition of disease) interruption occurring before the first official trial start.

Results

A total of 208 horses spent 11,339 training days at risk of an interruption before the first trial. There were 134/208 (64%) cases of interruptions, of which 115/134 (80%) were voluntary interruptions and 19/134 (14%) were due to musculoskeletal injury. Overall, the estimates for gender, age at the start of training, cumulative distance at canter, cumulative days off and high speed events differed significantly ($P<0.02$) between the two types of interruptions. Increasing age at the start of training was associated with a reduced risk of voluntary interruptions, whilst gender was not associated with voluntary interruptions but females had a decreased risk of musculoskeletal injury interruptions compared to males. Accumulating 2-3, 4-7 and

8+ days off during training was associated with an increased risk of voluntary interruptions compared to 0-1 days off, whilst there was no association between the number of high speed events and either voluntary or musculoskeletal interruptions.

Conclusions and clinical relevance

The study highlighted horse and training risk factors associated with two types of interruptions occurring during training. Identification of modifiable risk factors may help to reduce the proportion of horses experiencing an interruption before the first trial start, reducing the number of lost training days and the associated cost.

INTRODUCTION

A significant problem for the racing industries worldwide is the large proportion of horses in training that fail to start in a race (Wilsher *et al.* 2006; McCarthy 2009; Bolwell *et al.* 2010a). Therefore, the early identification of risk factors associated with training patterns would allow horses to fulfil their racing potential while reducing wastage, which is considerable in the industry (Perkins *et al.* 2004b; Dyson *et al.* 2008). Whilst risk factors for musculoskeletal injury (MSI) during training and racing have been identified (Parkin 2008), there is little information about reasons for retirement or failing to train and race due to non-health events. Perkins *et al* (2004b) found most retirements from training and racing were voluntary (based on a trainer's decision) and were most likely due to poor performance or lack of talent. Retirements and lost training days are of concern since they have economic implications for the trainer and the wider racing industry, and often lead to significant associated costs and effects.

In New Zealand, the first important milestone in a Thoroughbred horse's training career is an official trial start (Bolwell *et al.* 2010b). A pilot study indicated that whilst some horses enter training and progress uneventfully to their first official trial, other horses are delayed as a result of interruptions to their training programme (Bolwell *et al.* 2010a). Previous studies have investigated training-related factors affecting the time to first official trial/race start (Bailey *et al.* 1999; Cogger *et al.* 2008) and general racing performance (Verheyen *et al.* 2009; Ely *et al.* 2010). These studies focused on factors such as exercise, age, trainer and specific types of injury as opposed to the occurrence of an interruption, or the type of interruption. Identification of risk factors for these interruptions allows management to be modified, which, in turn, should reduce the number of training days lost, and increase the proportion of horses that progress to their first trial uneventfully.

The current study is part of a larger prospective cohort study following 2-year-old racehorses over two racing seasons. The aim of this paper is describe the time to the first interruption during training, and to identify horse and training risk factors for voluntary and MSI interruptions occurring before the first trial. We hypothesised that both horse and exercise variables would be associated with the risk of each type of interruption.

MATERIALS AND METHODS

A prospective cohort study was used to collect data on the training activity of 2-year-old racehorses followed for the 2008/09 and 2009/10 racing seasons. A convenience sample of 20 trainers from the Northern and Central Districts of New Zealand was selected based on their willingness to participate and whether they had 2-year-olds in training that season. Six trainers subsequently dropped out of the study because they were unable to comply with the requirement to keep daily records. Trainers were enrolled during February 2008 and data were collected until the 31st July 2010, the end of the New Zealand racing season. Trainers chose to enrol all, or a selection, of their 2-year-olds in training, depending on the extra work involved for them to record the information. Horses that were yearlings and not yet 2-years-old, but were approaching August 1 (official start of season) when they entered the study were classed as 2-year-olds.

Horses were enrolled in the study as they entered the trainers' yard and data were collected until the end of the study or until the horse was lost to follow-up, whichever occurred first. Horses that changed to trainers not enrolled in the study, or were sold overseas, were considered as lost to follow-up. Horse information such as dam, sire, and gender were provided by the trainer, whilst date of birth and sales information for each horse was obtained from the New Zealand Thoroughbred studbook and the yearling auction sales company (New Zealand Bloodstock Limited), respectively. Daily training data such as distances worked at canter (>15seconds/200m), and three measures of high speed exercise: 15 (15s), 13 (13s), and <12 (12s) seconds/200m, equivalent to average speed of 13.3, 15.4 and 16.7m/second, were recorded for each horse. Jump-outs, a practice start out of the gates at high speed, days off, swimming days, official race trials and races were also recorded. Trainers were asked to record reasons why horses were not working, or why they were having a break from training; veterinary diagnoses for health events were not obtained.

The methods of recording the training information varied between trainers, depending on their personal preference. Seven trainers used standardised paper forms that were returned by fax on a weekly basis and seven trainers already kept a daily training record prior to the start of the study. Five of these provided copies of their records, one trainer was telephoned each week and one trainer was visited on a monthly basis to transcribe the data. Regular contact, through visits or telephone calls, was maintained for the duration of the study to discuss and clarify data as it was being recorded.

Statistical analysis

Data were manually entered into a customised database (Microsoft Access, Microsoft Corporation, Redmond, Washington, USA) and random subsamples of the dataset were routinely cross-checked against the paper records to check for data entry errors. Additionally, a number of quality control measures were implemented in the design of the database to limit errors during the data entry process. Once all the data were entered, checks for outliers and inconsistencies were performed within the database. If errors were found, they were checked and corrected from the paper records.

Horses that were away from the training yard or not in work for >7 consecutive days were considered to have had an interruption to the training programme (Perkins *et al.* 2004a). Interruptions to training were classed as voluntary based on no known condition or disease present and involuntary due to the presence of a condition or disease. Two outcomes were investigated: 1) the time to the first interruption since entering training and 2) the time to the first interruption before the first trial start. Kaplan-Meier survival curves (Kaplan and Meier 1958) were used to quantify the median time to the first interruption during training. Competing risks survival analysis was used to investigate risk factors for two types of interruptions that occurred before the first trial: voluntary interruptions and MSI interruptions, with other types of involuntary interruptions considered as censored events. Two separate Cox regression models were created to determine cause-specific hazards for each interruption event; the other competing event was censored on the day that the event occurred.

The data were arranged so that there were multiple records per horse, with each record representing one day in training, in order to code the exercise variables as time-varying covariates. Distances at canter, 15s, and 13s, the number of days off, and the number of high speed events (12s) accumulated during the training period were calculated. The other not time-varying exposure variables investigated were age (months) at the start of training, sales background (yearling sale horse versus non-sale), gender, and trainer. The functional form of continuous variables was investigated by visually assessing the Martingale residuals as described in Dohoo *et al* (2003). If there was evidence of a non-linear relationship, the continuous variables were either investigated as fractional polynomial transformations using powers -3, -2, -1, -0.5 0, 0.5, 1, 2, or 3, (Royston and Sauerbrei 2005) or modelled as categorical variables.

Exposure variables were selected for inclusion in the multivariable models based on a cut-off of P<0.20. The final multivariable models were built using a backwards selection procedure, and exposure variables were retained in the model if they significantly improved the model fit (Likelihood ratio statistic (LRS) P-value <0.05). Non-significant exposure variables that were significant in the other models were then forced back into the final models of the other competing events, to reduce the possibility of informative censoring; an important assumption in competing risks (Singer and Willet 2003). A sensitivity analysis was performed whereby all censored observations were recoded and assumed to have experienced the event on the day of censoring.

Trainer was modelled as a frailty term to allow for potential clustering at the trainer level. As described by Singer and Willet (2003), the compound null hypothesis that the effects of all the variables collectively that were included in the final models was the same for both types of interruption, and the targeted hypothesis that the effect of individual variables was the same, were tested. The proportional hazards assumption was tested for non-time dependent exposure variables by using a statistical test that tests for a non-zero slope of the scaled Schoenfeld residuals against time (StataCorp 2009). Hazard ratios (HR) and 95% CI were calculated and the probability for assigning statistical significance was set at P<0.05. All analyses were conducted in intercooled Stata 11.1 (Statacorp LP, College Station, Texas, USA).

RESULTS

Data were collected from 220 horses across 14 trainers, and most trainers (9/14) enrolled all their 2-year-olds in training. The first day of training could not accurately be determined for 12 horses (1 trainer), as the trainer joined the study after the horses' training had started, so they were excluded from further analysis. Over half of the population were males (57%, 118/208) and most horses had come from the yearling sales (70%, 146/208).

Time to the first interruption

A total of 200 of the 208 horses experienced an interruption at some stage during their training, whilst 8 horses were lost to follow-up before an interruption occurred. Most (165/200; 83.5%) first interruptions were voluntary, whilst 30/200 (15%) were involuntary; for 5 horses the type of interruption was not recorded. The reasons stated by the trainers for each type of interruption are shown in Table 1. Not all the trainers described a specific reason for the voluntary interruptions as they were a break within exercise preparations, which formed part of the trainers' methods or practices; these interruptions were grouped together and classed as "break". Most of the involuntary interruptions were due to MSI. The time to the first interruption for the cohort of 2-year-olds is shown in Figure 1. The median number of days from entering training to the first interruption was 38 (95% CI=33-42).

Table 1: Reasons for, and duration of (days), the first voluntary and involuntary interruptions occurring during training, as reported by the trainer, for a cohort of 208 racehorses

Type of interruption and reason	Number of horses[a]	Percentage	Median duration (days)	Inter-quartile range
Voluntary				
Break[b]	81	50	50	36-94
To grow and strengthen	53	32.7	46	29-66
Immature	20	12.3	60.5	35-97
Rest	3	1.8	23	16-35
Gelded	3	1.8	73	56-152
Mentally not ready	2	1.2	54	22-86
Involuntary				
Musculoskeletal injury	25	83.3	67	42-87
Accidental injury	3	10	32	32-79
Respiratory	1	3.3	44	44-44
Other	1	3.3	93	93-93

[a] n=192; reasons were not given for 5 horses and 8 and 3 horses were lost to follow-up before and during an interruption, respectively. [b] Specific reasons were not given as the interruption was a break that was part of the trainers' methods or practices

Forty-one horses had a short median duration to the first interruption of 12 days (Interquartile Range 9-15). The trainers noted that this time in the training yard was given as education, or pre-training, to give the horses a "first look" at training. The start of these interruptions ranged from April to September with most occurring in April (10/41; 24%), June and July (9/41; 22%). Eighty-two percent (34/41) of these horses went into these education/pre-training periods after arriving at the training yard from being broken-in. Half of the trainers followed this pattern of early pre-training, but this was not applied to all their horses enrolled in the study. These 41 interruptions were excluded from further analysis as the trainer did not consider the horses to be in training during this time. Therefore, the training start date for these horses was calculated from when they entered the training stable for the second time.

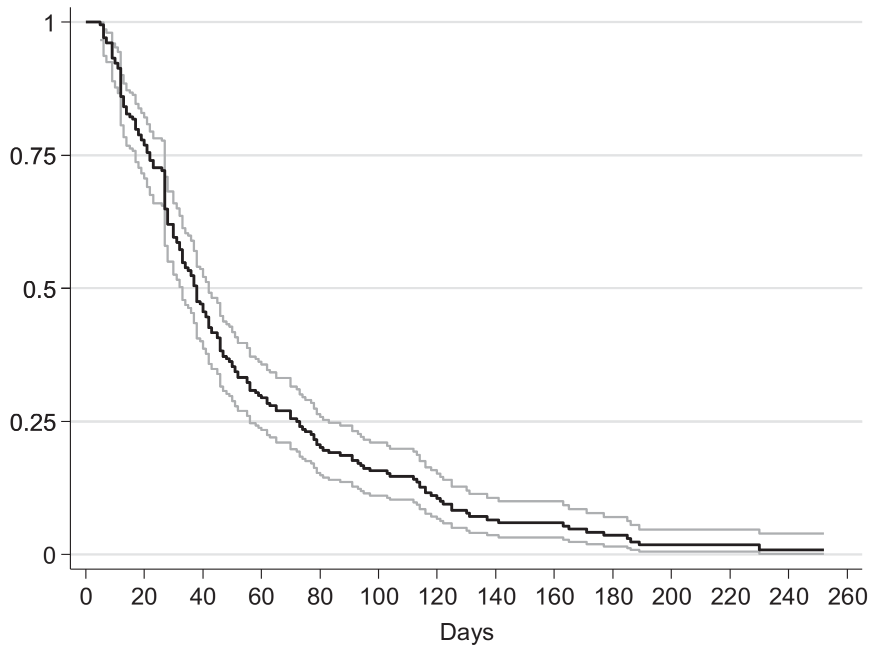


Figure 1: Kaplan-Meier 'survival' curve of the time from entering training until the first interruption for a cohort of 208 2-year-old Thoroughbred racehorses. Grey lines represent 95% confidence intervals

Time to the first interruption before the first trial start

The type of interruption was not recorded for 3 horses and these were excluded from any further analysis. Two hundred and five horses spent a total of 11,038 training days at risk and there were 137/205 (67%) cases of interruptions before the first trial. The incidence of interruptions before the first trial was 12.1 (95% CI=10.24-14.38) per 1,000 training days. Sixty-one (29%) horses progressed to their first trial with no interruptions to their training programmes, and 7 horses were lost to follow-up.

A total of 115/137 (84%) were voluntary interruptions and 19/137 (14%) were MSI interruptions. The median age at start of training was 22 months (IQR 20-25) and of those that experienced an interruption, 63% (85/134) were males and 37% (49/134) were sales horses. The distribution of the training exercise variables are shown in Table 2. The median survival time to voluntary interruptions was 58 days (95% CI=47-74), whilst the median time to MSI interruptions could not be calculated as the survival functions did not reach 50%.

Table 2: Descriptive statistics for age at the start of training and training exercise exposure variables included in competing risk models for interruptions occurring before the first trial start for a cohort of 205 2-year-old racehorses in training

Variable	Median	Interquartile range	Minimum	Maximum
Age at the start of training[a]	20	22-25	16	36
Cumulative distance at canter	52,800	24,000-99,300	0	492,300
Cumulative distance at 15s[b]	0	0-400	0	8,200
Cumulative distance at 13s[c]	0	0-0	0	6,900
Cumulative days off	4	1-8	0	14
Cumulative jump-outs				
Cumulative high speed events at 12s[d]	0	0-0	0	6

[a]months. [b]15s/200m. [c]13s/200m [d]12s/200m. Exercise variables represent the distances accumulated since entering training

Voluntary interruptions

The distances accumulated at 15s, 13s, the number of jump-outs, and the number of high speed events at 12s were not associated with the risk of voluntary interruptions following univariable screening (Table 3). The daily hazard of voluntary interruptions for female and sales horses was 0.65 (95%CI=0.44-0.95; P=0.03) and 0.70 (95%CI=0.48-1.04; P=0.08) times that of male and non-sale horses, respectively, although these were not significant in the multivariable models. The final multivariable model for voluntary interruptions is shown in Table 4.

Table 3: Results of univariable competing risks analysis of voluntary interruptions (n=115) occurring before the first trial start for a cohort of 205 2-year-old racehorses in training

Model	Coefficient	Hazard ratio	95%CI	Wald test p-value	LRS p-value[a]
Gender					
Male	-	Ref			
Female	-0.42	0.65	0.44-0.95	0.03	0.02
Sales horse					
No	-	Ref			0.09
Yes	-0.34	0.70	0.48-1.04	0.08	
Age at start of training [b]	-0.12	0.88	0.82-0.93	<0.001	<0.001
Cumulative jump-outs	0.05	1.05	0.80-1.37	0.71	0.71
Cumulative distance at canter[c]					
0-<24000	-	Ref			<0.001
24000- <52800	1.04	2.83	0.66-12.1	0.16	
52800- <100300	-0.07	0.92	0.20-4.10	0.92	
100300 +	-0.40	0.66	0.13-3.20	0.61	
Cumulative days off					
0-1	-	Ref			<0.001
2-3	2.33	10.37	1.23-87.0	0.03	
4-7	2.72	15.2	2.10-110.7	0.007	
8+	3.26	26.05	3.57-189.6	0.001	
Cumulative 15s[c]	-8.4e-06	0.99	0.99-1.00	0.94	0.94
Cumulative 13s[c]	8.3e-04	1.00	0.99-1.00	0.55	0.56
Cumulative number of high speed events [d]	0.10	1.11	0.88-1.39	0.35	0.37

[a]LRS = Likelihood ratio statistic P-value. [b]months. [c]Distance in metres. [d]High speed events = 12s/200m. Ref= reference level for comparison.

The risk of a voluntary interruption decreased approximately linearly with increasing age at start of training. After adjusting for the other variables included in the model, gender was no longer significantly associated with voluntary interruptions. Cumulative canter distance and the number of days off were modelled as categorical variables (based on quartiles) in the final model (Table 4). Trainer was significantly associated with the risk of a voluntary interruption, suggesting there was clustering at the trainer level.

Table 4: Final multivariable competing risks model of voluntary interruptions (n=115) occurring before the first trial start for a cohort of 205 2-year-old racehorses in training

Model	Coefficient	Hazard ratio	95%CI	Wald test p-value	LRS p-value[a]
Voluntary interruption (n=115)					
Gender					0.09
Male	Ref	Ref	-	-	
Female	-0.36	0.69	0.45-1.06	0.09	
Age at start of training (months)	-0.08	0.91	0.84-0.98	0.02	0.02
Cumulative distance at canter [b]					0.003
0-<24000	Ref	Ref	-	-	
24000- <52800	1.23	3.43	0.78-14.9	0.10	
52800- <100300	0.24	1.27	0.35-6.40	0.76	
100300 +	-0.05	0.94	0.15-5.65	0.95	
Cumulative days off					<0.001
0-1	Ref	Ref	-	-	
2-3	2.36	10.61	1.21-92.8	0.03	
4-7	2.70	14.91	1.87-118.6	0.01	
8+	3.16	23.74	2.90-194.1	0.003	
Cumulative number of high speed events [c]	0.17	1.19	0.93-1.52	0.16	0.18
Trainer[d]					<0.001

[a]LRS = Likelihood ratio statistic P-value. [b]Distance in metres. [c]High speed events = 12s/200m. [d]Variance estimate for the trainer shared frailty term = 0.36 (Standard error = 0.20). Ref= reference level for comparison

MSI interruptions

The distances accumulated at canter, 15s, 13s the number of jump-outs, being a sales horse, and age at the start of training were not associated with the risk of MSI interruptions following univariable screening (Table 5) The final multivariable model, with variables significant for voluntary interruptions included, is shown in Table 6. After adjusting for the other variables in the model, females were less likely to experience a MSI interruption compared to males. There was a trend for an association between the number of days off accumulated during training and an increased risk of MSI interruptions. After adjusting for the other variables in the model, there was no association between the cumulative number of high speed events at 12s, days off, and the distance accumulated at canter with the risk of MSI interruptions. Some clustering at the trainer-level may be present in the final model, although the frailty term for trainer was not statistically significant at the P<0.05 level.

Table 5: Results of univariable competing risks analysis of musculoskeletal injury interruptions (n=19) occurring before the first trial start for a cohort of 205 2-year-old racehorses in training

Model	Coefficient	Hazard ratio	95%CI	Wald test p-value	LRS p-value[a]
Gender					
Male	-	Ref			
Female	-0.85	0.42	0.16-1.12	0.08	0.07
Sales horse					
No	-	Ref			
Yes	-0.41	0.65	0.24-1.77	0.40	0.42
Age at start of training[b]	-0.01	0.98	0.86-1.12	0.85	0.85
Cumulative jump-outs	-0.33	0.71	0.34-1.48	0.36	0.32
Cumulative distance at canter[c]					
0-<24000	-	Ref			0.70
24000- <52800	-0.47	0.62	0.05-7.06	0.70	
52800- <100300	0.36	1.43	0.08-24.8	0.80	
100300 +	-0.29	0.74	0.03-14.0	0.84	
Cumulative days off					
0-1	-	Ref			0.13
2-3	1.30	3.69	0.34-39.6	0.28	
4-7	0.96	2.62	0.24-28.7	0.42	
8+	1.96	7.11	0.72-69.4	0.09	
Cumulative 15s[c]	2.9e-06	1.00	0.99-1.00	0.98	0.98
Cumulative 13s[c]	7.4e-04	1.00	0.99-1.00	0.75	0.75
Cumulative number of high speed events[d]	0.33	1.39	0.97-2.00	0.07	0.09

[a]LRS=Likelihood ratio statistic P-value. [b]months. [c]Distance in metres. [d]High speed events = 12s/200m. Ref= reference level for comparison

Table 6: Final multivariable competing risks model of musculoskeletal injury interruptions (n=19) occurring before the first trial start for a cohort of 205 2-year-old racehorses in training

Model	Coefficient	Hazard ratio	95%CI	Wald test p-value	LRS p-value[a]
Gender					0.04
Male	Ref	Ref	-	-	
Female	-1.03	0.35	0.12-1.00	0.05	
Age at start of training (months)	-0.06	0.94	0.80-1.09	0.43	0.43
Cumulative distance at canter[b]					0.56
0-<24000	Ref	Ref	-	-	
24000-<52800	0.05	1.06	0.07-15.15	0.96	
52800-<100300	1.58	4.89	0.16-147.3	0.36	
100300 +	1.52	4.61	0.09-217.9	0.43	
Cumulative days off					0.08
0-1	Ref	Ref	-	-	
2-3	1.81	6.13	0.50-74.05	0.15	
4-7	1.64	5.20	0.37-72.8	0.22	
8+	2.76	15.90	1.12-224.6	0.04	
Cumulative number of high speed events[c]	0.20	1.22	0.81-1.83	0.33	0.36
Trainer[d]					0.07

[a]LRS=Likelihood ratio statistic P-value. [b]Distance in metres. [c]High speed events = 12s/200m. [d]Variance estimate for the trainer shared frailty term = 0.54 (Standard error = 0.54). Ref= reference level for comparison.

Model fit

The sensitivity analysis identified some changes in the magnitude of the hazard ratios for cumulative days off and cumulative canter for voluntary interruptions. No variables were found to violate the proportional hazards assumption in either the voluntary or MSI interruption models (P=0.25 and P=0.67, respectively). Overall, the parameter estimates from the final models differed significantly between the type of interruption (P<0.02) and the effect of gender was found to differ significantly (P<0.02) across voluntary and involuntary interruptions.

DISCUSSION

This study aimed to identify risk factors for two types of interruptions occurring during training, before the first trial start. The study population consisted of a cohort of 2-year-old racehorses in training with trainers that were enrolled in the study through a convenience sample. As such, the study population may not be representative of all 2-year-old racehorses in training in New Zealand. However, due to the nature of the data collection, daily observations over an entire racing season and high levels of co-operation were important in order to ensure accuracy of the data. Although the trainers were able to choose the number of horses enrolled in the study, most trainers enrolled all their 2-year-olds in training, reducing the possibility of selection bias. In contrast to similar longitudinal studies conducted in the United Kingdom (Verheyen and Wood 2004), evaluation of the external validity of our study population could not be performed as there is no equivalent publication of the horses in training in New Zealand. However, interval validity was maintained through regular contact with the trainers during data collection and through quality control measures during data entry.

Most of the first interruptions occurring before an official trial were voluntary, due to a decision made by the trainer. Most horses entered training before they had officially turned two and the risk of a voluntary interruption decreased as the age of the horse at the start of training increased. After standardised breaks that formed part of the trainers' programme, most voluntary interruptions were due to the trainer believing the horse needed to "strengthen and grow" or "mature" before continuing with its racing campaign. However, it should be noted that some conditions may have gone undiagnosed and could have been misclassified as a voluntary interruption. Accumulating more days off was a risk factor for voluntary interruptions, suggesting they may be the horses that are perceived to be less "strong" and "mature" and so they experience an interruption. Similarly, a previous cross-sectional survey (Bolwell *et al.* 2010b) identified the duration of spells (breaks/interruptions) in 2-year-olds was related to the perceived physical maturity of the horse. This suggests that young horses brought into training earlier are in training primarily for education, to become familiar with the stable routines and track work, which is in agreement with the findings of Bolwell *et al* (2010b) and Perkins *et al* (2004a).

Gender was found to be associated with the risk of MSI interruptions and the effects of gender differed for the two types of interruption. In agreement with the literature reporting significant effects of gender on a number of MSI case definitions (Perkins *et al.* 2005b; Boden *et al.* 2007; Dyson *et al.* 2008), females were less likely than males to experience an involuntary interruption. Despite this, gender represents a factor that cannot be easily modified by a racing industry. However, a recent study showed that the average exercise accumulated by yearlings during a sales preparation differed significantly between colts and fillies (Bolwell *et al.* 2011 [Chapter 5]). This, along with an increasing body of evidence (Barneveld and van Weeren 1999; Rogers *et al.* 2008a, 2008b), suggests that the early conditioning environment may have a role to play in the future training and racing ability of racehorses. Further work to investigate the hypotheses relating to early exercise in our study is ongoing and will be reported on separately [Chapter 7 and 8].

Studies investigating the effect of high speed exercise on a number of MSI case definitions have usually focused on the distances accumulated rather than the number of high speed events (Perkins *et al.* 2005a; Verheyen *et al.* 2006). However, one study investigating retirements from tendon injury in Hong Kong (Lam *et al.* 2007), showed a reduced risk of tendon injury with an increasing number of high speed events. In contrast, the current study did not find any association between MSI interruptions and the accumulation of high speed events during training. The lack of significance in the final model may be due to a lack of power as a result of few MSI interruptions.

Significant clustering at the trainer level was evident for voluntary interruptions, but not for musculoskeletal interruptions. Voluntary interruptions are based on the trainers' decision to give the horse a rest from training, which may be influenced by a number of factors. These results suggest that there may be other management factors, or decisions, not measured in the current study that are influencing the risk of voluntary interruptions during training. A recent survey highlighted differences in training practices in New Zealand with trainer location and number of horses in work (Bolwell *et al*. 2010b), however further investigation of trainer-level factors is required. Although the trainers' detailed record of specific distances and speeds were utilised in the current study, differences between terminology used and the subjective nature of recording training data has been highlighted (Rogers and Firth 2004). Future studies should aim to utilise GPS-based systems to record data on the speeds and distances travelled (Kingston *et al*. 2006; Fonseca *et al*. 2010), in order to enhance the accuracy of training data.

This study identified horse and training risk factors for two types of interruptions during training. Each type of interruption was associated with a different set of risk factors. Identification of modifiable risk factors may help to reduce the proportion of horses experiencing an interruption before the first trial start, reducing the number of lost training days and the associated cost.

REFERENCES

Bailey, C.J., Reid, S.W., Hodgson, D.R. and Rose, R.J. (1999) Factors associated with time until first race and career duration for Thoroughbred racehorses. *Am. J. vet. Res.* **60**, 1196-1200.

Barneveld, A. and van Weeren, P.R. (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine. vet. J., Suppl.* **31**, 112-119.

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Clarke, A.F. and Slocombe, R.F. (2007) Risk factors for Thoroughbred racehorse fatality in flat starts in Victoria, Australia (1989-2004). *Equine vet. J.* **39**, 430-437.

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2010a) Identification of three distinct sub-populations of 2-year-old racehorses in training. In: *Proceedings of the 18th International Conference of Racing Analysts and Veterinarians* Queenstown, New Zealand. p 49.

Bolwell, C.F., Russell, L.J. and Rogers, C.W. (2010b) A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comp. Exerc. Physiol.* **7**, 37-42.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011) Exercise in Thoroughbred yearlings during sales preparation: A cohort study. *Equine vet. J.*, no.10.1111/j.2042-3306.2011.00370.x.

Cogger, N., Perkins, N., Hodgson, D., Reid, S. and Evans, D. (2008) Profiling training preparation in young Australian Thoroughbred racehorses. *Aust. vet. J.* **86**, 419-424.

Dohoo, I., Martin, W. and Stryhn, H. (2003) Modelling survival data. In: *Veterinary Epidemiologic Research*, Eds: I. Dohoo, W. Martin and H. Stryhn, AVC Inc, Charlottetown, Canada. p 439.

Dyson, P.K., Jackson, B.F., Pfeiffer, D.U. and Price, J.S. (2008) Days lost from training by two- and three-year-old Thoroughbred horses: A survey of seven UK training yards. *Equine vet. J.* **40**, 650-657.

Ely, E.R., Price, J.S., Smith, R.K., Wood, J.L.N. and Verheyen, K.L.P. (2010) The effect of exercise regimens on racing performance in National Hunt racehorses. *Equine vet. J.* **42**, 624-629.

Fonseca, R.G., Kenny, D.A., Hill, E.W. and Katz, L.M. (2010) The association of various speed indices to training responses in Thoroughbred flat racehorses measured with a global positioning and heart rate monitoring system. *Equine vet. J.* **42**, 51-57

Kaplan, E.L. and Meier, P. (1958) Nonparametric estimation from incomplete observations. *J. Amer. Statistical. Assoc.* **53**, 457-481.

Kingston, J.K., Soppet, G.M., Rogers, C.W. and Firth, E.C. (2006) Use of a global positioning and heart rate monitoring system to assess training load in a group of Thoroughbred racehorses. *Equine vet. J.* **38**, 106-109.

Lam, K.K.H., Parkin, T.D.H., Riggs, C.M. and Morgan, K.L. (2007) Evaluation of detailed training data to identify risk factors for retirement because of tendon injuries in Thoroughbred racehorses. *Am. J. vet. Res.* **68**, 1188-1197.

McCarthy, G. (2009) Analysis of supply chain wastage in the Thoroughbred and Harness racing codes. In: *The foundation bulletin. Volumne 14. Number 4*, New Zealand Equine Research Foundation, Palmerston North, New Zealand.

Parkin, T.D.H. (2008) Epidemiology of Racetrack Injuries in Racehorses. *Vet. Clin. N. Am.: Equine Pract.* **24**, 1-19.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004a) Profiling the New Zealand Thoroughbred racing industry. 2. Conditions interfering with training and racing. *N.Z. vet. J.* **53**, 69-76.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004b) Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *N.Z. vet. J.* **53**, 59-68.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2005a) Risk factors for injury to the superficial digital flexor tendon and suspensory apparatus in Thoroughbred racehorses in New Zealand. *N.Z. vet. J.* **53**, 184-192.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2005b) Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *N.Z. vet. J.* **53**, 171-183.

Rogers, C.W. and Firth, E.C. (2004) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 2. Measurement error and effect of training stage on the relationship between objective and subjective criteria of training workload. *N.Z. vet. J.* **52**, 272 - 279.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008a) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine vet. J.* **40**, 111-118.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008b) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2 and 3 year old racing careers. *Equine vet. J.* **40**, 119-127.

Royston, P. and Sauerbrei, W. (2005) Building Multivariable Regression Models with Continuous Covariates in Clinical Epidemiology. *Meth. Inform. Med.* **44**, 561-571.

Singer, J.D. and Willet, J.B. (2003) *Applied Longitudinal Data Analysis: Modeling Change and Event Occurence*, Oxford University Press, Inc, Oxford, New York.

StataCorp (2009) *Survival Analysis and Epidemiological Tables Reference Manual: Release 11* Stata Press, College Station, Texas, USA.

Verheyen, K., Price, J., Lanyon, L. and Wood, J. (2006) Exercise distance and speed affect the risk of fracture in racehorses. *Bone* **39**, 1322-1330.

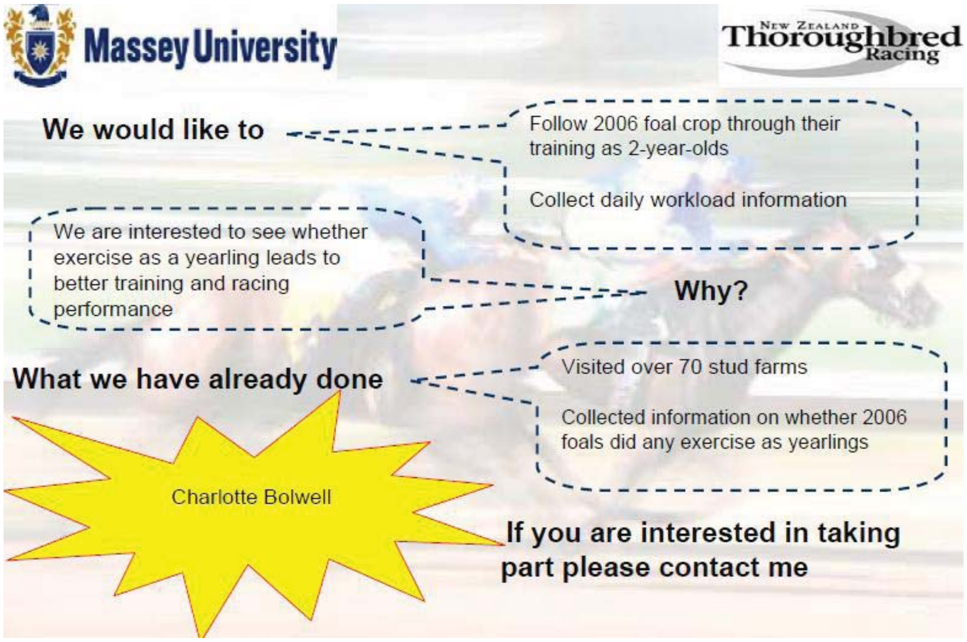
Verheyen, K.L. and Wood, J.L. (2004) Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. *Equine vet. J.* **36**, 167-173.

Verheyen, K.L.P., Price, J.S. and Wood, J.L.N. (2009) Exercise during training is associated with racing performance in Thoroughbreds. *Vet. J.* **181**, 43-47.

Wilsher, S., Allen, W.R. and Wood, J.L. (2006) Factors associated with failure of thoroughbred horses to train and race. *Equine vet. J.* **38**, 113-118

APPENDIX A

In this appendix, examples of the flyer (Figure A1) and notice (Figure A2) used to raise awareness of the project are presented. This appendix includes an example of the standardised forms used by half of the trainers to record the daily training information and an extract of data from the customised database (Figures A3 and A4). Furthermore, an example of how the data were structured for the competing risks analysis is shown in Figure A5, and the results of the sensitivity analysis for informative censoring are presented in Table A1.



We would like to

Follow 2006 foal crop through their training as 2-year-olds

Collect daily workload information

Why?

We are interested to see whether exercise as a yearling leads to better training and racing performance

What we have already done

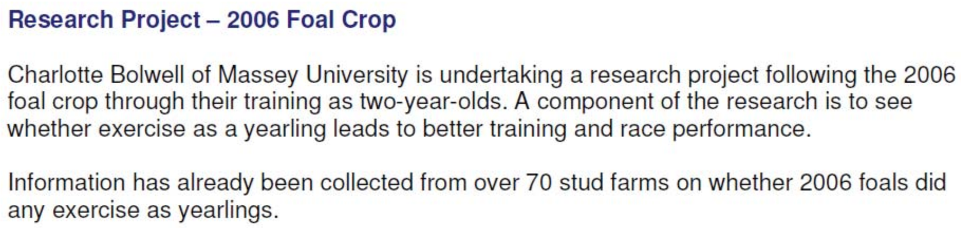
Visited over 70 stud farms

Collected information on whether 2006 foals did any exercise as yearlings

Charlotte Bolwell

If you are interested in taking part please contact me

Figure A1: Flyer given to trainers to raise awareness of the project. The contact information was provided in the yellow area but has been removed for confidentiality reasons.



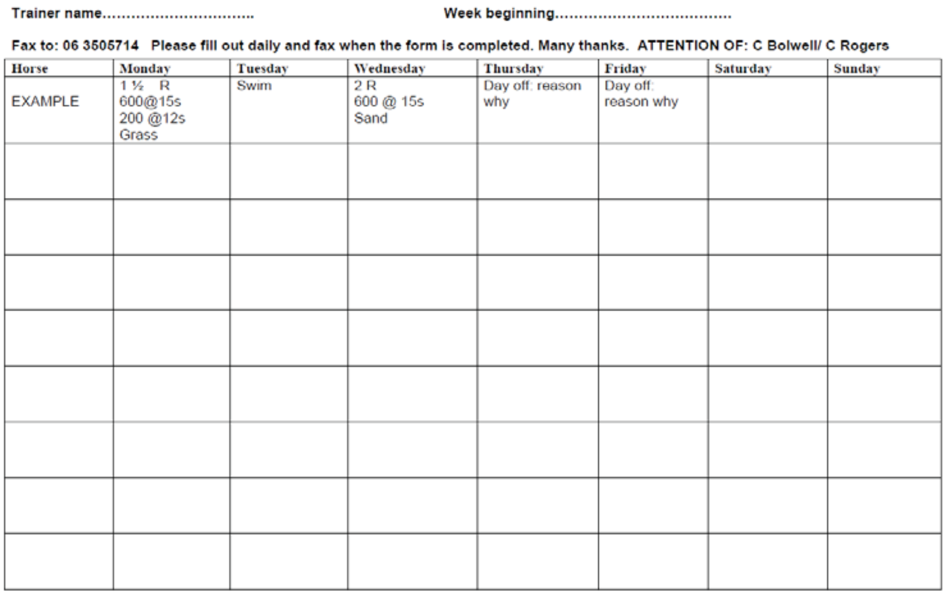
Research Project – 2006 Foal Crop

Charlotte Bolwell of Massey University is undertaking a research project following the 2006 foal crop through their training as two-year-olds. A component of the research is to see whether exercise as a yearling leads to better training and race performance.

Information has already been collected from over 70 stud farms on whether 2006 foals did any exercise as yearlings.

Figure A2: An excerpt from the New Zealand Thoroughbred Racing Inc Media Bulletin emailed to trainers on Tuesday 6th May 2008, to raise awareness of the project. For confidentiality reasons, the contact information given to trainers has been removed.

An example of the standardised form used by trainers to record daily training information is shown in Figure A3. The full size of the form was A4 landscape, and some trainers had personalised forms with the names of the horses enrolled in the study included on the form, and the number of rows altered to match the number of horses. Figure A4 shows an example of the structure of the data in the customised database.

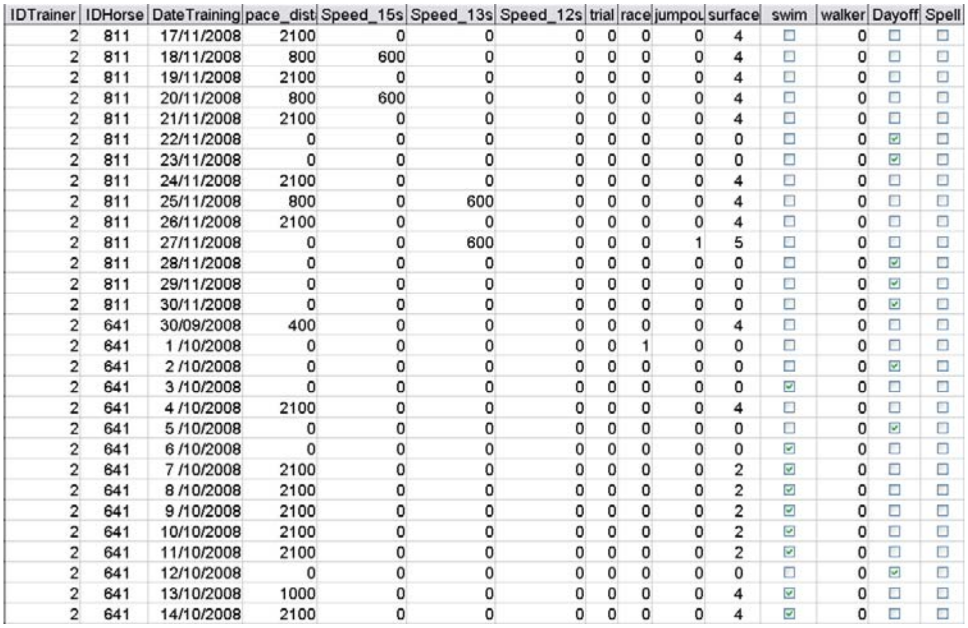


Trainer name................................ **Week beginning.....................................**

Fax to: 06 3505714 Please fill out daily and fax when the form is completed. Many thanks. ATTENTION OF: C Bolwell/ C Rogers

Horse	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
EXAMPLE	1 ½ R 600@15s 200 @12s Grass	Swim	2 R 600 @ 15s Sand	Day off: reason why	Day off: reason why		

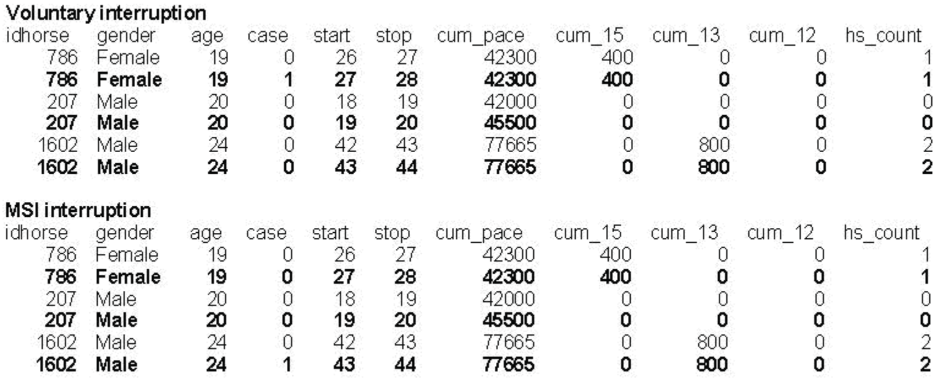
Figure A3: An example of the forms used to record daily exercise during training.



IDTrainer	IDHorse	DateTraining	pace_dist	Speed_15s	Speed_13s	Speed_12s	trial	race	jumpou	surface	swim	walker	Dayoff	Spell
2	811	17/11/2008	2100	0	0	0	0	0	0	4	☐	0	☐	☐
2	811	18/11/2008	800	600	0	0	0	0	0	4	☐	0	☐	☐
2	811	19/11/2008	2100	0	0	0	0	0	0	4	☐	0	☐	☐
2	811	20/11/2008	800	600	0	0	0	0	0	4	☐	0	☐	☐
2	811	21/11/2008	2100	0	0	0	0	0	0	4	☐	0	☐	☐
2	811	22/11/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	811	23/11/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	811	24/11/2008	2100	0	0	0	0	0	0	4	☐	0	☐	☐
2	811	25/11/2008	800	0	600	0	0	0	0	4	☐	0	☐	☐
2	811	26/11/2008	2100	0	0	0	0	0	0	4	☐	0	☐	☐
2	811	27/11/2008	0	0	600	0	0	0	1	5	☐	0	☐	☐
2	811	28/11/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	811	29/11/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	811	30/11/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	641	30/09/2008	400	0	0	0	0	0	0	4	☐	0	☐	☐
2	641	1 /10/2008	0	0	0	0	0	1	0	0	☐	0	☐	☐
2	641	2 /10/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	641	3 /10/2008	0	0	0	0	0	0	0	0	☑	0	☐	☐
2	641	4 /10/2008	2100	0	0	0	0	0	0	4	☐	0	☐	☐
2	641	5 /10/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	641	6 /10/2008	0	0	0	0	0	0	0	0	☑	0	☐	☐
2	641	7 /10/2008	2100	0	0	0	0	0	0	2	☑	0	☐	☐
2	641	8 /10/2008	2100	0	0	0	0	0	0	2	☑	0	☐	☐
2	641	9 /10/2008	2100	0	0	0	0	0	0	2	☑	0	☐	☐
2	641	10/10/2008	2100	0	0	0	0	0	0	2	☑	0	☐	☐
2	641	11/10/2008	2100	0	0	0	0	0	0	2	☑	0	☐	☐
2	641	12/10/2008	0	0	0	0	0	0	0	0	☐	0	☑	☐
2	641	13/10/2008	1000	0	0	0	0	0	0	4	☑	0	☐	☐
2	641	14/10/2008	2100	0	0	0	0	0	0	4	☑	0	☐	☐

Figure A4: Extract of the data entered for each horse in the customised database

Figure A5 provides an example of the data structure used for the competing risk analysis. An extract has been taken from the daily records of three horses to indicate the process of censoring in the competing risks analysis. Each horse has additional daily entries and other exercise variables not presented here. Three different datasets were created for each outcome, where the ‘case’ variable for each analysis was classed as either voluntary or MSI interruption. The ‘case’ variable was coded as one to represent the occurrence of an event, and zero to indicate censoring, due to other events or loss to follow up. Only the first case event that occurred for each horse was considered in the analysis and horses were no longer considered at risk after the first interruption occurred. The entries highlighted in bold in Figure A5, indicate how the ‘case’ variable for the same horse was coded in the three different models. For example, horse 786 has a voluntary event on day 28 and is therefore censored on day 28 in the MSI interruption datasets. Horse 1602 has an MSI event on day 43 and is therefore coded as censored on day 43 in the voluntary datasets.



Voluntary interruption

idhorse	gender	age	case	start	stop	cum_pace	cum_15	cum_13	cum_12	hs_count
786	Female	19	0	26	27	42300	400	0	0	1
786	**Female**	**19**	**1**	**27**	**28**	**42300**	**400**	**0**	**0**	**1**
207	Male	20	0	18	19	42000	0	0	0	0
207	**Male**	**20**	**0**	**19**	**20**	**45500**	**0**	**0**	**0**	**0**
1602	Male	24	0	42	43	77665	0	800	0	2
1602	**Male**	**24**	**0**	**43**	**44**	**77665**	**0**	**800**	**0**	**2**

MSI interruption

idhorse	gender	age	case	start	stop	cum_pace	cum_15	cum_13	cum_12	hs_count
786	Female	19	0	26	27	42300	400	0	0	1
786	**Female**	**19**	**0**	**27**	**28**	**42300**	**400**	**0**	**0**	**1**
207	Male	20	0	18	19	42000	0	0	0	0
207	**Male**	**20**	**0**	**19**	**20**	**45500**	**0**	**0**	**0**	**0**
1602	Male	24	0	42	43	77665	0	800	0	2
1602	**Male**	**24**	**1**	**43**	**44**	**77665**	**0**	**800**	**0**	**2**

Figure A5: Example of the data structure used in the competing risks analysis.

Table A1 shows the results of the sensitivity analysis to check for informative censoring in the competing risks analysis. Hazard ratios and 95% confidence intervals are presented for the final model and the informative censoring model for both the voluntary outcome. Some changes in the magnitude of the hazard ratios were observed, suggesting that informative censoring may have occurred in the competing risks models. However, the sensitivity analysis was a worst case scenario as it presumed that horses experienced a voluntary or MSI event had they not been censored. Given some of the reasons cited for voluntary interruptions and the nature of training, this scenario seems doubtful in reality.

Table A1: Results of the final voluntary and involuntary interruption competing risks models and of a sensitivity analysis for informative censoring.

	Final model		Informative censoring model	
Variable	**Hazard Ratio**	**95%CI[a]**	**Hazard Ratio**	**95%CI[a]**
Voluntary interruption				
Gender				
Male	Ref		Ref	
Female	0.69	0.45-1.06	0.65	0.44-0.96
Age at start of training (months)	0.91	0.84-0.98	0.91	0.85-0.98
Cumulative distance at canter [b]				
0-<24000	Ref		Ref	
24000- <52800	3.43	0.78-14.9	2.60	0.85-7.94
52800- <100300	1.27	0.35-6.40	1.21	0.34-4.33
100300 +	0.94	0.15-5.65	0.98	0.23-4.12
Cumulative days off				
0-1	Ref		Ref	
2-3	10.61	1.21-92.8	20.2	2.47-165.3
4-7	14.91	1.87-118.6	24.2	3.09-189.9
8+	23.74	2.90-194.1	38.1	4.78-304.4
Cumulative number of high speed events (12s)[c]	1.19	0.93-1.52	1.27	1.04-1.55

[a]CI = Confidence interval. [b]Distance in metres. [c]12s = 12s/200m. Ref = Reference level for comparison.

PRELUDE TO CHAPTER 3

Chapter 2 quantified the exercise that occurred during training in a cohort of 2006-born Thoroughbred, over two racing seasons. The horse and training factors that were associated with the time to two types of interruptions occurring before the first trial were identified. Although the factors associated with the interruptions were discussed, there is no information on the effect of these interruptions on training and racing performance.

Therefore, the manuscript presented in Chapter 3 investigates the effect of interruptions, before the first trial, on the time to starting in a trial or a race in the same cohort of 2- and 3-year-old horses.

Supplementary information on the model diagnostics used in the statistical analysis is presented in the appendix for this chapter. Chapter 3 is based on a manuscript submitted to Preventive Veterinary Medicine.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011) The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses.

CHAPTER 3

THE EFFECT OF INTERRUPTIONS DURING TRAINING ON THE TIME TO THE FIRST TRIAL AND RACE START IN THOROUGHBRED RACEHORSES

ABSTRACT

Few studies have investigated the effect of having interruptions during training on future training and racing performance in Thoroughbred racehorses. The aim of this paper was to investigate the effect of having an interruption before the first trial on starting in a trial or a race. A prospective cohort study was used to record the training activity of a cohort of Thoroughbred racehorses, over two racing seasons. Fourteen racehorse trainers recorded information on the distances worked at canter and at fast speeds (<15s/200m) and provided reasons for horses not training, or for having interruptions (break from training). Trial and racing results were obtained from the New Zealand Thoroughbred Racing online database. A Cox proportional hazards regression model was developed to investigate two outcome measures of performance: 1) time to the first trial and 2) time to the first race. The type of interruption that had occurred before the first trial was the main exposure of interest, and was grouped into: no interruption, voluntary (no known condition or disease present) and involuntary interruptions (due to the presence of a condition or disease).

A total of 160/200 (80%) horses started in at least one trial and 100/205 (48%) horses started in at least one race during the study period. The median time to starting in a trial or a race differed significantly (P<0.001) with the type of interruption. Horses experiencing voluntary and involuntary interruptions were significantly (P<0.001) less likely to trial but there was no association with starting in race, after adjusting for confounding variables. Horses that were older at the start of training were less likely to trial than younger horses. Horses accumulating longer distances at 15s/200m were more likely to start in a trial. Horses accumulating fewer events at high speed and fewer trials were less likely to start in a race. There was significant clustering at the trainer level for both the outcomes investigated. Interruptions to training occurring before the first trial start had an effect on the time to, and hazard of, a trial but not a race start. The timing of these interruptions may have implications for future racing success and career longevity.

INTRODUCTION

Success of the Thoroughbred racing industry relies on the production of horses that can race as 2-year-olds and continue to race for a number of seasons. However, there has been a steady decline in the number of starters and starts per horse over recent seasons (McCarthy 2008; Anon 2011a). One of the major threats the industry faces is the loss of horses from training and racing due to lack of talent, or as a result of musculoskeletal injury (MSI). A detailed prospective epidemiological study of racehorses in training in New Zealand reported that 65% and 35% of retirements from training were due to voluntary and involuntary events, respectively (Perkins *et al.* 2004a).

A number of terms such as: spell (Perkins *et al.* 2004a, b; Bolwell *et al.* 2010), layup (Carrier *et al.* 1998; Estberg *et al.* 1998), and interruptions have been used to describe the rest periods given to horses during training. Perkins *et al* (2004a, b) identified training preparations that had voluntary or involuntary interruptions, classified as more than 7 days out of training, and described the conditions causing the interruptions and their effect on the number of starts and places per start. Other studies show that exercise distances performed during training were associated with racing performance (Verheyen *et al.* 2009; Ely *et al.* 2010), suggesting training distances should be considered as potential confounders for other observed associations of horse and trainer-level variables with racing performance.

To date, there is not one standard outcome measure of racing performance that is used within the scientific equine research community. Thus, a number of outcome measures, such as starting in a trial or race, winning a race, amount of prize money won, and number of starts, are often used (Cheetham *et al.* 2010; Tanner *et al.* 2011), in an attempt to quantify racing performance. Bolwell *et al* (2010) reported that the first training gallop and the first trial were important milestones used by trainers when evaluating a horse's progress. Similarly, starting in a race is an important milestone that provides the first opportunity for a financial return. Reaching key milestones, such as being registered with a trainer, trialling and racing as a 2-year-old, appears to be positively associated with racing success and career length (Bailey *et al.* 1999; More 1999; Tanner *et al.* 2011). Exercise, specific types of injury, age, and trainer have been found to be associated with the time to the first trial (Bailey *et al.* 1999; Cogger *et al.* 2008), but these studies did not consider the occurrence, or type, of an interruption to training.

Information on the effect of interruptions on training and racing milestones is scant. We have recently conducted a prospective cohort study, carried out in New

Zealand, following 2-year-old racehorses over two racing seasons, which identified risk factors for interruptions occurring during training before the first trial (Bolwell *et al.* 2011 [Chapter 2]).

The aim of the work reported here was to investigate the effect of an interruption to training occurring before the first trial on the time to starting in a trial or a race. Such data may assist in making important training decisions, and affect how a horse progresses through training to racing. We hypothesised that there would be an association between an interruption to training and the time taken to start in a trial or race

MATERIALS AND METHODS

Sample population

Training activity data of a cohort of Thoroughbred racehorses were collected over two racing seasons as part of a recent epidemiological study, of which details of enrolment of trainers and horses have been reported elsewhere (Bolwell *et al.* 2011 [Chapter 2]). Briefly, 14 racehorse trainers were selected as part of a convenience sample to record the daily training activity for their 2-year-old racehorses. Horses were enrolled into the study when they first entered the trainers' yard (earliest date 10th March 2008) and were followed for two racing seasons until the 31st July 2010 (the end of the New Zealand racing season). A sample of 131 horses was required to detect a hazard ratio of 2 with 80% power and precision of 0.05, based on 50% of the sample surviving to 70 days and 0.5 years of accrual and follow-up.

Data collected

The daily training activity such as the distances (metres) worked at canter and at high speeds (<15s/200m) were recorded. Full details on the methods of collecting training activity have been described elsewhere (Bolwell *et al.* 2011 [Chapter 2]). Briefly, trainers recorded data using specifically designed, standardised paper forms or provided copies of, or access to, their own paper records. Trainers were asked to provide reasons for horses not training, information on health events that occurred during training, and the dates of trials and races. Further information on the distances, places, total prize money, end of season rating for the 2008/09 and 2009/10 racing seasons, and date of birth were obtained from the New Zealand Thoroughbred Racing online database. The dates of trials and races provided by the trainer were validated against the online database and where a difference was seen, the date was replaced with the official date from the database.

Statistical analysis

Exposure variables

The type of interruption (first occurrence only) that had occurred before the first trial was the main exposure of interest, and was grouped into: no interruption, voluntary (no known condition or disease present) or involuntary interruption (due to the presence of a condition or disease). Horses that were away from the training yard or not in work for >7 consecutive days were considered to have had an interruption, and were not considered at risk of starting in a trial or race. The distances accumulated since entering training at canter (>15s/200m) and speeds of 15s/200m (15s) and 13s/200m (13s), were calculated. Other training exposures accumulated since entering training were: the number of days off, high speed events (12s/200m), jump outs (a practice start out of gates at high speed), swimming days, water walker days, and trial starts (for outcome 2, see below). Additional exposure variables investigated were daily walking time (on a mechanical walker), age (months) at the start of training, sales background (yearling sale horse versus non-sale), gender, and trainer.

Cox proportional hazards model

Cox regression and Kaplan-Meier survival analysis (Kaplan and Meier 1958) were used to investigate associations between the exposure variables and two outcome measures of performance: 1) time to the first trial and 2) time to the first race start. A log-rank test was used to investigate differences in the median time to the first trial or race by type of interruption. The functional form of continuous variables was investigated by visually assessing the Martingale residuals as described in Dohoo *et al* (2003a). If a non-linear relationship was shown, the continuous variables were investigated as fractional polynomial transformations using powers -3, -2, -1 -0.5, 0, 0.5, 1, 2, or 3. The best fitting transformations were identified by comparing the deviances of the models with that of a linear model, on a χ^2 distribution (Royston and Sauerbrei 2005). Exposure variables were selected for inclusion in the multivariable models based on a cut-off of P<0.20. The final multivariable models were built using a backwards selection procedure, and exposure variables were retained in the model if they significantly improved the model fit (likelihood ratio statistic [LRS] P-value <0.05). Age at the start of training and the type of interruption were considered *a priori* variables of interest and were forced into the final models, if applicable. Trainer was modelled as a frailty term to allow for potential clustering at the trainer level, which has been reported previously (Verheyen *et al.* 2009).

Testing assumptions of Cox proportional hazards model

The proportional hazards assumption was tested for non-time dependent exposure variables by using a statistical test that tests for a non-zero slope of the scaled Schoenfeld residuals against time (StataCorp 2009a). To determine the model fit, Cox-Snell residuals were calculated and plotted to see if they followed a unit exponential distribution; a straight line with a slope of one indicated a good model fit (Dohoo *et al.* 2003b). Influential observations were investigated through plots of likelihood displacement values against time (Cleves *et al.* 2010). If missing data were present, the effect of using complete case analysis was investigated by using a multiple imputation method. The missing values were replaced using a predicted mean matching method for monotone missing data patterns, as described in the STATA multiple imputation reference manual (StataCorp 2009b). The variables were then modelled using Cox regression and compared with the results from the complete case analysis. Hazard ratios (HR) and 95% confidence intervals (95% CI) were calculated and the critical probability for assigning statistical significance was set at $P<0.05$. All analyses were conducted in intercooled STATA 11 (Statacorp LP, College Station, Texas, USA).

RESULTS

Time to first trial

Two hundred horses were included in the analysis, resulting in 22,635 training days at risk. Four horses were excluded from the analysis as their first start was in a race, not a trial. The first analysis was run with 201 horses but a plot of likelihood displacement values showed one horse to be influential, which was confirmed when removal of this horse altered the hazard ratio for the distance at 15s by 26%. Further investigation showed this horse had accumulated 8200m at 15s compared to the median of 2200m for horses that accumulated distance at 15s, indicating that this horse was an outlier from the population. Therefore, this horse was removed from any further analysis of time to first trial.

A total of 160/200 (80%) horses had at least one trial during the study period, of which 51% (82/160) were male and 75% (120/160) were sale horses from the yearling sales series. Of those that had no interruptions (63/200), voluntary (112/200) and involuntary (25/200) interruptions, 95%, 88% and 67% of horses, respectively, started in a trial. The median time to first trial for no interruption, voluntary and involuntary interruption horses (70 (95% CI 61-79), 184 (95% CI 166-198) and 195 (95% CI 177-

254) days, respectively) was significantly different (P<0.001) (Figure 1). Descriptive statistics of the continuous exposure variables are shown in Table 1.

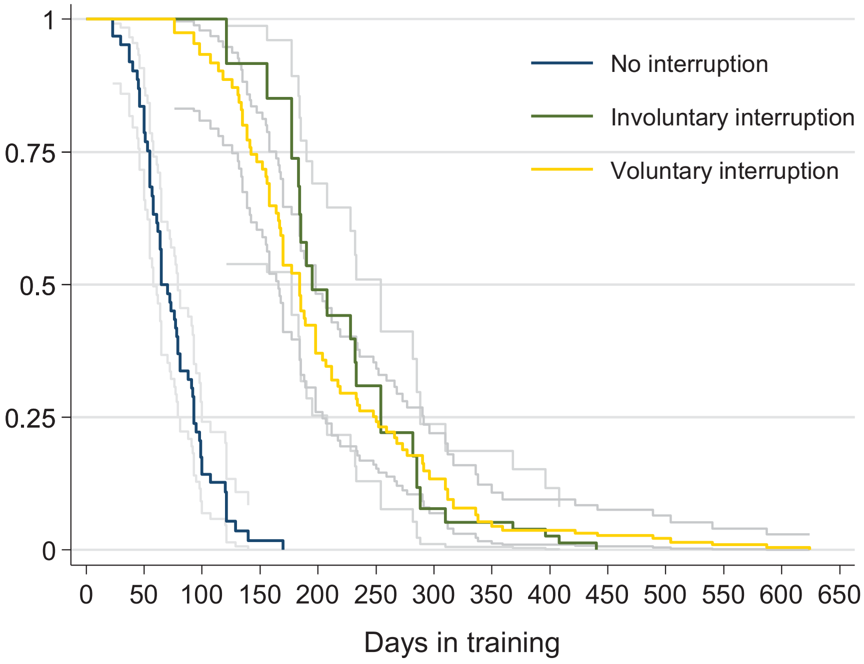


Figure 1: Kaplan-Meier 'survival' curve showing the cumulative probability of not having a trial since entering training, for horses that had no interruption, an involuntary interruption, or a voluntary interruption.

Univariable analysis

Results of univariable analysis are shown in Table 2. The daily hazard of a trial for voluntary and involuntary interruptions was both 0.07 times (95% CI 0.04-0.15 and 0.04-0.12, respectively) that of horses with no interruption. An increased chance of starting in a trial was associated with the following exercise parameters: increasing canter distance, 15s distance, the number of days off, jump outs, swim events and high speed events. Horses were less likely to start in a trial with increasing daily time spent on the walker.

Table 1: Distribution of continuous variables investigated for factors affecting the time to first trial and race start in a cohort of Thoroughbred horses in training

Variable	Trial start		Race start	
	Median	Inter-quartile range	Median	Inter-quartile range
Age (months)[a]	22	20-25	22	20-25
Canter distance [b]	1525	668-2668	1051	477-1861
Distance at 15s/200[b]	10	0-29	5	0-16
Distance at 13s/200[b]	7	0-29	3	2-11
High speed event 12s/200[c]	2	0-6	4	3-6
Jump outs [c]	1	0-2	2	2-3
Days off [c]	22	8-43	16	6-30
Daily walker time[cd]	0	0-0	40	30-40
Swim days[c]	2	0-10	1	0-5
Trial starts[c]	-	-	2	2-3

[a]At the start of training. [b]Distance in furlongs (1 furlong = 201.168m). [c]Data presented for only those horses that experienced these events. [d]Minutes. Training and exercise variables represent the amount or distance accumulated since entering training.

Table 2: Results of univariable screening of variables associated with the time to first trial start for 200 2-year-old racehorses in training

Variable		β coefficient	Standard error	Hazard ratio	95%C.I.[a]	LRS[b] P-value
Interruption						
	None	Reference		Reference		<0.001
	Involuntary	-2.53	0.34	0.07	0.04-0.15	
	Voluntary	-2.62	0.28	0.07	0.04-0.12	
Age (months)		0.04	0.02	1.04	0.99-1.08	0.08
Gender						
	Colts	Reference		Reference		0.10
	Fillies	0.26	0.16	1.29	0.94-1.77	
Sale horse						
	No	Reference		Reference		0.10
	Yes	0.29	0.18	1.33	0.93-1.91	
Canter distance[c]		0.001	0.0001	1.00	1.00-1.00	<0.001
Distance at 15s[c]		0.09	0.009	1.09	1.07-1.12	<0.001
Distance at 13s[c]		0.11	0.01	1.11	1.09-1.14	<0.001
High speed events		0.21	0.03	1.23	1.16-1.31	<0.001
Number of jump outs		0.64	0.06	1.90	1.67-2.16	<0.001
Number of days off		0.01	0.01	1.01	0.99-1.03	0.09
Number of swim days		0.03	0.01	1.03	1.00-1.03	0.04
Daily walker time (mins)		-0.03	0.01	0.96	0.93-0.99	0.001

[a]95% confidence interval. [b]Likelihood ratio statistic P-value. [c]Exercise variables represent the distance in furlongs (1 furlong = 201.168m) accumulated since entering training.

Multivariable analysis

The results of the multivariable Cox proportional hazards regression are shown in Table 3. After adjusting for the exercise variables and age, the daily hazard of a trial for horses experiencing voluntary and involuntary interruptions was lower than that of horses with no interruptions. Increasing distances at 15s were associated with an increased hazard of starting in a trial. Horses accumulating 800m, 1200m and 1800m were 1.4, 1.7 and 2.2 times more likely to start in a trial, respectively, than horses not exercising at 15s. Increasing age at the start of training and daily time spent on the walker were associated with a reduced hazard of starting in a trial. The number of high speed events and jump outs accumulated since entering training were found to be significantly non-linearly related with starting in a trial, and were modelled as fractional polynomials as (cumulative jump outs+1)^-0.5 and ((cumulative high speed events+1)/10)^-2, respectively (Figures 2 and 3). The final model did not violate the proportional hazards assumption (P=0.44) and there were no influential observations identified. A plot of the Cox-Snell residuals indicated the model fit was good.

Table 3: Multivariable Cox regression results of variables associated with the time to first trial for 2-year-old racehorses in training

Variable	β coefficient	Standard error	Hazard ratio	95%C.I.[a]	LRS[b] P-value
Interruption					
None			Reference		<0.001
Involuntary	-2.78	0.48	0.06	0.02-0.15	
Voluntary	-3.20	0.46	0.04	0.01-0.10	
Age start training (months)	-0.07	0.03	0.92	0.86-0.98	0.01
Daily walker time (mins)	-0.03	0.01	0.96	0.93-0.99	0.001
High speed events^-2	-0.01	0.002	0.98	0.98-0.99	
Number of jump outs^-0.5	-2.96	0.56	0.05	0.01-0.15	<0.001
Distance at 15s/200m [c]	0.09	0.01	1.09	1.06-1.12	<0.001
Trainer [d]					<0.001

[a]95% confidence interval. [b]Likelihood ratio statistic P-value. [c]Exercise variables represent the distance in furlongs (1 furlong = 201.168m) accumulated since entering training. [d]Trainer modelled as a frailty term, variance estimate for the trainer shared frailty term = 0.47 (standard error 0.23)

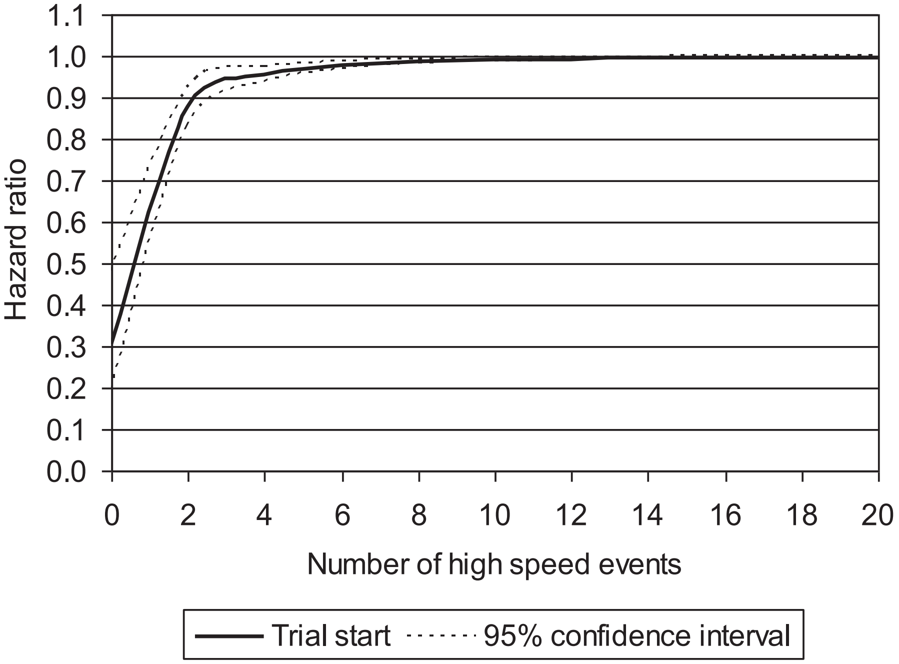


Figure 2: Relationship between the number of high speed events accumulated since entering training and the likelihood of a trial, after adjusting for age at the start of training, the type of interruption, daily walker time, the number of jump outs, distance at 15s/200m and clustering at the trainer level. Number of high speed events modelled as a fractional polynomial as ((cumulative high speed events+1)/10)^-2.

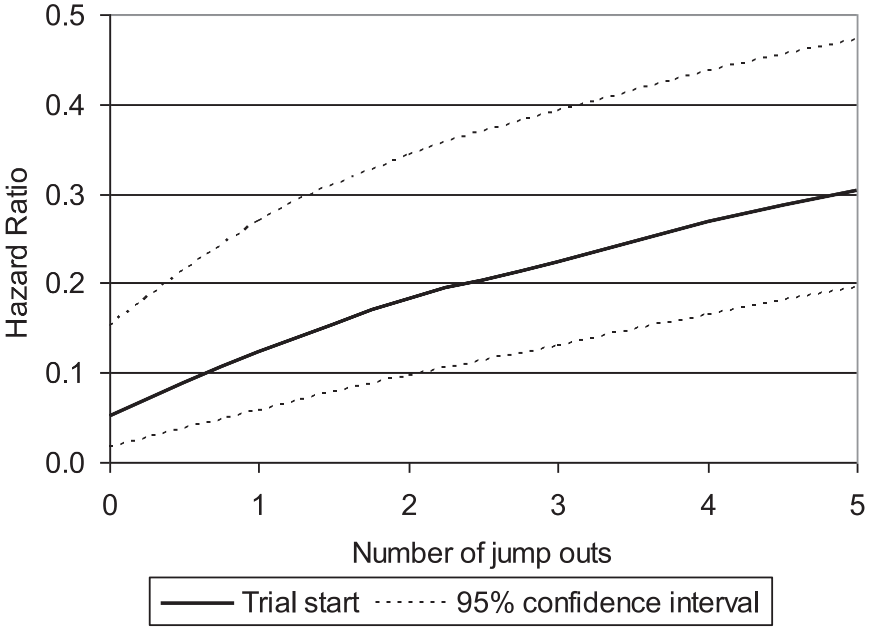


Figure 3: Relationship between the number of jump outs accumulated since entering training and a the likelihood of a trial, after adjusting for age at the start of training, the type of interruption, daily walker time, the number of high speed events, distance at 15s/200m and clustering at the trainer level. Number of jump outs modelled as a fractional polynomial as (cumulative jump outs+1)^-0.5.

Time to first race

Two hundred and five horses were included in the analysis, which includes the four horses that first started in a race (and the one influential horse previously excluded from the trial analysis), resulting in 41,693 training days at risk. In total, 529 (1.3%) training days had missing values for the daily exercise information across 14 horses and 5 trainers. A total of 100/205 (48%) horses in the study population started in at least one race during the study period, of which 63% were female and 79% were from the sales. Half of the horses first raced as 2-year-olds and the rest did not start in a race until their 3-year-old season. Seventy-eight (74%) horses that did not start in a race were lost to follow-up, of which 77% were exported or sold. An additional 13% were retired before they raced and 10% were censored (had not raced) when the study ended. Most (93%) of the horses that were sold or exported were colts, whilst most (56%) of the horses that were retired were fillies. Of the horses that were censored at the end of the study or retired before they could race, 60% and 57%, respectively, had experienced voluntary interruptions.

Of those that had no interruptions, voluntary and involuntary interruptions, 45%, 40% and 15% of horses, respectively, started in a race. The median time to starting in a race for no interruption, voluntary and involuntary interruption horses (194 (95%CI 146-255), 356 (95%CI 311-452) and 465 (95%CI 361-490) days, respectively) differed significantly (P<0.001) (Figure 4). The distributions of the continuous exposure variables are shown in Table 1.

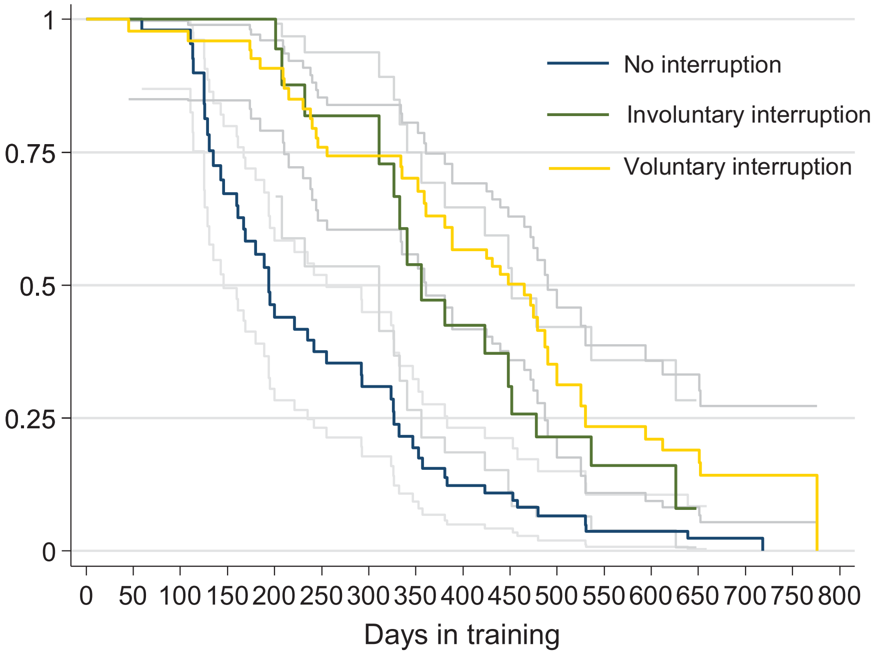


Figure 4: Kaplan-Meier 'survival' curve showing the cumulative probability of not starting in a race since entering training for horses that had no, voluntary and involuntary interruptions during training.

Univariable analysis

The model with missing values imputed showed no difference in the estimates of the hazard ratios, confidence intervals and significance levels compared with the complete case estimates. Therefore, the analysis reported was conducted on the complete case dataset that excluded the missing values. All exposure variables, except for age at the start of training, were associated with starting in a race (Table 4). Horses with voluntary and involuntary interruptions were less likely to start in a race compared to horses that did not have an interruption before their first trial start.

Table 4: Results of univariable screening of variables associated with the time to first race start for 2-year-old racehorses in training

Variable	β coefficient	Standard error	Hazard ratio	95%CI[a]	Wald test P-value	LRS[b] P-value
Interruption						<0.001
None	Ref		Ref			
Involuntary	-0.78	0.30	0.45	0.25-0.82	0.009	
Voluntary	-1.13	0.22	0.32	0.20-0.49	<0.001	
Age (months)[c]			0.99	0.92-1.06	0.81	0.80
Gender						
Colts	Ref		Ref			
Fillies	0.95	0.21	2.60	1.71-3.96	<0.001	0.001
Sale horse						
No	Ref		Ref			
Yes	0.38	0.24	1.47	0.91-2.39	0.11	0.10
Canter distance [d]	0.0008	0.0001	1.00	1.00-1.00	<0.001	<0.001
Distance at 15s [d]	0.05	0.007	1.05	1.04-1.07	<0.001	<0.001
Distance at 13s (ln+1)[d]	0.88	0.12	2.43	1.91-3.09	<0.001	<0.001
High speed events^-1	-0.20	0.04	0.81	0.74-0.88	<0.001	<0.001
Number of jump outs	0.24	0.08	1.27	1.08-1.49	0.003	0.003
Number of days off	0.03	0.008	1.03	1.01-1.04	<0.001	<0.001
Number of swim days	0.04	0.008	1.04	1.02-1.05	<0.001	<0.001
Number of trials^-1	-5.10	0.69	0.006	0.001-0.02	<0.001	<0.001

[a]CI = 95% confidence interval. [b]LRS = Likelihood ratio statistic P-value. [c]At the start of training. [d]Exercise variables represent the distance (furlongs, 1 furlong = 201.168m) accumulated since entering training.

Multivariable analysis

The results of the final multivariable model are shown in Table 5. After adjusting for the exercise variables and the number of trial starts, the type of interruption experienced before the first trial was no longer associated with starting in a race. The main confounding factor for the association between type of interruption and a race start was number of trial starts The number of high speed events and trials accumulated since entering training showed evidence of a non-linear relationship with the hazard of starting in a race, and were modelled as fractional polynomials as (number of trials+1)^-1 and ((high speed events+1)/10)^-1 (Figure 5 and 6). Horses accumulating fewer events at high speed and fewer trial starts were less likely to start in a race.

Table 5: Multivariable Cox regression results of variables associated with the time to first race start for 2-year-old racehorses in training

Variable	β coefficient	Standard error	Hazard ratio	95%C.I.[a]	Wald test P-value	LRS[b] P-value
Number of trial starts^$^{-1}$	-3.63	0.85	0.02	0.005-0.14	<0.001	<0.001
High speed events^$^{-1}$	-0.18	0.04	0.83	0.75-0.91	0.001	<0.001
Distance at 13s (ln+1) [c]	0.70	0.17	2.02	1.45-2.83	0.002	<0.001
Trainer [d]						<0.001

[a]CI = 95% confidence interval. [b]LRS = Likelihood ratio statistic P-value [c]Exercise variables represent the distance (furlongs, 1 furlong=201.168) accumulated since entering training. [d]Trainer modelled as a frailty term, variance estimate for the trainer shared frailty term = 0.60 (standard error 0.31).

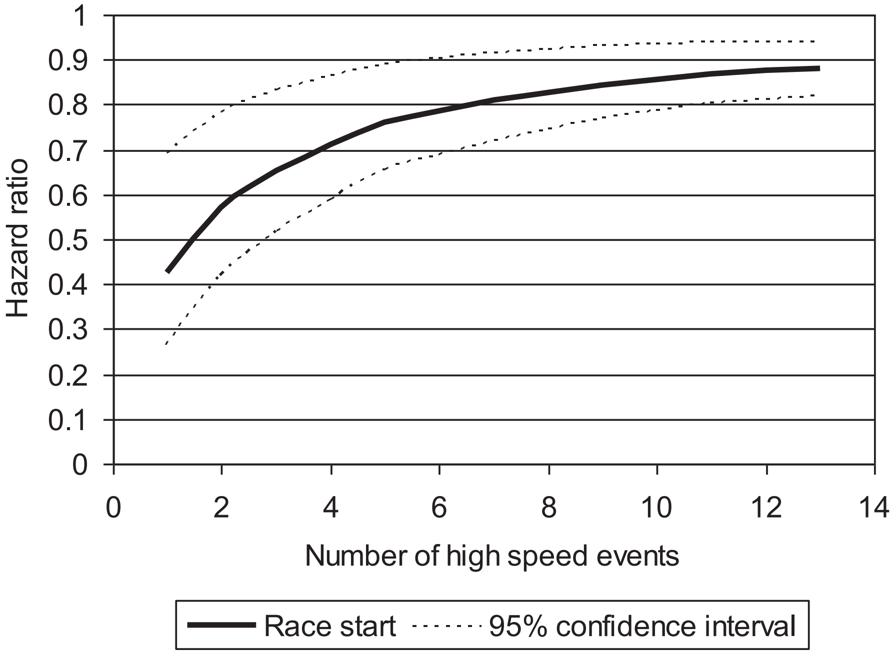


Figure 5: Relationship between the number of high speed events accumulated since entering training and the likelihood of a race start, after adjusting for the distance accumulated at 13s/200m and the number of trial starts. Number of high speed events modelled as a fractional polynomial as ((high speed events+1)/10)^-1.

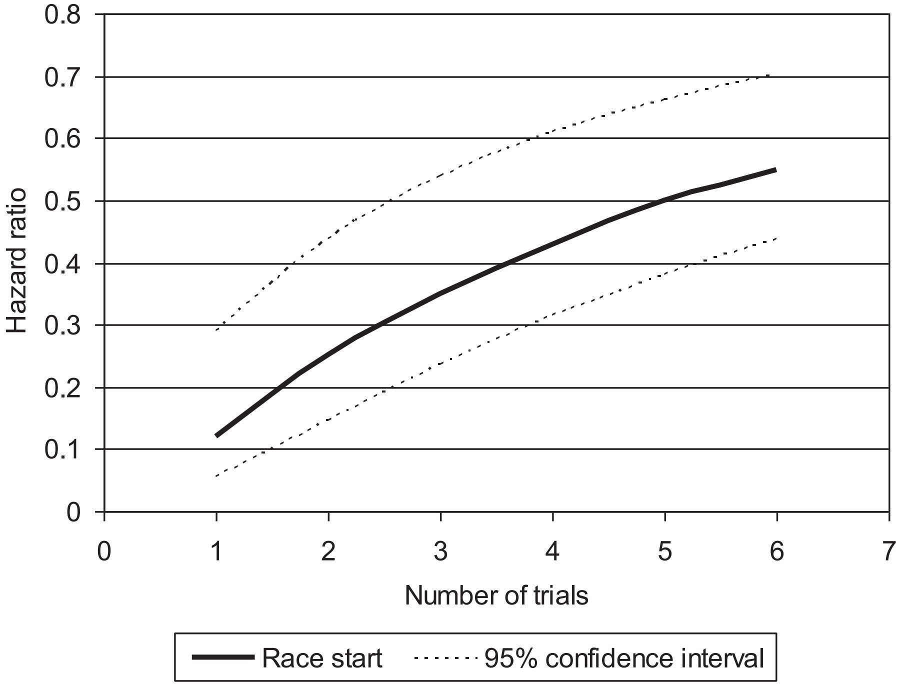


Figure 6: Relationship between the number of trials accumulated since entering training and the likelihood of a race start, after adjusting for the distance accumulated at 13s/200m and the number of high speed events. Number of trials modelled as a fractional polynomial as (number of trials+1)^-1

The final model indicated there was clustering at the trainer level. The final model did not violate the proportional hazards assumption (P=0.51) and a plot of the Cox-Snell residuals indicated a good model fit.

DISCUSSION

The aim of this study was to investigate the effect of training interruptions before the first trial on the time to starting in a trial and a race. Results showed that horses that had experienced interruptions, voluntary or involuntary, took significantly longer to start in a trial than did horses that had had no interruption during training. The median number of days to a trial for horses without an interruption was similar to the mean of 70 (95%CI 68-72) days for a trial or race start as a 2-year-old, reported by Perkins *et al* (2004b). However, the time to starting in a race for horses without an interruption was much longer in the current study, as it considered race starts separately from trial starts. Similarly, the current study considered the first start since entering training, as opposed to the number of days to the first start within each training preparation. The former is a more patent indication of the costs of poor performance.

A trial is considered to be an important milestone for judging a horse's progress in training and assessing its suitability for continuing with training and progressing to a race (Bolwell *et al.* 2010). Trainers aim to have horses starting in a trial within the first 10 weeks of entering training (Perkins *et al.* 2004b; Bolwell *et al.* 2010). If a voluntary or involuntary interruption occurred, horses took twice as long to reach the trialling milestone and were less likely to start in a trial at all. Whether this was an effect of having a voluntary interruption or whether it reflects the trainer's perception of a lack of ability of the horses to start in a trial, cannot be inferred from the results of this study. However, the results do suggest that experiencing any condition or disease that resulted in a forced interruption, before the first trial, does have an impact on the likelihood of reaching the trialling milestone.

After adjusting for the number of trials and exercise distances accumulated since entering training, an interruption was not associated with the likelihood of starting in a race. The results showed that an important confounder for the association of interruptions and starting in a race was the number of previous trial starts, and this variable was a significant factor associated with a race start. Horses that had accumulated fewer trials were less likely to start in a race. Additionally, horses that had an interruption were less likely to start in a trial; having an interruption reduced the chance of starting in a trial, which in turn resulted in fewer trials and therefore a reduced chance of a race start.

As a result of declining foal crops in a number of racing jurisdictions (Anon 2009, 2010, 2011b), it has been suggested that, along with reducing wastage within these populations, an increase in the number of starts per horse is needed in order to sustain/maintain the racing industries (McCarthy 2008). Our results showed that half of the horses in the two years studied did not start in their first race until they were three years old. The delay in reaching these important milestones, as a result of an interruption, may impact on the horses' future success. Horses that are in training earlier, registered, trialling and racing at two, have more race starts, and are more likely to place or win a race (Tanner *et al.* 2011). Similarly, other studies have indicated performance during the first years of racing is related to career longevity and success (Bailey *et al.* 1999; More 1999).

An Australian study (Cogger *et al.* 2008) showed an association between age and trial or race starts but because that study used age at the start of each training preparation and combined trial and race starts, direct comparison to our results is difficult. The current study showed that horses that were older at the start of training were less likely to trial than younger horses. This suggests that horses that have the shortest time from birth to starting race training reached the trialling milestone earlier. However, yearlings that were younger at the time of starting a yearling preparation received more exercise during the preparation compared to older yearlings (Bolwell *et al* unpublished data, 2011). Therefore, the association between age at the start of training and a trial start may be confounded by previous early conditioning. Early exercise has a positive effect on the development of the horse's musculoskeletal system (Barneveld and van Weeren 1999; Rogers *et al.* 2008a, b), and work to identify the effects of early exercise on reaching milestones in training and racing, in our study, is reported elsewhere [Chapter 7 and 8].

A general pattern showed that accumulating less distances and events at high speed were each associated with a reduced chance of a trial and race start. Horses that were spending more time walking and not accumulating events at high speed were apparently not being trained with the primary objective of a trial or race start. Studies in the UK have shown exercise during training is associated with a number of racing performance measures, such as winning a race, placing in a race and prize money (Verheyen *et al.* 2009; Ely *et al.* 2010). However, direct comparisons with these UK studies are difficult due to the different racing outcomes used and the time frame of the exercise accumulated, such as 30 day windows before the case race. Our results showed that the effect of exercise over longer windows, e.g. time since entering training, should be considered, and it is not the exercise occurring only immediately before a race that can influence performance. The results of this study provide further support that exercise during training is associated with indicators of training and racing performance and these variables are important confounders that need to be considered when assessing the effect of racing performance or success.

Results indicated there was significant clustering at the trainer level, in both the trialling and racing models. The decision of when to trial and race a horse is likely to be the same within trainers, as standard training programmes are used for most horses up to the trialling stage (Bolwell *et al.* 2010); horses with the same trainer were clustered together in terms of having a trial or race start. These results highlight that there may be variations in the decisions made by trainers regarding a horses progress to starting a trial or race (highlighted by trainers that were more frail and had a higher rate of trial or race), which may allow targeted research into specific trainers and their management practices. Further study into the factors that may vary between trainers is of importance in order to better quantify the effects of trainer on outcomes of training and racing performance.

Although associations between interruptions, training variables, and starts in either a trial or race have been demonstrated, the limitations of the study should be considered. The current study is part of a larger prospective cohort study that utilised a convenience sample of trainers and some horses were excluded for racing before trialling, resulting in a cohort that may not be representative of the all 2-and 3-year-old racehorses in New Zealand. High levels of co-operation were required in order to maintain the longitudinal data collection and the measures used to preserve internal validity and reduce bias in the cohort study have been previously discussed (Bolwell *et al.* 2011 [Chapter 2]).

A potential form of bias present in the data of the time to first race (but not trial) was that due to missing training data. Despite having only 1% of missing training data, analysing only complete cases could have produced biased estimates (Little and Rubin 1987). An assessment of the effect of missing values, using a multiple imputation method, showed that missing data were unlikely to result in biased estimates as there was no difference in the hazard ratios generated from the two models (complete case versus multiple imputation analysis).

CONCLUSION

Horses that were older at the start of training were less likely to trial than younger horses. Accumulating shorter distances and fewer events at high speed were each associated with a reduced chance of a trial and race start. Interruptions to training had an effect on the time to, and hazard of, a trial but not a race start.. The timing of these interruptions results in delays in reaching important training milestones, which may have an impact on the future athletic performance of racehorses.

REFERENCES

Anon (2009) *New Zealand Thoroughbred Racing Fact Book 2009*, New Zealand Thoroughbred Racing Inc., Welllington.

Anon (2010) Return of mares press release. Irish Thoroughbred Breeders Association. http://www.itba.info/news.php?id=485 Accessed 4th March 2011.

Anon (2011a) Size of field and starts per horse. The Jockey Club 2011 Online Fact Book. http://www.jockeyclub.com/factbook.asp?section=1. Accessed on 4th March 2011.

Anon (2011b) Annual North American Registered Foal Crop. The Jockey Club 2011 Online Fact Book. http://www.jockeyclub.com/factbook.asp?section=2 Accessed 3rd March 2011.

Bailey, C.J., Reid, S.W., Hodgson, D.R. and Rose, R.J. (1999) Factors associated with time until first race and career duration for Thoroughbred racehorses. *Am. J. vet. Res.* **60**, 1196-1200.

Barneveld, A. and van Weeren, P.R. (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine. vet. J., Suppl.* **31**, 112-119.

Bolwell, C.F., Russell, L.J. and Rogers, C.W. (2010) A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comp. Exerc. Physiol.* **7**, 37-42.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011) Risk factors for interruptions occurring before the first trial start of 2-year-old Thoroughbred racehorses in training. *N.Z. vet. J.* **Submitted**.

Carrier, T.K., Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Read, D.H. and Ardans, A.A. (1998) Association between long periods without high-speed workouts and risk of complete humeral or pelvic fracture in Thoroughbred racehorses: 54 cases (1991-1994). *J. Am. vet. med. Ass.* **212**, 1582-1587.

Cheetham, J., Riordan, A.S., Mohammed, H.O., McIlwraith, C.W. and Fortier, L.A. (2010) Relationships between race earnings and horse age, sex, gait, track surface and number of race starts for Thoroughbred and Standardbred racehorses in North America. *Equine vet. J.* **42**, 346-350.

Cleves, M., Gould, W., Gutierrez, R.G. and Marchenko, Y.V. (2010) The Cox model:Diagnostics. In: *An Introduction to Survival Analysis Using Stata*, Stata Press, Texas. pp 223-227.

Cogger, N., Perkins, N., Hodgson, D., Reid, S. and Evans, D. (2008) Profiling training preparation in young Australian Thoroughbred racehorses. *Aust. vet. J.* **86**, 419-424.

Dohoo, I., Martin, W. and Stryhn, H. (2003a) Modelling survival data. In: *Veterinary Epidemiologic Research*, Eds: I. Dohoo, W. Martin and H. Stryhn, AVC Inc, Charlottetown, Canada. p 439.

Dohoo, I., Martin, W. and Stryhn, H. (2003b) Validity in observational studies. In: *Veterinary Epidemiologic Research*, Eds: I. Dohoo, W. Martin and H. Stryhn, AVC Inc, Charlottetown, Canada. p 213.

Ely, E.R., Price, J.S., Smith, R.K., Wood, J.L.N. and Verheyen, K.L.P. (2010) The effect of exercise regimens on racing performance in National Hunt racehorses. *Equine vet. J.* **42**, 624-629.

Estberg, L., Gardner, I.A., Stover, S.M. and Johnson, B.J. (1998) A case-crossover study of intensive racing and training schedules and risk of catastrophic musculoskeletal injury and lay-up in California thoroughbred racehorses. *Pre. vet. Med.* **33**, 159-170.

Kaplan, E.L. and Meier, P. (1958) Nonparametric estimation from incomplete observations. *J. Amer. Statistical. Assoc.* **53**, 457-481.

Little, R.J. and Rubin, D.B. (1987) Statistical analysis with missing data, John Wiley & Sons Inc. pp 40-43.

McCarthy, G. (2008) Wastage Discussion Paper. New Zealand Thoroughbred Racing. http://www.nzracing.co.nz/Documents/2475/Wastage%20Discussion%20Paper%202008.pdf Accessed on 27th August 2008.

More, S.J. (1999) A longitudinal study of racing Thoroughbreds: performance during the first years of racing. *Aust. vet. J.* **77**, 105-112.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004a) Profiling the New Zealand Thoroughbred racing industry. 2. Conditions interfering with training and racing. *N.Z. vet. J.* **53**, 69-76.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004b) Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *N.Z. vet. J.* **53**, 59-68.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008a) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine vet. J.* **40**, 111-118.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008b) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2 and 3 year old racing careers. *Equine vet. J.* **40**, 119-127.

Royston, P. and Sauerbrei, W. (2005) Building Multivariable Regression Models with Continuous Covariates in Clinical Epidemiology. *Meth. Inform. Med.* **44**, 561-571.

StataCorp (2009a) *Survival Analysis and Epidemiological Tables Reference Manual: Release 11* Stata Press, College Station, Texas, USA.

StataCorp (2009b) Multiple-Imputation Reference Manual: Release 11 Stata Press, College Station, Texas, USA.

Tanner, J.C., Rogers, C.W. and Firth, E.C. (2011) The relationship of 2-year-old training milestones with racing success in a population of Standardbred horses in New Zealand. *N.Z. vet. J.*, in press.

Verheyen, K.L.P., Price, J.S. and Wood, J.L.N. (2009) Exercise during training is associated with racing performance in Thoroughbreds. *Vet. J.* **181**, 43-47.

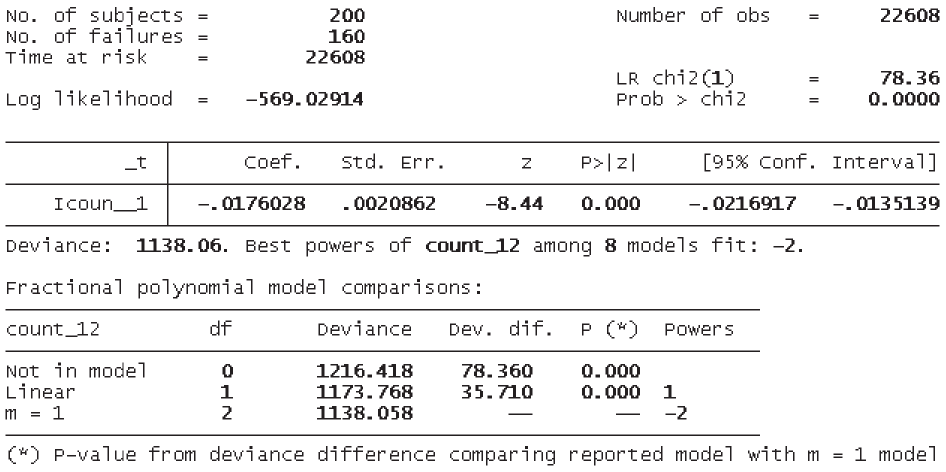
APPENDIX B

This appendix includes an example of fitting fractional polynomials in Stata, and supplementary information on the model diagnostics used for both the time to first trial and race is shown.

Fitting fractional polynomials

When time-varying covariates are present, it is often difficult to interpret non-linearity using plots of Martingale residuals, since one horse may have multiple values for time varying covariates. The procedure followed in Stata 11 for investigating the suitability of fractional polynomials, compared the transformations to the variable in its linear form; an assessment of the linearity of the continuous variable is therefore made through this process, in addition to visualising the Martingale residuals.

When investigating the relationship between high speed events and the time to the first trial, the best fitting 2-degree model was initially determined but this did not provide a significantly better fit than the 1-degree model (P=0.57). Therefore, the best fitting powers for a 1-degree model were investigated, and Figure A1 shows the 1-degree model based on power -2 fit the data significantly better than the linear or the null model.



```
No. of subjects =          200                  Number of obs   =      22608
No. of failures =          160
Time at risk    =        22608
                                                LR chi2(1)      =      78.36
Log likelihood  =   -569.02914                  Prob > chi2     =     0.0000

------------------------------------------------------------------------------
          _t |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    Icoun__1 |  -.0176028   .0020862    -8.44   0.000    -.0216917   -.0135139
------------------------------------------------------------------------------
Deviance:  1138.06. Best powers of count_12 among 8 models fit: -2.

Fractional polynomial model comparisons:
---------------------------------------------------------------
count_12          df       Deviance    Dev. dif.   P (*)   Powers
---------------------------------------------------------------
Not in model       0       1216.418     78.360     0.000
Linear             1       1173.768     35.710     0.000  1
m = 1              2       1138.058       --         --   -2
---------------------------------------------------------------
(*) P-value from deviance difference comparing reported model with m = 1 model
```

Figure A1: An example of the Stata output of fitting a fractional polynomial to explore the relationship between high speed events (count_12) and the time to first trial.

Fit of the multivariable model for time to first trial

Plots of the likelihood displacement values against time indicated that one horse may be considered an outlier that was influential in the working model of time to first trial (Figure A2). A plot of the Cox-Snell residuals that provided a visual assessment of the model fit, without the influential horse, is shown in Figure A3. The same plot for the outcome time to first race is shown in Figure A4. If the model fits the data well, the plot of the Cox-Snell residuals versus the cumulative hazard will be close to the reference line. It should be noted that there are limitations to the interpretation of plots of Cox-Snell residuals and these plots are suggested to be of limited value in practice, for assessing model fit. Deviations away from the reference line may be apparent when large amounts of censoring are present and assessing the plot, and overall model fit, is deemed to be a subjective procedure. However, other suggested alternatives such as Harrells C statistic and goodness of fit tests, are not applicable to data with time varying covariates or multiple records per horse, respectively.

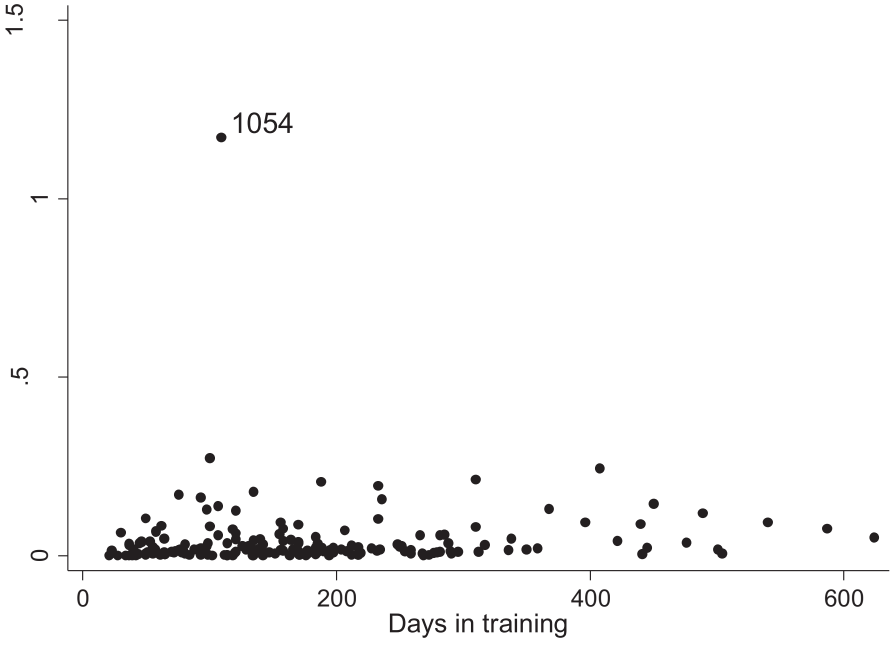


Figure A2: Plot of likelihood displacement values against time. The numbered point is the horse that was considered to be influential in the model.

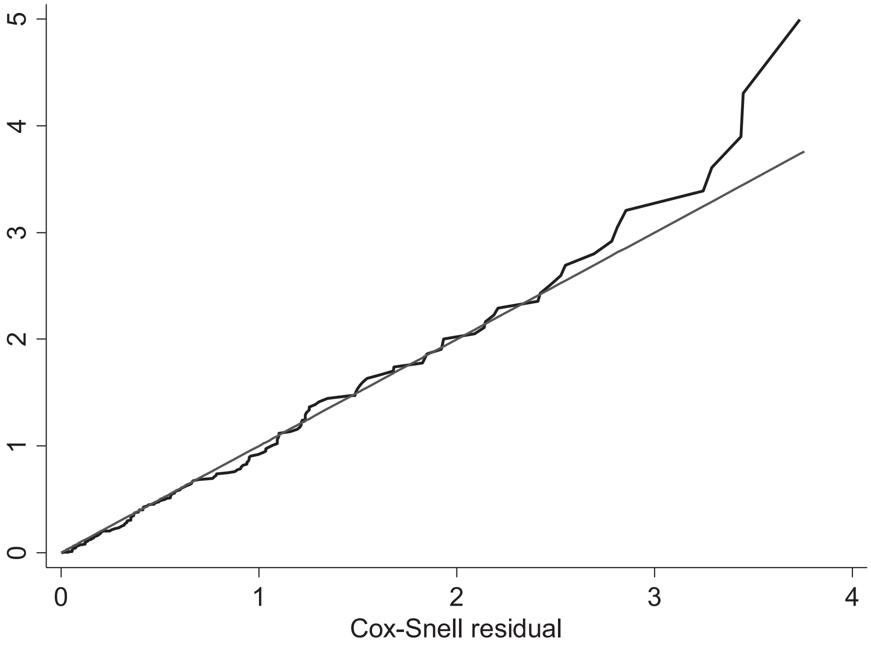


Figure A3: Plot of the Cox-Snell residuals against the cumulative hazard for the final multivariable model for time to first trial. A reference line with a slope=1 is also displayed.

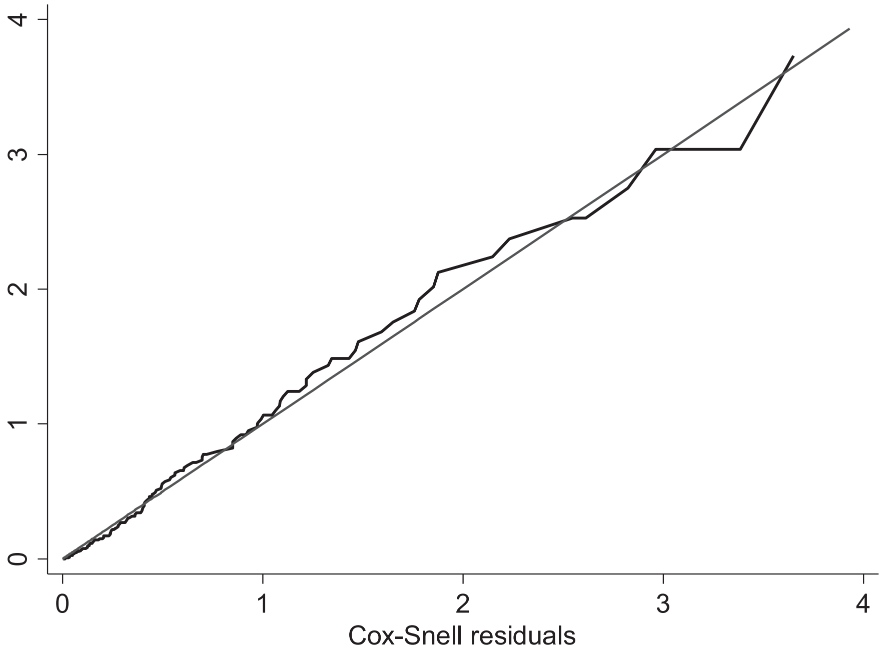


Figure A4: Plot of the Cox-Snell residuals against the cumulative hazard for the final multivariable model for time to first race. A reference line with a slope=1 is also displayed.

PRELUDE TO CHAPTER 4

Before the effect of early exercise on future training or racing performance can be investigated, the type and amount of exercise that yearlings are exposed to during sales preparation must be quantified. There is currently limited data describing whether or not exercise is used during a sale preparation and, if so, what or how much is given.

The manuscript presented in Chapter 4 provides baseline data on the current industry practices of preparing yearlings for sales. A cross-sectional survey was used to describe the management and exercise regimens of yearlings during sales preparation on stud farms in New Zealand. Furthermore, the associations between stud farm practices and the provision of exercise are examined using logistic regression.

The survey used in this study and the results of the logistic regression analysis are presented in the appendix for this chapter. Chapter 4 is based on a publication in the Proceedings of the New Zealand Society of Animal Production.

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2010) Management and exercise of Thoroughbred yearlings during preparation for yearling sales in North Island of New Zealand. *Proc. N. Z. Soc. Anim. Prod*. **70**, 157-161.

CHAPTER 4

MANAGEMENT AND EXERCISE OF THOROUGHBRED YEARLINGS DURING PREPARATION FOR YEARLING SALES IN THE NORTH ISLAND OF NEW ZEALAND

ABSTRACT

A cross-sectional survey was conducted to describe the management and exercise regimen at stud farms during preparation for the 2008 national yearling sales. A total of 1,166 yearlings were included in the survey, representing 82% of those offered at the Karaka sales in 2008. Ninety-two percent of farms (69/75) used a combination of both pasture turnout and stabling during yearling preparation, with most farms (47/75; 63%) giving yearlings access to pasture for >12 hours per day. Controlled exercise was performed on 80% (60/75) of stud farms, with most (54/60; 90%) farms exercising at walk. Management practices appeared to be relatively homogeneous across the farms surveyed. The provision of free exercise at pasture and controlled exercise were common practices during a sales preparation.

INTRODUCTION

Each year, around 1,500 young Thoroughbreds are catalogued to attend the New Zealand yearling sales series. The allocation of the yearlings to the different sales levels (Premier, Select and Festival) is determined by the sales company and is based on the strength/commercial appeal of the pedigree (i.e. quantity of ‘black type’ (stakes races) in the pedigree) and the conformation and ‘type’ of the yearling. Therefore, producing a well-grown yearling with correct conformation is of importance to the vendors. However, despite the greater return for presentation of a correct, well-grown, yearling (Pagan *et al.* 2006), there are limited data on the management practices of young Thoroughbreds from weaning through to yearling sales.

In the USA, Gibbs and Cohen (2001) conducted a survey of the management of weanlings and yearlings on 58 Thoroughbred and Quarter horse stud farms. Over half of the farms kept weanlings and yearlings at pasture for 24 hours a day and controlled exercise as yearlings was conducted on 64% of farms. Recent studies have suggested the importance of early exercise in young horses for the development of the musculoskeletal system (Barneveld and van Weeren 1999; Firth 2006; Rogers *et al.* 2008a). However, it has been suggested that too much forced exercise superimposed on the box regimen may be detrimental compared to horses at pasture (Barneveld and van Weeren 1999; Cherdchutham *et al.* 1999; Cornelissen *et al.* 1999; van de Lest *et al.* 2002). A conditioning exercise programme imposed on foals, kept at pasture, produced no adverse effects on the musculoskeletal system (Nugent *et al.* 2004; Doube *et al.* 2007; Moffat *et al.* 2008; Rogers *et al.* 2008a; Stanley *et al.* 2008; van Weeren *et al.* 2008) and some positive effects (Dykgraaf *et al.* 2008).

These findings highlight the opportunity and importance of developing management protocols that optimise musculoskeletal health within the constraints of the existing production system. However, before modifications to management practices can be made, the current industry practices must be quantified. The aim of the current study was to obtain baseline data on the management and early exercise of young Thoroughbred horses at stud farms on the North Island, New Zealand.

MATERIALS AND METHODS

A cross-sectional survey was conducted at stud farms in the North Island of New Zealand, during March 2008. The source population consisted of 152 registered vendors at the 2008 Karaka yearling sales. An initial letter or email was sent to inform vendors of the survey and to request their participation. Within two weeks, a follow-up telephone call was made to arrange a suitable time to conduct the survey; stud farms not able to be contacted after 4 attempts were excluded from the survey. The survey was conducted as a face-to-face interview, lasting 10-15 minutes, with the stud or yearling manager of the farm during March 2008. The survey consisted of 33 questions to provide information related to all yearlings on the farm that were involved in a sales preparation. The survey collected information on farm characteristics and the management and exercise of yearlings during sales preparation.

The data were collected by one interviewer (CB) using a proforma datasheet. Data were entered twice into a data entry file created in EpiData Data Entry (EpiData Association Odense Denmark; Version 3.1) and were then exported into Microsoft Excel 2003 (Microsoft Corporation, Redmond, WA, USA). Stud farms were grouped into three categories based on the median sale price of yearlings at the 2008 sales, for each stud farm; farms in the upper 25% were classed as Commercial, farms in the middle 50% were Mid-range, and farms in the lower 25% were classed as Non-commercial farms. Medians and interquartile range (IQR) are presented throughout, for non-normally distributed data. Associations between explanatory variables and whether or not yearlings received controlled exercised during sales preparation were investigated using logistic regression. Multiple correspondence analysis procedures were used to investigate the associations between stud farm demographic and management factors. Categorical variables of interest were selected for inclusion in the analysis and the results were projected onto a two-dimensional plot. All analyses were performed in R for Windows (version 2.7.1; Comprehensive R archive network).

RESULTS

The selection of stud farms for inclusion in the survey is shown in Figure 1. The participation rate of those eligible (75/114) was 66% and the response rate of those contacted (75/88) was 85%. A total of 1,166 yearlings were included in the survey, representing 82% of those offered at the Karaka sales in 2008. During the 2007/2008 season, the median number of yearlings on farm was 15 (IQR 8-40), with a median of 10 (IQR 5-26) yearlings entering a sales preparation. Descriptive results regarding general management during yearling preparation are shown in Table 1. The median duration of yearling preparation was 12 (IQR 12-16) weeks. Using a combination of both pasture turnout and stabling during yearling preparation was a common practice (Table 1) with most farms (47/75; 63%) providing >12 hours per day at pasture.

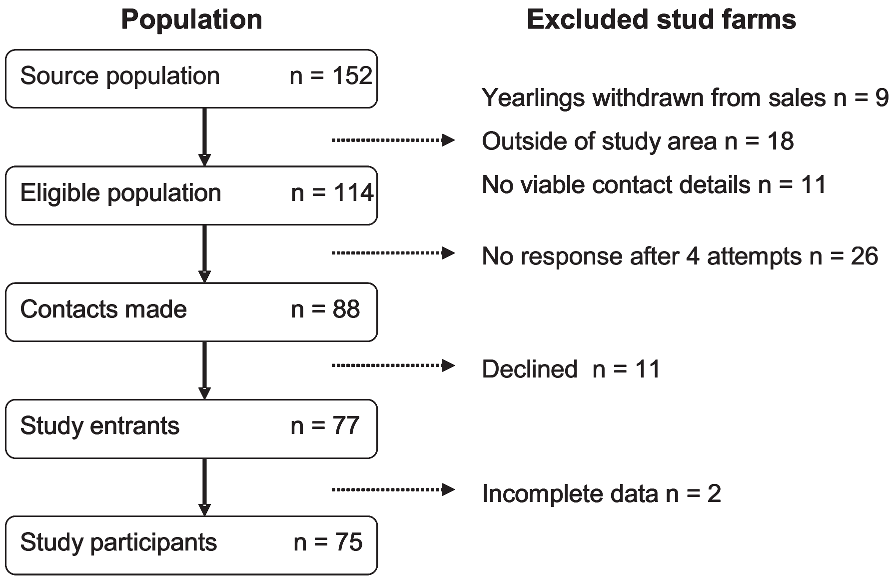


Figure 1: The selection of stud farms from source population through to study participants. The number of stud farms excluded at each stage and the reason for exclusion is shown. Adapted from Elwood (2007).

Table 1: Description of general management factors during yearling preparation for 2008 Karaka yearling sales expressed as the number of farms, percentage and 95% confidence interval. Central Districts = Manawatu and Wanganui Northern Districts = Waikato and South Auckland.

Variable	Level	Number of farms	Percentage	95% Confidence Interval
Location				
	Central Districts	9	12	6-22
	Northern Districts	66	88	78-94
Identify sales candidates[a]				
	Before/at weaning	27	36	26-47
	After weaning	29	39	28-50
	Bred to be sold	18	24	16-35
Month preparation started				
	September	3	4	1-12
	October	33	44	33-56
	November	30	40	29-52
	December	7	9	4-19
	January	2	3	0.4-10
Where yearlings were kept				
	Pasture 24 hours	2	3	0.4-10
	Box 24 hours	4	5	2-14
	Both	69	92	83-97
Size of box[a] (m)				
	<3.6x3.6	14	19	11-30
	3.6x3.6-4.4x4.4	51	68	56-78
	>4.4x4.4	7	9	4-19
Measured height				
	No	72	96	91-100
	Yes	3	4	1-8
Measured weight				
	No	67	89	82-96
	Yes	8	11	4-17
Assessed condition				
	No	52	69	59-80
	By eye	15	20	11-29
	Score/grade	8	11	4-17

[a] Not all farms provided this information.

Controlled exercise during yearling preparation was performed on 80% (60/75) of stud farms, with most (38/60; 63%) farms starting exercise from November onwards. The median number of weeks spent exercising was 10 (IQR 6-12). Walking was performed on 90% (54/60) of farms, with a few (6/60; 10%) also choosing to exercise yearlings at trot. Hand walking was performed on 40 (67%) farms and was the most common method used; other methods included a combination of hand walking and a mechanical horse walker (12/60; 20%), mechanical horse walker only (6/60; 10%), and exercising the horse at the end of a rope (lungeing) (2/60; 3%). A total of 11 (18%) farms lunged their yearlings, with 9 (82%) of these farms using lungeing in conjunction with other methods. On 18% (11/60) of farms controlled exercise was provided two to three times a week, with 45% and 37% of farms giving exercise five days a week and six to seven times a weeks, respectively. Of the farms giving controlled exercise, 66% (40/60) kept yearlings at pasture for ≥12 hours a day, whilst 53% (8/15) of farms not giving controlled exercise gave yearlings <12 hours a day at pasture.

A pre-determined exercise regimen was used on 18/60 (30%) stud farms, but none of the farms kept a record of the exercise that was done. On 26/60 (43%) farms the exercise programme was modified if the yearlings had a higher body condition score than desired (9/26; 35%), were difficult to handle (6/26; 23%), were colts (3/26; 12%), or had variation in conformation (2/26; 8%), whilst on 5 (8%) farms the exercise programme was tailored to each individual yearling. The main reason for providing controlled exercise was for education (31/58; 53%), as opposed to fitness (3/58; 5%). The main reason for not giving exercise (8/15; 53%) was that 'yearlings exercised themselves whilst at pasture'. Farm category, number of yearlings in preparation, percentage of yearlings sent to a Premier sale and percentage of yearlings sent to a Select sale were associated with controlled exercise ($P<0.20$ level; Likelihood ratio test [Appendix C]). None of these variables were significantly associated with exercise ($P<0.05$) in a multivariable model [Appendix C].

Results of the multiple correspondence analysis are shown in Figure 2. Farms positioned in the centre of the plot that only deviate slightly from the average profile were located in the Northern Districts. They prepared between 6 and 25 yearlings and exercised their yearlings. Figure 2 shows three clusters of farm management characteristics. Farms were clustered together based on the number of yearlings they prepared, how many were sent to each sale type, and the category of the farm. The total inertia or variance explained by the plot was 80%.

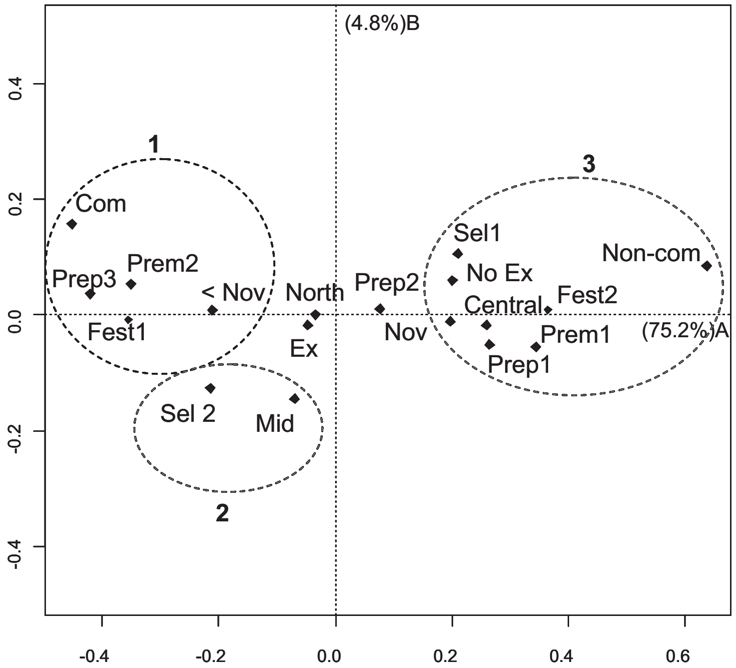


Figure 2: Multiple correspondence analysis results of stud farms participating in a cross-sectional survey of the management of yearlings during sales preparation. Projections are shown on the first two dimensions. Dotted circles highlight identified clusters 1, 2 and 3. A (Y axis), B (X axis) = Percentage of inertia or variance explained by the first and second dimension, respectively. Central Districts = Manawatu and Wanganui, Northern Districts = Waikato and South Auckland. Explanation of the abbreviations used are shown in the table below.

Parameter	Variable	Abbreviations
Farm Category		
	Commercial	Com
	Midrange	Mid
	Non-commercial	Non-com
Region of the North Island		
	Central Districts	Central
	Northern Districts	North
Exercised		
	Not exercised	No Ex
	Exercised	Ex
Number of yearlings prepared		
	Prepared <6 yearlings	Prep1
	Prepared 6-25 yearlings	Prep2
	Prepared >25 yearlings	Prep3
Time preparation started		
	Started prep before November	< Nov
	Started prep from November	Nov
Proportion sold by type of sale		
	<20 % sent to Premier sale	Prem1
	≥20% sent to Premier sale	Prem2
	< 42% sent to Select sale	Sel1
	> 42% sent to Select sale	Sel2
	<10% sent to Festival sale	Fest1
	≥10% sent to Festival sale	Fest2

DISCUSSION

To our knowledge, this is the first study to specifically describe the management and exercise regimens of yearlings during sales preparations, in New Zealand. The source population of the current study consisted of all farms registered as vendors for the national yearling sales in 2008. By selecting farms from this population, we aimed to include most of the farms, and subsequently most of the yearlings that would be prepared for sale.

The decision to send a yearling to sales was made on most farms in March (pre-wean/weaning) or August (post weaning), which coincided with the New Zealand Bloodstock sales nominations or assessments. A small percentage of farms began preparation during December (9%) and January (3%), which probably reflected smaller numbers of yearlings being prepared or that the yearlings were going to the Festival sale; as indicated by the multiple correspondence analysis results. Measuring the height or weight of the yearlings was not common practice during sales preparation. The additional time required to weigh and record height would probably outweigh the benefit gained, since most of the farms can judge their progress visually. In agreement, most of the farms that monitored the condition of yearlings did so ‘by eye’ and did not use a scale or keep a record of the assessment.

In agreement with a USA study (Gibbs and Cohen 2001), 92% of the farms used a combination of pasture and stabling during yearling preparation. However, in that study over half the farms kept yearlings at pasture for 24 hours a day and 78% kept yearlings at pasture for >12 hours a day, compared to 63% of farms in the current study. Previous studies have indicated free exercise at pasture to be a superior regimen compared to confinement, or confinement and forced exercise (Barneveld and van Weeren 1999). Controlled exercise played a large role in the sales preparation with most (60%) farms providing some form of exercise to yearlings. These findings were similar to those in the USA study by Gibbs and Cohen (2001), but the frequency of exercise varied. In that study, most farms gave exercise every other day, in contrast to 5 days a week in the current study. Additionally, only 7% of farms in that study used hand walking, with most using a mechanical horse walker, compared to 67% hand walking and only 10% of farms using only a mechanical horse walker in our study.

Most farms gave controlled exercise in addition to >12 hours of free exercise at pasture. Recently, a large intervention trial investigated the effect of a conditioning programme in addition to free exercise at pasture (Rogers *et al.* 2008a). Whilst the age at which exercise began was younger and the exercise regimen most likely more intense than during sales preparation, there was no evidence of any adverse effects on tendons (Moffat *et al.* 2008; Stanley *et al.* 2008) or cartilage (Nugent *et al.* 2004; Doube *et al.* 2007) and there was some indication of positive effects (Dykgraaf *et al.* 2008). Additionally, after being broken and trained for racing, there were apparently no negative effects of early conditioning exercise on their careers as 2- and 3-year-old racehorses (Rogers *et al.* 2008b). These findings suggest there may be scope to manipulate the intensity of exercise given during yearling preparation in order to adequately prepare young horses earlier for their training and racing campaigns.

After adjusting for other variables, exercise was not significantly associated with any farm management factors. Similarly, results of multiple correspondence analysis showed that exercise was close to the average profile suggesting this was a common practice. Since farms need yearlings to be looking and behaving a specific way for the sales, regardless of the type of sale or the number of yearlings in preparation, it is perhaps not surprising that the provision of exercise is common and does not vary with other management factors. In agreement with Rogers *et al* (2007), management practices appear to be relatively homogeneous across the farms surveyed.

Multiple correspondence analysis was an effective procedure to identify variations in the factors used to describe types of farms or breeding operations. Results suggest farms may be grouped together based on the number of yearlings prepared, the percentage sent to each sale, and farm category (Commercial versus Non-commercial). In agreement with Stowers *et al* (2009), the findings suggest that the focus of Commercial farms is to prepare more yearlings and direct more towards the premier session and less to the festival session, whilst this is opposite for Non-commercial farms. This exploratory technique is a useful way of identifying patterns when a large number of variables are present. These findings could be used in future studies to classify farms into groups based on more than one factor, which better describes the type or group of farms.

The data were collected at farm-level in this study which may be seen as a limitation, since many farms tailored their preparations to suit individual yearlings. Therefore, future studies should consider collecting horse-level data so they can be specifically related to future training and racing performance.

CONCLUSION

Management practices appear to be relatively homogeneous across the farms surveyed, with most farms managing an adequate balance between confinement for preparation and the opportunity for exercise to stimulate musculoskeletal development. The study has provided data which may serve as baseline data for determining if degree/type of exercise prior to sale has an effect on later athletic performance.

REFERENCES

Barneveld, A. and van Weeren, P.R. (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine. vet. J., Suppl.* **31**, 112-119.

Cherdchutham, W., Becker, C., Smith, R.K.W., Barneveld, A. and van Weeren, P.R. (1999) Age-related changes and effect of exercise on the superficial molecular composition of immature equine superficial digital flexor tendons. *Equine. vet. J., Suppl.* **31**, 86-93.

Cornelissen, W., van Weeren, P.R., Ederveen, A.G.H. and Barneveld, A. (1999) Influence of exercise on bone mineral density of immature cortical and trabecular bone of the equine metacarpus and proximal sesamoid bone. *Equine. vet. J., Suppl.* **31**, 79 - 85.

Doube, M., Firth, E.C. and Boyde, A. (2007) Variations in articular calcified cartilage by site and exercise in the 18-month-old equine distal metacarpal condyle. *Osteoarthr. Cartilage* **15**, 1283-1292.

Dykgraaf, S., Firth, E.C., Rogers, C.W. and Kawcak, C.E. (2008) Effects of exercise on chondrocyte viability and subchondral bone sclerosis in the distal third metacarpal and metatarsal bones of young horses. *Vet. J.* **178**, 53-61.

Elwood, M. (2007) Critical Appraisal of Epidemiological Studies and Clinical Trials: 3rd Edition, Oxford University Press, Oxford, UK. pp 80-81.

Firth, E.C. (2006) The response of bone, articular cartilage and tendon to exercise in the horse. *J. Anat.* **208**, 513-526.

Gibbs, P.G. and Cohen, N.D. (2001) Early management of race-bred weanlings and yearlings on farms. *J. Equine vet. Sci.* **21**, 279-283.

Moffat, P.A., Firth, E.C., Rogers, C.W., Smith, R.K.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., McIlwraith, C.W. and van Weeren, P.R. (2008) The influence of exercise during growth on ultrasonographic parameters of the superficial digital flexor tendon of young thoroughbred horses. *Equine vet. J.* **40**, 136-140.

Nugent, G.E., Law, A.W., Wong, E.G., Temple, M.M., Bae, W.C., Chen, A.C., Kawcak, C.E. and Sah, R.L. (2004) Site- and exercise-related variation in structure and function of cartilage from equine distal metacarpal condyle. *Osteoarthr. Cartilage* **12**, 826-833.

Pagan, J.D., Nash, D.M., Koch, A., Caddel, S. and Brown-Douglous, C.G. (2006) The influence of body weight, wither height and body condition score on sale price of Thoroughbred yearlings at public auction. *Proceedings Australian Equine Science Symposium* **1**, 27.

Rogers, C.W., Gee, E.K. and Firth, E.C. (2007) A cross-sectional survey of Thoroughbred stud farm management in the North Island of New Zealand. *N.Z. vet. J.* **55**, 302-307.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008a) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine vet. J.* **40**, 111-118.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008b) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2 and 3 year old racing careers. *Equine vet. J.* **40**, 119-127.

Stanley, R.L., Edwards, L.J., Goodship, A.E., Firth, E.C. and Patterson-Kane (2008) Effects of exercise on tenocyte cellularity and tenocyte nuclear morphology in immature and mature equine digital tendons. *Equine vet. J.* **40**, 141-146.

Stowers, N.L., Rogers, C.W. and Hoskin, S.O. (2009) Management of weanlings on commercial Thoroughbred studs farms in the North Island of New Zealand. *Proc. N. Z. Soc. Anim. Prod.* **69**, 4-9.

van de Lest, C.H.A., Brama, P.A.J. and van Weeren, P.R. (2002) The influence of exercise on the composition of developing equine joints. *Biorheology* **39**, 183-191.

van Weeren, P.R., Firth, E.C., Brommer, H., Rogers, C.W., DeGroot, J. and Brama, P.A.J. (2008) Early exercise advances the maturation of glycosaminoglycans and collegen in the extracellular matrix in the horse. *Equine vet. J.* **40**, 128-135.

APPENDIX C

This appendix includes the initial letter used to inform studmasters of the survey, a copy of the survey used to collect the data, and further information on entering and processing the data. A comparison between responders and non-responders of the survey, and an expansion of the method and results of the multiple correspondence analysis is also presented. A description of the methods and results of the logistic regression analysis for the provision of exercise during sales preparation are shown.

Copy of the initial letter emailed/posted to studmasters

18th February 2008

Dear [insert studmaster's name]

Massey University on behalf of New Zealand Thoroughbred Racing is currently conducting a study to investigate the effect of early exercise and management of yearlings at stud farms on future racing performance. Part of this project is to describe the current management and exercise regimen of yearlings during the preparation of yearling sales.

In order to obtain this information we will conduct a survey of leading thoroughbred stud farms. Questions relate to the management of yearlings during yearling preparation, specifically the exercise that they may or may not receive during this time. All information collected will remain confidential and no names of horses, studmasters or farm names will be revealed in the project.

Previously, you have assisted us with obtaining vital data on the New Zealand Thoroughbred breeding industry, which resulted in the following publication: http://equinepfx.massey.ac.nz/researchbriefs.html (Article attached). Also on this website there are two companion papers on 'modelling foal growth in New Zealand' and 'the management of Thoroughbred racehorses and what they are fed.

As a successful producer of thoroughbred yearlings and racehorses we would like to include your farm in the survey to benchmark how yearlings are produced for sale. I anticipate conducting interviews in March and I will ring you closer to the time to make an appointment to meet with you. If you wish, a copy of the survey can be provided to you before the visit.

Your co-operation in this project would be greatly appreciated
Kind Regards

Charlotte Bolwell
PhD student
Institute of Veterinary, Animal and Biomedical Sciences

Copy of the questionnaire

CONFIDENTIAL

Exercise and management of yearlings for the 2007-08 season

Name of farm:

Location:

1) What is the farm size? [ ] acres

2) How many yearlings did you have on farm this year? [ ]

3) How many yearlings started yearling preparation? [ ]

4) How many yearlings were sent to the following sales?

a. Premier [ ]
b. Select [ ]
c. Festival [ ]

5) In what month was the decision to send a yearling to the sales made? [ ]

6) What influences this decision? [ ]

7) Typically, when did weaning occur? [ ]

8) Was the weaning method:

1. Progressive
2. Abrupt
3. Both (state % of each)

9) Did you have a target weight/ height for starting preparation? [ ]

If yes what? [ ]

10) When did you start preparation for yearling sales?

a. 1.August 2.September 3.October 4.November 5.December 6. January

b. Number of weeks before the sale [ ]

Id [ ]
L. [ ]
1. [ ]
2. [ ]
3. [ ]
4a. [ ]
4b. [ ]
4c. [ ]
5. [ ]
6. [ ]
7. [ ]
8. [ ]
9a.[ ]
10a.[ ]
10b.[ ]

11) How long did yearling preparation last? 11a. [ ]

a. Days [ ]

12) What was fed during the following time periods?

a. Weaning up to yearling preparation [ ] 12a. [ ]

b. During yearling preparation [ ] 12b. [ ]

13) Was this the same for all horses? [ ] 13 [ ]

If not: how did it vary and why?

14) How much feed was given during the following time periods?

a. Weaning up to yearling preparation [ ] 14a. [ ]

b. During yearling preparation [ ] 14b. [ ]

15) How often did they get fed?	**1xday**	**2xday**	**3xday**	**Other**	
a. Weaning up to yearling preparation	[ ]	[ ]	[ ]	[ ]	15a. [ ]
b. Start of yearling preparation	[ ]	[ ]	[ ]	[ ]	15b. [ ]
c. Middle of yearling preparation	[ ]	[ ]	[ ]	[ ]	15c. [ ]
d. End of yearling preparation up to sale	[ ]	[ ]	[ ]	[ ]	15d. [ ]

16) Did you feed any oil?

a. Weaning up to yearling preparation [ ] 16a. [ ]

b. Start of yearling preparation [ ] 16b. [ ]

c. Middle of yearling preparation [ ] 16c. [ ]

d. End of yearling preparation up to sale [ ] 16d. [ ]

If so: What: [ ]

How much [ ]

17) Were any other supplements fed? 17. [ ]

18) Did you weigh or measure height during the following time periods?

	Weight	Height	W H
a. Weaning up to yearling preparation	[ ]	[ ]	a [ ] [ ]
b. Start of yearling preparation	[ ]	[ ]	d.[ ] [ ]
c. Middle of yearling preparation	[ ]	[ ]	b.[ ] [ ]
d. End of yearling preparation up to sale	[ ]	[ ]	c [ ] [ ]

19) Did you grade the condition of the yearlings and record it using a system?

a. Grade [ ] b. Record [ ] If yes: seen [ ] 19a.[ ]

19b.[ ]

20) Where were weanlings and yearlings kept during the following time periods?

	Pasture	Box	Box + Pasture		
	24hr	24hr	Hours	Hours	
a. Weaning - yearling preparation	[ ]	[ ]	[ ]	[ ]	20a. [ ]
b. During yearling preparation	[ ]	[ ]	[ ]	[ ]	20b. [ ]

Of the yearlings kept at pasture:

21) What is the average size of the paddocks? [ ] acres 21. [ ]

22) What is the size of the smallest and largest paddocks?

a. Smallest [ ] acres 22a. [ ]

b. Largest [ ] acres 22b. [ ]

23) What is the minimum/maximum number of yearlings per paddock?

Colts	Fillies	
a. Minimum [ ]	a. Minimum [ ]	a [ ] [ ]
b. Maximum [ ]	b. Maximum [ ]	b.[ ] [ ]

24) What is the size of the boxes used for yearlings? [ ]m 24. [ ]

25) Did the yearlings receive any exercise, such as walking in hand, as part of yearling preparation? [ ] 25. [ ]

Reason: [ ]

26) When did exercise start? (Month) [ ] 26. [ ]

27) Typically, what exercise was done? (Separate sheet) 27. [ ]

28) Was this the same for all yearlings? [ ] 28. [ ]

If not: reason/what was different:

29) What surface was most of the exercise performed on? (One answer) 29. [ ]

1. Grass
2. Sand
3. Dirt
4. Concrete
5. Hard compacted i.e. gravel
6. Other:

Seen surface: [] (tick)

30) Was this the same for all yearlings? [ ] 30. [ ]

If not: reason/what surface:

31) Did you follow a pre-determined exercise regimen?

[ ] 31. [ ]

32) For how many weeks in total was exercise performed? 32. [ ]

[ ]

33) Did you keep a record of the exercise that was done for each yearling? [ ] 33. [ ]

If yes: reason:

Seen [ ] (Tick)

Thank you for giving your time to assist with this survey.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
August								
Exercise								
Duration (min)								
September								
Exercise								
Duration (min)								
October								
Exercise								
Duration (min)								
November								
Exercise								
Duration (min)								
December								
Exercise								
Duration (min)								
January								
Exercise								
Duration (min)								

Exercise code: None =0; Walk in hand = HandW; Walk horse walker =HorseW; Walk on lunge = WL; Walk long reigning = Wlong; Trot in hand = HT; Trot on walker =TW

Figure A1: An example of the separate sheet used in the questionnaire for recording exercise information

Data entry and processing

In order to facilitate data entry, all closed questions were assigned a code which was recorded to the right hand side of the question on the survey. Data were entered into a data entry file and each farm was automatically given a farm identification number. A number of validation rules were set up for during data entry, such as: legal range for numeric values, a code for missing information (999), 'must enter' rules, jumps to the next applicable question, defining the values as Yes/No, text or numeric, and assigning labels to the codes. After entering the data, the files were checked for consistency, using the double entry verification tool in EpiData Data Entry. When inconsistencies between the two files were present, they were checked against the raw data and the correct information was entered into the master file. The specific exercise data, collected in the table, were entered into Microsoft Excel.

Non-response

To assess for non-response bias, a comparison between the surveyed farms and non-responders was made using publicly available data: the location of the stud farm, the number of yearlings sent to the sales, and the type of phone number (landline or mobile) used to establish contact. Chi-square tests were used to compare binary data whilst the Wilcoxon rank-sum (Mann-Whitney) test was used to compare the median number of horses sent to the sale by responders and non-responders.

The median number of horses sent to the sales was significantly ($p<0.001$) different between responders (10 interquartile range 4-23) and non-responders (2 interquartile range 1-5). There was a significant difference between the location of the farm and responders and also with the type of phone number used to establish contact (Table A1).

Overall, significant differences were identified indicating that response bias towards larger, commercial stud farms located in the Waikato, with more horses catalogued for Premier sale may have been present in this population. However, MCA highlighted that exercise was not part of one of the clusters of farm variables, suggesting there would be limited effect on the exercise results. Additionally, there was no overall association between farm variables and provision of exercise during sales preparation, indicating that it is unlikely that the association (or lack of) would differ between responders and non-responders.

Table A1: The number and percentage of responders and non-responders, the location of the stud farm and the type of phone used to contact eligible participants.

Variable	**Did not respond N (%)**	**Responded N (%)**	**P-value**
Location			<0.001
Central	16	9	
Northern	21	66	
Phone for contact			0.01
Landline	30	43	
Mobile	7	32	

Multiple correspondence analysis

The analysis was adjusted to take account of the inflation of inertia due to the diagonal inertia in the Burt Matrix; the adjusted analysis considers only the off-diagonal sub tables of the Burt Matrix. The centre of the map represents the average profile and is said to be homogenous, so variables in this position are very similar to each other and the average profile. The first axis was characterised by: farms preparing >25 yearlings, when the farm started preparation, and the percentage of yearlings sent to the Premier and Festival sales. Midrange stud farms were associated with the second axis. Based on the individual inertia values, the variables contributing strongly to the overall variance in the plot include: Commercial and Non-commercial farms and the percentage of yearlings farms sent to Premier and Festival sales.

Logistic regression analysis: factors associated with the provision of exercise

Simple logistic regression was used to investigate associations between explanatory variables and whether or not a farm exercised yearlings. Variables were considered for inclusion in multivariable models based on a cut off of $p<0.20$. A multivariable logistic regression model was developed using a backwards elimination procedure, fitting a model with all selected variables and removing variables that were not significant at a level of $P<0.05$. The significance of the variables included in the model was assessed using a likelihood ratio test (LRT).

Table A2 presents the results of the univariable logistic regression. Studmasters preparing >25 yearlings for sale were at higher odds of providing exercise, compared to studmasters preparing <6 yearlings. The odds of providing exercise during sales preparation were less for both Mid-range and Non-Commercial stud farms, compared to Commercial stud farms. After adjusting for the other variables included in the multivariable model, none of the variables were significantly associated with the provision of exercise (Table A3)

Table A2: Results of univariable logistic regression of exposure variables and the provision of exercise during sales preparation.

Variable	Number of Stud farms	Number giving exercise	Odds ratio (95% CI)[a]	Wald test P-value	LRS[b] P-value
Location					0.45
Central Districts[c]	9	8	Ref	-	
Northern Districts[d]	66	52	0.46 (0.02-2.85)	0.48	
Category					0.15
Commercial	21	18	Ref	-	
Mid-range	35	29	0.81 (0.15-3.47)	0.77	
Non-commercial	19	13	0.36 (0.07-1.63)	0.20	
Month preparation started					0.29
Before November	36	27	Ref	-	
November or later	39	33	1.83 (0.59-6.09)	0.30	
Yearlings prepared					0.09
<6	23	19	Ref	-	
6-25	32	23	0.54 (0.13-1.94)	0.35	
>25	20	18	1.89 (0.33-14.90)	0.49	
Premier sale[e]					0.16
≤20%	38	28	Ref	-	
>20%	37	32	2.29 (0.72-8.09)	0.17	
Select sale[e]					0.19
≤42%	39	29	Ref	-	
>42%	36	31	2.14 (0.67-7.56)	0.21	
Festival sale[e]					0.35
<10%	38	32	Ref	-	
≥10%	37	28	0.58 (0.18-1.82)	0.35	
Size of box[f] (metres)					0.34
<3.6x3.6	14	10	Ref	-	
3.6x3.6 - 4x4	51	42	1.87 (0.44-7.11)	0.37	
>4x4	7	6	2.40 (0.27-53.03)	0.47	
Hours at pasture					0.46
<12	28	20	Ref	-	
≥ 12	47	40	2.29 (0.72-7.41)	0.15	

[a]CI = 95% confidence interval. [b]LRS = Likelihood ratio statistic. [c]Manawatu and Wanganui. [d]Waikato and South Auckland [e]Percentage of horses sent to this type of sale.[f]3 farms did not provide this information. Ref = reference level for comparision

Table A3: Results of the multivariable logistic regression analysis for exposure variables and the provision of exercise during a sales preparation.

Variable	**Coefficient (SE)[a]**	**Odds ratio (95% CI)[b]**	**Wald test P-value**
Premier sale[c]			
≤20%	Ref	Ref	-
>20%	0.56 (0.92)	1.75 (0.31-13.90)	0.54
Select sale[c]			
≤42%	Ref	Ref	-
>42%	0.64 (0.74)	1.90 (0.43-8.57)	0.39
Category			
Commercial	Ref	Ref	-
Mid-range	0.11 (1.01)	1.13 (0.15-9.98)	0.90
Non-commercial	0.08 (1.25)	1.08 (0.09-14.83)	0.94
Yearlings prepared	0.01 (0.02)	1.02 (0.97-1.08)	0.48

[a]SE = Standard error. [b]CI = confidence interval. [c]Percentage of horses sent to this type of sale. Ref = Reference level for comparison

PRELUDE TO CHAPTER 5

The manuscript presented in Chapter 4 identified that whilst exercise was a common practice during sales preparation, the type and amount of exercise was tailored to individual yearlings based on a number of factors. The data presented in Chapter 4 were collected at the farm-level, but provided the necessary foundation for developing a prospective cohort study to collect exercise information at the horse-level.

Chapter 5 presents the findings of Part 1 of the cohort study, which describes the daily and total exercise accumulated during the sales preparations and the variation in exercise between and within stud farms. The cohort study allowed individual horses to be followed through sales preparation and into race training as 2-year-olds, and provided detailed information on the exposure to exercise during sales preparation.

An example of the form used to record the exercise data is presented in the appendix for this chapter. The manuscript presented in Chapter 5 is published in Equine Veterinary Journal.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011) Exercise in Thoroughbred yearlings during sales preparation: A cohort study. Equine vet. J., no.10.1111/j.2042-3306.2011.00370.x

CHAPTER 5

EXERCISE IN THOROUGHBRED YEARLINGS DURING SALES PREPARATION: A COHORT STUDY

ABSTRACT

Reasons for performing the study

There is increasing evidence suggesting that early exercise in Thoroughbred racehorses may be beneficial to the development of the musculoskeletal system. At present, information on the exercise programmes and health problems of individual yearlings during sales preparation is scant.

Objectives/Hypothesis

To describe the exercise and health problems of Thoroughbred yearlings during preparation for sales, and to identify variations in exercise between and within farms.

Methods

A prospective cohort study was used to collect exercise and health information from 18 farms across New Zealand. Daily exercise records for individual horses were recorded during the stud farms' preparation for the annual national yearling sales in January 2009.

Results

Data were collected from 319 yearlings, of which 283 (88.7%) were exercised (hand walking, mechanical walker and lungeing) during their preparations. Sales preparation lasted a median of 69 days (interquartile range (IQR) 61-78), and differed significantly between farms ($P<0.001$). The median exercise time (minutes) performed differed significantly by gender ($P<0.001$), farm ($P<0.001$) and month of the preparation ($P<0.001$), but not by type of sale ($P=0.14$) or category of sales price ($P=0.12$). Within certain farms, daily exercise differed between horses as did total exercise by gender, and the number of days spent in the sales preparation. Lameness was the most common condition affecting yearlings, and the overall incidence rate of lameness was 0.08 per 100 horse days (95% confidence interval 0.05-0.13). Incidence rates of lameness varied significantly between farms ($P=0.02$), but not by age (in months) ($P=0.77$), sales type ($P=0.58$) or month of the preparation ($P=0.53$).

Conclusions and potential relevance

Yearling exercise programmes varied between and within farms. Since exercise is already being tailored for each individual horse, there may be an opportunity to allow for modifications to sales preparation with the future career in mind.

INTRODUCTION

One of the major causes of wastage in Thoroughbred racing within New Zealand, and worldwide, is musculoskeletal injury (MSI) (Bailey *et al.* 1999; Perkins *et al.* 2004; Dyson *et al.* 2008). Previous studies have shown that the early rearing environment, specifically exposure to exercise, influences the development of the musculoskeletal system (Barneveld and van Weeren 1999; Firth 2006; Rogers *et al.* 2008a). Therefore, it is important to identify if early conditioning programmes could be developed or modified in order to minimise the risk of MSI during training and racing.

A recent intervention trial indicated that a conditioning programme imposed on foals kept at pasture did not affect the horses' welfare, and there were no negative effects on clinical musculoskeletal health (Rogers *et al.* 2008a). Additionally, after being broken and trained for racing, there were apparently no negative effects of the early conditioning programme on their careers as 2- and 3-year-old racehorses (Rogers *et al.* 2008b). Apart from this study (Rogers *et al.* 2008b), there is currently little knowledge on the long-term effects of early controlled exercise on the ability of racehorses to train and race.

Over the past five years, 22-29% of the annual Thoroughbred foal crop in New Zealand has been sold through the national yearling sales series (Anon 2009). The annual sales consist of Premier, Select and Festival categories and yearlings are allocated to one of the three sales based on their pedigree, conformation and type. Previous studies have reported that yearlings have an average of 12-13 weeks of preparation at the stud farm (Rogers *et al.* 2007; Bolwell *et al.* 2010 [Chapter 4]) to ensure they are well educated and ready for the sale. In a recent cross-sectional study (Bolwell *et al.* 2010 [Chapter 4]), exercise was found to be an integral part of these preparations, with 80% of farms providing some form of scheduled exercise. Similarly, Gibbs and Cohen (2001) found 64% of Thoroughbred and Quarter horse stud farms, in the USA, surveyed provided a scheduled exercise programme for yearlings between 14-18 months of age.

A prospective epidemiological study has recently been conducted, following a cohort of yearlings from the 2007 New Zealand Thoroughbred foal crop. This study followed horses from sales preparation through to training and racing as 2-year-olds. The current paper reports on the first part of that study and describes the exercise programmes and health problems during preparation for the yearling sales.

MATERIALS AND METHODS

Study design

A prospective cohort study was used to collect data on the exercise activity of Thoroughbred racehorses born in the 2007 foal crop, from yearling sales preparation through to training and racing as a 2-year-old. The study began in September 2008 and concluded on the 31st July 2010 (the last day of the New Zealand racing season). Horses that were exported overseas, relocated to the South Island of New Zealand, died or were retired from racing during this period were considered as lost to follow-up.

The data were collected during yearling sales preparation (Part 1) and race training as a 2-year-old (Part 2). Part 1 began on 29th September 2008 and ended on the 25th January 2009 (the day before the National Yearling Sales 2009). The start of data collection for each of the farms varied within these dates, depending on their usual start time for a sale preparation. Data collection for Part 2 began on the first day a horse entered race training (earliest date 6th April 2009) and ended on the 31st July 2010 and full details will be reported separately.

Selection of farms and horses

The target population consisted of farms that exercised yearlings during sales preparation. A convenience sample of farms was selected from the 75 farms (85% response rate) that participated in a previous cross-sectional survey of yearling preparation (Bolwell *et al.* 2010 [Chapter 4]). In that survey, 60 farms stated they exercised yearlings, however eight farms were excluded from the sample as they had no yearlings registered for the 2009 sales. Farms were then selected from the source population based on their willingness to participate and enthusiasm for the previous survey. An initial telephone call or email was used to inform studmasters about the project and to request a suitable time to visit and discuss the project further. Studmasters who could not be reached after three attempts were excluded from the sample. In some cases, the extra work required to enrol all yearlings in preparation was too demanding for the studmasters and so a selection was chosen. The studmasters were encouraged to enrol a random group when selecting yearlings, but often, for ease of recording, yearlings that were grouped together in the same barn were chosen.

Data collection

Horse data: Horse information, such as dam, sire, gender and date of birth, was either provided by the farm or obtained from the New Zealand Thoroughbred studbook[1]. Sales information for each horse, such as sale type, if it was sold or withdrawn, purchaser, and price, were obtained from the online catalogue of New Zealand Bloodstock Limited[2].

Exercise data: Data were collected individually for all horses enrolled on each farm. The number of hours spent at pasture, the type of exercise (hand walking, mechanical walker and lunge) and the duration of exercise were recorded daily. The reasons for changes to the exercise programme or time at pasture and health problems or withdrawal from the sales preparation were also noted. Only horses that were withdrawn from the sales due to health reasons were guaranteed to have been diagnosed by a veterinarian. No information was recorded on whether other health events were diagnosed by a veterinarian.

The data were recorded by one person on each farm, either the yearling manager or another nominated staff member, throughout the duration of the preparation. Data were recorded onto standardised forms that had the sire and dam names (or stable name) of the yearlings printed onto each page, to facilitate recording. Regular contact was maintained through telephone calls and two visits were made to each farm during the preparation to check the data were up-to-date and pictures were taken to check consistency of hand writing and pen colour. At the end of the sales preparation the forms were either collected in person by one investigator (C.F.B) or posted back by mail, depending on what was convenient for each farm.

Data processing and statistical analysis

All data were entered into a customised database (Microsoft Access, Microsoft Corporation, Redmond, Washington, USA) and then checked for errors and consistency. Median values and interquartile ranges (IQR) are presented throughout for non-normally distributed data. Unless stated, exercise is presented as time in

---

[1] www.nzracing.co.nz/Breeding/Default.aspx

[2] www.nzb.co.nz/sales/index.cfm?sale_year=2009

minutes. Box and Whisker plots were used to display summaries of exercise by gender, within each calendar month of the preparation, and the number of preparation days by stud farm. Age at entry (months) to the preparation was categorised into groups based on quartiles. Summary measures for exercise between and within farms, days in preparation, sale type, and month of preparation were compared using the Kruskal-Wallis test for non-normally distributed data. The Wilcoxon rank-sum test (Mann-Whitney) was used to compare exercise summaries by gender. Lameness incidence rates, calculated directly from the Microsoft Access database, were based on the number of lameness cases reported and the number of horse days at risk, expressed as a rate per 100 horse days; 95% confidence intervals (95% CI) for rates were calculated. Cases of accidental injury or horses that were already lame at the start of the preparation were excluded from the analysis. Poisson regression was used to compare incidence rates by gender, age at entry to the preparation (months), and sales category with stud farm included in each of the models as a random effect to adjust for potential clustering at the farm-level. Additionally, stud farm was modelled as a fixed effect in a univariable model to compare the incidence rates across farms. Analyses were conducted in Intercooled STATA 11 (Statacorp LP, College Station, Texas, USA) and the critical probability for assigning statistical significance was set at $P<0.05$.

RESULTS

Study population

Forty farms were included in the sampling frame, which consisted of 1,009 yearlings, 64% colts and 36% fillies, catalogued for the sales in 2009. Of the 35 (of 40) contacts successfully made, eight farms declined to participate as they were too busy. Twenty-seven farms entered the study and at the end of the data collection period, six farms had not regularly recorded the data, two farms said they had ‘lost’ the completed forms before they could be collected by the investigator, and one farm withdrew all their yearlings from the sales, resulting in 18 farms included in the study.

Across the 18 farms, a total of 497 yearlings were catalogued for the sales; 62% (306/497) were colts and 38% (191/497) were fillies. Eleven farms enrolled 100% of their yearlings, four farms enrolled more than 50%, two farms enrolled ~20% and one farm <10% (2/27) of their yearlings in preparation. In total, data were recorded for 319/497 (64%) yearlings of which 210 (66%) were colts and 109 (33%) were fillies. The number of yearlings enrolled by each farm ranged from 2-65. Twelve yearlings were withdrawn from the sales once preparation had begun and were subsequently turned out to the paddock. For farm 8, data were missing for the last month of preparation (5 Jan – 25th Jan) as the farm became too busy to continue recording the data.

Preparation

Most yearlings were catalogued for the Premier sale (139/307; 45.2%) followed by the Select (127/307; 39.8%) and Festival sales (41/307; 13.3%). Of those that went to the sales, 245 (76.8%) yearlings were sold and 62 yearlings were passed in (did not meet the reserve price). The median duration of the sales preparation was 69 days (IQR 61-78) and the length of the preparation differed significantly ($P<0.001$) between farms (Figure 1). The median number of preparation days did not differ significantly by sales category (Premier, Select or Festival) ($P=0.66$).

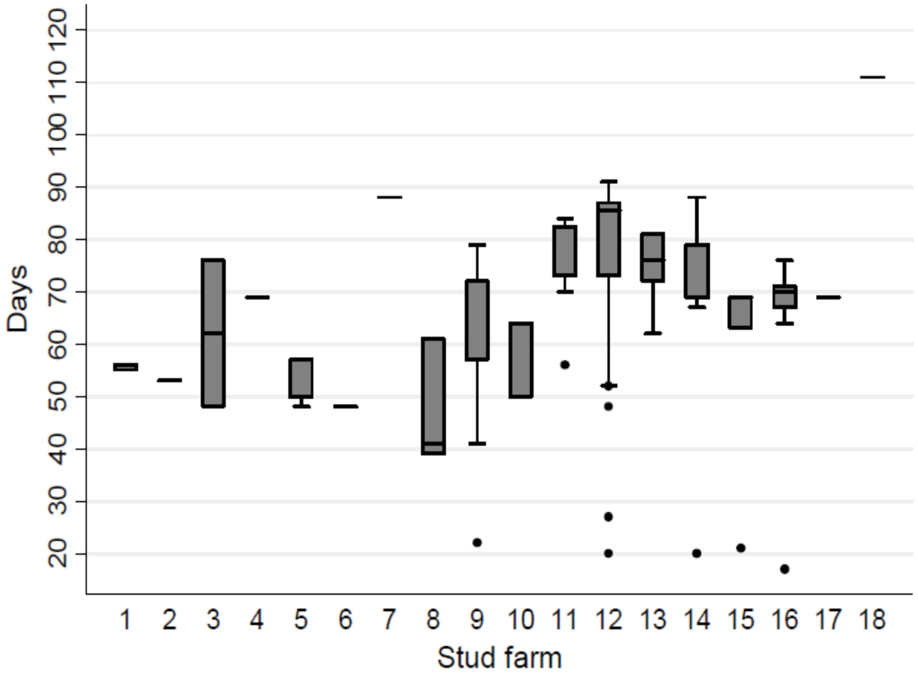


Figure 1: Box plots for the number of days of a yearling sales preparation across 18 Thoroughbred stud farms

Exercise

Three types of exercise were performed during the preparations: hand walking, walking on a mechanical walker, and lungeing exercise. Three stud farms did not exercise all of their enrolled yearlings, resulting in exercise data being collected for 283 (of 319) yearlings. The median number of days from starting a preparation (first stabled) to beginning exercise was seven (IQR 0-19), with a maximum of 70 days. The median number of days spent exercising was 34 (8-45). Most (170/283; 60%) yearlings undertook hand walking, followed by both hand walking and using a mechanical walker (81/283; 28.6%), using only a mechanical walker (17/283; 6%), and both types of walking and lungeing (8/283; 2.8%). Six horses were hand walked and received lungeing exercise, whilst one horse received only lungeing exercise.

The distributions of the exercise types are shown in Table 1. The median amount of exercise (all exercise types combined) was significantly different by gender (P=0.009) but did not differ significantly by type of sale (P=0.14), sold (yes/no; P=0.13), or sales price category (P=0.12) (Table 1). The median total exercise differed significantly by month (P<0.001) of the preparation, with the most exercise being done in October and December and the least in January. The median total exercise by gender varied significantly across each month of the preparation (Colts P<0.001, Fillies P=0.01): median total exercise for colts was highest in October (305, IQR 255-305) and December (278, IQR 83-475), whilst the median total exercise for fillies increased each month from October to December (100, IQR 100-100; 110 IQR 50-265; 180 IQR 77-390, respectively), then decreased in January (98 IQR 50-195). No difference in exercise was seen by gender in October, but colts were exercised significantly more than fillies in November (P=0.009), December (P=0.02) and January (P<0.001) (Figure 2). The median total exercise differed significantly by stud farm (P<0.001) (Figure 3).

Table 1: Distributions of continuous exercise variables for sales preparations, and total exercise by gender and month of preparation.

Variable	Median time exercised[a] (min)	Interquartile range	Minimum	Maximum
Hand walking	180	66-625	0	1735
Mechanical walker	0	0-155	0	1520
Lungeing	20	10-540	5	900
Total exercise	450	150-935	11	2985
Gender				
Males	475	160-980	20	2985
Females	275	132-675	11	1570
Month				
October	305	205-305	80	305
November	165	75-270	5	400
December	260	80-420	10	1560
January	160	80-300	10	1000
Sale type				
Premier	510	205-885	20	2985
Select	325	110-835	11	2115
Festival	900	105-1295	25	1435
Sold				
No	251	143-625	20	2045
Yes	465	160-980	11	2985
Sales price				
$1,500-20,000	325	77-980	11	2115
$22,000-50,000	455	85-980	20	2985
$52,000-100,000	583	215-973	20	2985
$105,000-700,000	590	205-1013	45	1570

[a] Total time for the whole preparation. Values for gender and month differed significantly $P<0.05$

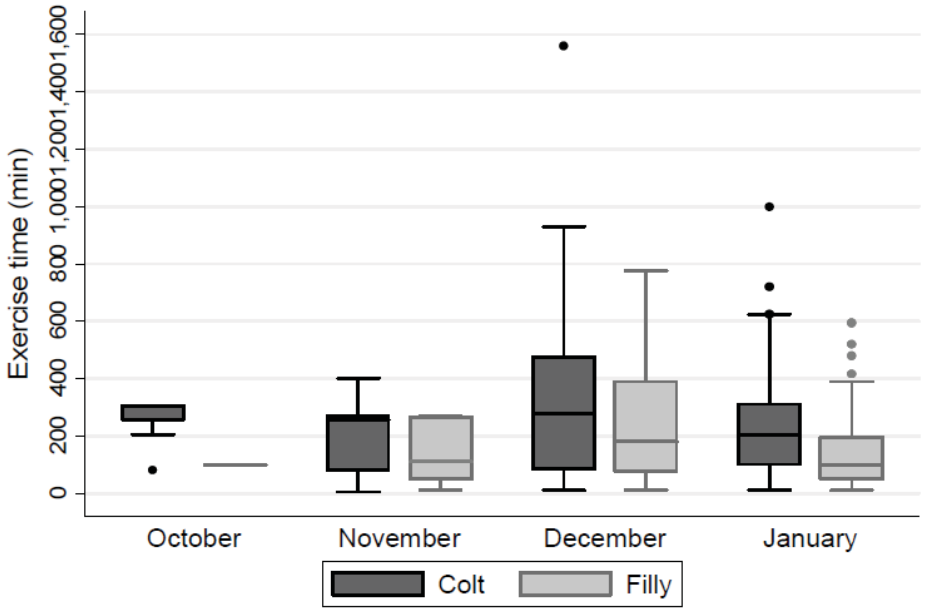


Figure 2: Box plots of total exercise for males and females within each month of sales preparation.

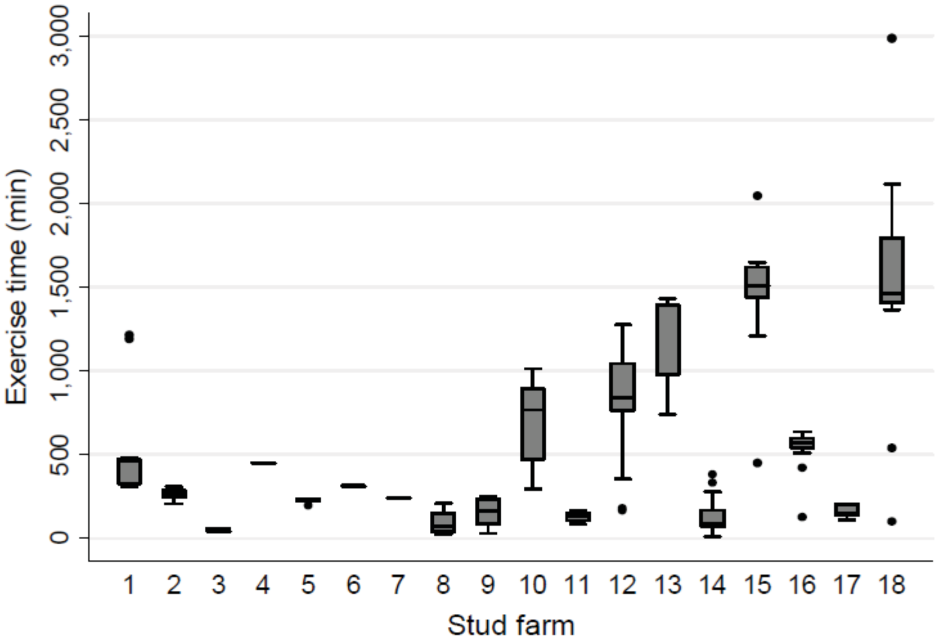


Figure 3: Median exercise time during sales preparation across 18 Thoroughbred stud farms.

Within farm

The amount of daily exercise per horse differed significantly between horses on farms. The median daily exercise ranged from 5-25 minutes ($P<0.001$), 5-15 minutes ($P=0.001$) and 0-20 minutes ($P<0.001$) on Farms 1, 10 and 18, respectively. On Farms 9 ($P=0.001$) and 14 ($P<0.001$) the median daily exercise per horse was zero due to a higher number of days spent not exercising (63, IQR 18-75 and 70 IQR 21-87, respectively) compared to exercising (7.5 IQR 1-10 on both farms); maximum daily exercise ranged from 15-44 and 11-20 minutes on Farms 9 and 14, respectively. The median total exercise of colts and fillies was significantly different within some farms. Colts were given more exercise than fillies on Farms 12 ($P<0.001$), 14 ($P=0.001$), 16 ($P=0.003$) and 18 ($P=0.02$), whilst fillies were given more exercise than colts on Farm 13 ($P=0.02$).

Changes to exercise programme

In total, 150/319 (47%) yearlings, across five farms, experienced changes to their exercise programme as a result of voluntary decisions by the yearling manager. Horse factors such as ill discipline (18/150), boredom (6/150) and parade practice (10/150) resulted in increased exercise for colts, whilst fillies received more exercise due to being overweight (11/150) and in order to 'refresh yearlings on how to walk' (10/150). Wet weather (28/150), caution over the use of the mechanical walker (9/150), and being understaffed (14/150) were reasons for reduced exercise duration in both colts and fillies.

Health problems

A total of 31 health events were reported, with lameness being the most common condition recorded (21/31), followed by accidental injuries (8/31), laminitis (1/31) and one case of muscle spasms. In total, 63 (of 22,298; 0.28%) preparation days were lost due to lameness, seven horses losing seven days and one horse 14 days. Exercise was not performed on these days and the number of hours at pasture per day was reduced from an average of 15.5 hours to zero. One lameness case (type unspecified) was excluded as the horse was already lame when sales preparation began. Twenty cases of lameness were recorded, resulting in an overall incidence rate of 0.08 per 100 horse days (95% CI 0.05-0.13). The most common causes of lameness were recorded as 'swollen joints' or 'swollen tendons' (7/20) or were unspecified (7/20), followed by 'splints' (3/20) and foot lameness (3/20). Incidence rates varied significantly by farm ($P=0.02$) but not by gender ($P=0.22$), age ($P=0.93$) or sale type ($P=0.66$) (Table 2).

Table 2: Days at risk, number of lameness cases and lameness incidence rates by gender, age at entry (months), stud farm and sale type

Variable	Level	Days at risk	No. of cases	Lameness incidence[a] (95% CI)
Gender[b]	Male	14,680	11	0.07 (0.03-0.13)
	Female	7,618	9	0.11 (0.05-0.22)
Age at entry[b]	10-12	5,485	3	0.06 (0.01-0.15)
	13	7,729	8	0.10 (0.04-0.20)
	14	5,957	6	0.10 (0.03-0.21)
	15+	3,127	3	0.09 (0.01-0.28)
Sale type[b]	Premier	10,341	7	0.06 (0.02-0.13)
	Select	8,983	10	0.11 (0.05-0.20)
	Festival	2,974	3	0.10 (0.02-0.29)
Stud farm	1	850	0	0
	2	324	2	0.61 (0.07-2.22)
	3	252	0	0
	4	140	0	0
	5	376	1	0.26 (0.006-1.48)
	6	147	0	0
	7	178	0	0
	8	1,228	4	0.32 (0.08-0.83)
	9	1,736	0	0
	10	1,123	1	0.08 (0.002-0.49)
	11	914	2	0.21 (0.02-0.007)
	12	3,008	0	0
	13	2,235	1	0.04 (0.001-0.24)
	14	4,730	5	0.10 (0.03-0.24)
	15	1,100	3	0.27 (0.05-0.79)
	16	1,647	1	0.06 (0.001-0.33)
	17	630	0	0
	18	1,680	0	0

[a] Incidence of lameness per 100 horse days. [b] Adjusted for potential clustering at the farm-level with the inclusion of a random effect for stud farm.

DISCUSSION

This paper reports the descriptive results of Part 1 of a large epidemiological study, following a cohort of Thoroughbred yearlings from sale preparation through to training as 2-year-olds. The study expands on previous work that reported on sales preparation at the farm-level and indicated exercise was a common practice during this time (Bolwell *et al.* 2010 [Chapter 4]). A convenience sample of stud farms was selected and due to non-response and failure to comply with data collection, only 30% of yearlings from the sampling frame were included in the study. Therefore, the exercise programmes and health problems may not be representative of all the yearlings that were exercised during sales preparation in New Zealand. However, due to the nature of the data collection, high levels of co-operation were important in order to ensure accuracy of the data.

Compared to both the sampling frame and the eligible population, colts were slightly over-represented in the cohort of enrolled yearlings. Seven farms enrolled only a selection of yearlings in the study, which was typically dependent on which yearlings were grouped together on the farm. Often, for management reasons, colts and fillies were housed in separate barns potentially leading to an over-representation of colts within the study population. However, 11 farms enrolled all their sales yearlings, reducing the potential for selection bias within farms. Information on health problems that occurred during preparation were reported by the studmaster and not a veterinarian, which could have resulted in some misclassification bias. However, as the types of lameness were not always recorded by the studmaster, cases were grouped together as opposed to creating specific lameness categories. Although farms were asked to report any health events observed, differential reporting of events may have contributed to the differences in the lameness rates seen between farms.

In order to enhance the internal validity of the data, a number of steps were taken in the design of the study. The studmasters were visited before the data collection began to identify the best method of collecting the data, and to identify one person who would be responsible for recording the information. This ensured that data were recorded by a person who had been trained to record the data and was responsible for the daily management and exercise of the yearlings. Regular contact was maintained by telephone and through visits made to the farms, to check the information recorded was up-to-date and was being recorded on a daily basis. Despite this, from the time of the last visit to the end of data collection some farms did not regularly record the data, resulting in the data being excluded from the analysis.

The duration of the sales preparation varied by farm but there was no difference with sale category. Sale category has been previously grouped together with the type of farm (Commercial, Midrange or Non-commercial) and the start of preparation. Commercial farms preparing more yearlings for Premier sale start earlier in the season and have longer preparations than Non-commercial farms that prepare more yearlings for Festival sale (Bolwell *et al.* 2010 [Chapter 4]). However, in the current study, only 13% of yearlings were catalogued for Festival sale, which may explain why no difference was seen.

Lameness was found to be the most common cause of health problems occurring during sales preparation, resulting in adjustments to exercise programmes or complete withdrawal from the sales. Days lost from the sales preparation are of economic importance to a stud farm through the keep of injured horses and in some cases a loss of return due to withdrawals from the sales. Lameness is a common cause of wastage and days lost from training in Thoroughbred racing industries across the world. Studies in the United Kingdom and Australia found lameness accounted for 81.5% (Dyson *et al.* 2008) and 56% (Bailey *et al.* 1999) of lost training days, whilst a study in New Zealand found 47.9% of MSI cases were due to lameness (Perkins *et al.* 2004). Within that study, the incidence rate of lameness (non-fracture) in 2-year-old horses in training was 1.29 per 1,000 training days (95% CI 1.06-1.57). In contrast, the current study showed a lower incidence rate of lameness and a lower percentage of lost preparation days (0.28%). However, the present study involved a younger cohort of Thoroughbreds not yet exposed to the higher intensity exercise of race training. Despite this, the study highlighted the potential importance of lameness even during the early stages of a racehorse's career.

Total exercise varied by gender within each month of the preparation, between and within farms, with colts having more exercise, on average, than fillies. Possible reasons for these differences include a number of farms increasing exercise for yearlings perceived as being bored or ill-disciplined; these groups of yearlings were all colts. Additionally, previous studies have shown gender to be associated with sales price, with colts achieving higher prices than fillies (Robbins and Kennedy 2001; Parsons and Smith 2008; Waldron *et al.* 2011). Therefore, farms may focus more on colts during a preparation, due to the high demand for colts and the potential for a greater financial return.

Exercise varied not only between farms, but also between individual horses within farms. Horse factors such as sire, pedigree, dam age and parity are part of determining the sales category of the yearling and there is a strong association between the type of sale and price (Waldron *et al.* 2011). Therefore, the sale category for which a yearling is destined will influence the exercise and management of the horse. As most of the yearlings were catalogued for the Premier sale, no difference was seen between sales category and exercise. However, 46% of farms previously reported that yearlings were treated as individuals and preparations would be tailored to suit them (Bolwell *et al.* 2010 [Chapter 4]). Similarly, results showed changes to exercise programmes occurred within farms due to staffing problems, bad weather and the consumer demand to view the product (i.e. practice for yearling parades).

The exercise programmes during yearling preparation appeared to be focused on the short-term goal of the sales rather than preparing the horse for its future athletic career as a racehorse. A recent study investigated the effect of early exercise on the development of the musculoskeletal system, by keeping foals at pasture and supplying an additional 30% increase in exercise from 3 weeks up to 19-21 months of age (Rogers *et al.* 2008a). Although the foals exercised up to a maximum of ~13 m/s there were generally no negative effects on clinical musculoskeletal health or on the horses' careers as 2- and 3-year-olds (Rogers *et al.* 2008b). The current study showed most exercise was performed at walk, which is much slower and less intense than the exercise regimen given to the foals. Therefore, there may be an opportunity to modify or adapt sales preparations, without doing harm, in order to minimise the risk of MSI in the future. However, implementations with the industry may prove difficult unless associations between early exercise programmes and future racing success and long-term musculoskeletal health can be shown through epidemiological studies, and buyers start to place a premium on yearlings prepared in this manner. The effect of early exercise during these sales preparations on indicators of training and racing performance, in our study, will be reported on separately [Chapters 7 and 8].

In conclusion, exercise programmes varied between and within farms due to studmasters aiming to maximise the potential of each yearling at the sales. Since exercise is already being tailored for each individual horse, there may be an opportunity to modify yearling sales preparation if the value of exercise in reducing future MSI and enhancing racing careers can be shown.

REFERENCES

Anon (2009) *New Zealand Thoroughbred Racing Fact Book 2009*, New Zealand Thoroughbred Racing Inc., Welllington.

Bailey, C.J., Reid, S.W., Hodgson, D.R. and Rose, R.J. (1999) Impact of injuries and disease on a cohort of two- and three-year-old thoroughbreds in training. *Vet. Rec.* **145**, 487-493.

Barneveld, A. and van Weeren, P.R. (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine. vet. J., Suppl.* **31**, 112-119.

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2010) Management and exercise of Thoroughbred yearlings during preparation for yearling sales in North Island of New Zealand. *Proc. N. Z. Soc. Anim. Prod.* **70**, 157-161.

Dyson, P.K., Jackson, B.F., Pfeiffer, D.U. and Price, J.S. (2008) Days lost from training by two- and three-year-old Thoroughbred horses: A survey of seven UK training yards. *Equine vet. J.* **40**, 650-657.

Firth, E.C. (2006) The response of bone, articular cartilage and tendon to exercise in the horse. *J. Anat.* **208**, 513-526.

Gibbs, P.G. and Cohen, N.D. (2001) Early management of race-bred weanlings and yearlings on farms. *J. Equine vet. Sci.* **21**, 279-283.

Parsons, C. and Smith, I. (2008) The price of Thoroughbred yearlings in Britain. *J. Sport Econ.* **9**, 43-66.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004) Profiling the New Zealand Thoroughbred racing industry. 2. Conditions interfering with training and racing. *N.Z. vet. J.* **53**, 69-76.

Robbins, M. and Kennedy, P.E. (2001) Buyer behaviour in a regional thoroughbred yearling market. *Appl. Econ.* **33**, 969-977.

Rogers, C.W., Gee, E.K. and Firth, E.C. (2007) A cross-sectional survey of Thoroughbred stud farm management in the North Island of New Zealand. *N.Z. vet. J.* **55**, 302-307.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008a) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine vet. J.* **40**, 111-118.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008b) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2 and 3 year old racing careers. *Equine vet. J.* **40**, 119-127.

Waldron, K., Rogers, C.W., Gee, E. and Bolwell, C.F. (2011) Production variables influencing the auction sales price of New Zealand Thoroughbred yearlings. *Proc. N. Z. Soc. Anim. Prod.*, in press.

APPENDIX D

In this appendix the email used to contact participants and an article of previous results, referred to in the email, are presented. Further, this appendix includes the information sheet from the data collection booklets that were provided to each farm and examples of the forms used to record the data (Figure A1 and A2).

Copy of the email used to inform studmasters about the study (August 2008).

Dear [Insert studmaster's name]

I wanted to let you know that some preliminary results of the survey you did in March will be in the next issue of the Waikato Breeders' bloodline. I am currently collecting training data from the yearlings involved in the survey, which will continue until the end of this racing season.

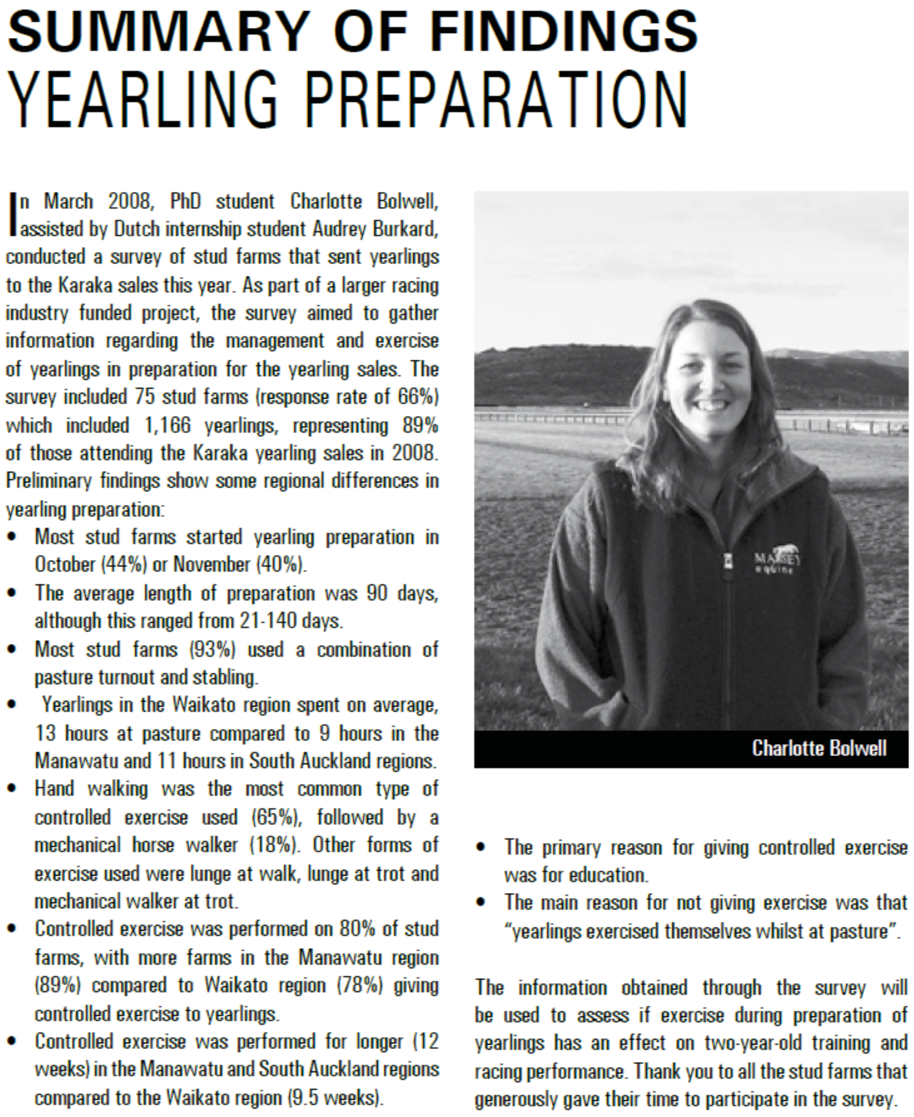
I wondered if you might be interested in participating in the second part of my PhD studies. We would like to follow the yearlings through their yearling preparation collecting individual daily exercise information in preparation for the sales. Although the survey provided us with an insight into the preparation, it was retrospective and related generally to all yearlings. An important finding of the study was that yearling preparation is often tailored to the individual horse.

We know that preparation is a very busy time on the farm and so we would be looking for ways to collect the data that has minimal impact on you and your workload. At this stage I would just like to know if it is something you might consider taking part in?

Kind Regards

Charlotte

Copy of the article published in the Waikato Breeders' Bloodline (September 2008).



SUMMARY OF FINDINGS
YEARLING PREPARATION

In March 2008, PhD student Charlotte Bolwell, assisted by Dutch internship student Audrey Burkard, conducted a survey of stud farms that sent yearlings to the Karaka sales this year. As part of a larger racing industry funded project, the survey aimed to gather information regarding the management and exercise of yearlings in preparation for the yearling sales. The survey included 75 stud farms (response rate of 66%) which included 1,166 yearlings, representing 89% of those attending the Karaka yearling sales in 2008. Preliminary findings show some regional differences in yearling preparation:

- Most stud farms started yearling preparation in October (44%) or November (40%).
- The average length of preparation was 90 days, although this ranged from 21-140 days.
- Most stud farms (93%) used a combination of pasture turnout and stabling.
- Yearlings in the Waikato region spent on average, 13 hours at pasture compared to 9 hours in the Manawatu and 11 hours in South Auckland regions.
- Hand walking was the most common type of controlled exercise used (65%), followed by a mechanical horse walker (18%). Other forms of exercise used were lunge at walk, lunge at trot and mechanical walker at trot.
- Controlled exercise was performed on 80% of stud farms, with more farms in the Manawatu region (89%) compared to Waikato region (78%) giving controlled exercise to yearlings.
- Controlled exercise was performed for longer (12 weeks) in the Manawatu and South Auckland regions compared to the Waikato region (9.5 weeks).

Charlotte Bolwell

- The primary reason for giving controlled exercise was for education.
- The main reason for not giving exercise was that "yearlings exercised themselves whilst at pasture".

The information obtained through the survey will be used to assess if exercise during preparation of yearlings has an effect on two-year-old training and racing performance. Thank you to all the stud farms that generously gave their time to participate in the survey.

Copy of the information sheet provided in the data collection booklet provided to studmasters.

Yearling Study – Sales Preparation 2008

Information to be recorded each day:

Horse	e.g. what ever you use to identify the yearling
Type of exercise	e.g. Hand walking
Duration of exercise	e.g. 10 Minutes
Number of hours at pasture	e.g. 18
Reason for any changes to exercise	e.g. too fat, naughty

If the exercise involved a walker or treadmill, please note the approximate speed.

Other information:

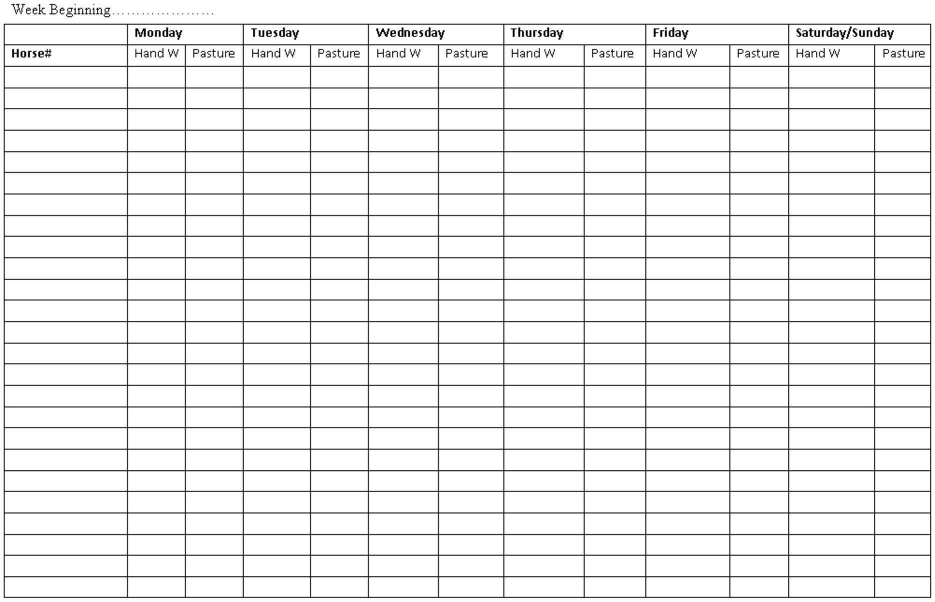
- A list of all the yearlings in the study with the date of birth and gender
- A list of yearlings that are to be kept as 'stores' (if applicable)

Once the data has been collected I can provide you with a personalised copy of the results for your farm.

I would like to thank you for your participation in this project and I look forward to receiving the completed forms once the sales have finished.

Please contact me if you have any questions.

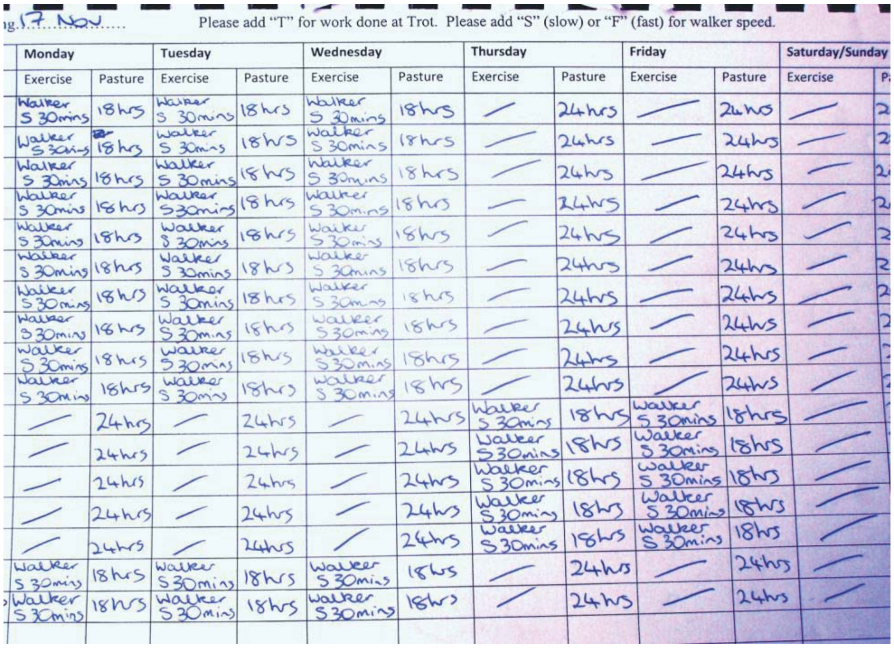
Kind Regards
Charlotte



Week Beginning…………………

	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday/Sunday	
Horse#	Hand W	Pasture	Hand W	Pasture	Hand W	Pasture	Hand W	Pasture	Hand W	Pasture	Hand W	Pasture

Figure A1: An example of the forms that were used to record daily exercise during sales preparations on stud farms. The horse names were provided for each farm to facilitate recording, but have been removed to maintain confidentiality and anonymity.



ig.17 Nov……… Please add "T" for work done at Trot. Please add "S" (slow) or "F" (fast) for walker speed.

Monday		Tuesday		Wednesday		Thursday		Friday		Saturday/Sunday
Exercise	Pasture	Exercise	Pasture	Exercise	Pasture	Exercise	Pasture	Exercise	Pasture	Exercise
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
/	24hrs	/	24hrs	/	24hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/
/	24hrs	/	24hrs	/	24hrs	Walker S30mins	18hrs	Walker S 30mins	18hrs	/
/	24hrs	/	24hrs	/	24hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/
/	24hrs	/	24hrs	/	24hrs	Walker S 30mins	18hrs	Walker S 30mins	18hrs	/
/	24hrs	/	24hrs	/	24hrs	Walker S30mins	18hrs	Walker S 30mins	18hrs	/
Walker S 30mins	18hrs	Walker S30mins	18hrs	Walker S 30mins	18hrs	/	24hrs	/	24hrs	/
Walker S 30mins	18hrs	Walker S30mins	18hrs	Walker S30mins	18hrs	/	24hrs	/	24hrs	/

Figure A2: An example of a completed data collection form used to record daily exercise during sales preparations on stud farms.

PRELUDE TO CHAPTER 6

Chapter 5 described the first part of the prospective cohort study that tracked yearlings from the stud farm. In Part 1, yearlings were followed at the stud farm up to the point of sale. In Part 2, the yearlings were tracked from the sale to their registered trainers and followed to the end of their 2-year-old racing season. During this process, there are a number of ways horses could be lost from the study, starting with the dispersal of horses that occurs after the yearling sales.

Therefore, Chapter 6 describes the fate of the yearlings after the sale and the losses that occurred whilst following the yearlings from the stud farm to training and racing. Further, the data collected by New Zealand Thoroughbred Racing, on the whole 2007 foal crop, provided an opportunity to compare sales, trial and race outcomes in the study population with the wider population of horses. This chapter has not been submitted for publication.

CHAPTER 6

FATE OF THOROUGHBRED HORSES AFTER YEARLING SALES

ABSTRACT

Aim

To determine the fate of horses after the yearling sales and compare the horses in a cohort of Thoroughbred yearlings with the whole foal crop in the same year (2007), in terms of sales, trial and race outcomes.

Method

As part of a larger prospective study, Thoroughbred horses born in 2007 were followed from the stud farm to the end of their 2-year-old racing season (31st July 2010). Official data extracts containing sales and racing data of all the horses in the 2007 foal crop were linked to the horses followed in the study population. To describe the fate of the yearlings after the sales, horses were categorised into five groups: 1) Registered with a trainer at two years of age, 2) Registered with a trainer at three, but not at two, 3) Exported at two, 4) Died and 5) Unknown. The loss of horses from the study population, as they were followed from the stud farm to the end of the 2-year-old season, was described as the number and percentage of horses that reached specific four milestones in training: 1) Registered with a trainer in the study, 2) Entered training, 3) Trialled and 4) Raced. Pearson's Chi-squared test was used to compare the distribution of two cohorts 1) the study population and 2) the whole foal crop, using horse-level and trial and race variables, and to compare the distribution of horses catalogued for sales in the respective cohorts.

Results

The official extract of the 2007-born foal crop consisted of 4,819 foals, of which 627 were included in the study population. .After the sales, the fate of most (53%; 333/627) horses in the study population was 'registered with a trainer at two years of age', 24% (151/627) were exported and 8% (49/627) were 'unknown'. There was a significant difference in the proportion of sales horses, ($P<0.01$), horses registered with a trainer ($P<0.01$) and horses exported before three years of age ($P<0.01$) after stratifying by gender. There was no difference between the sales horses

catalogued for sale by gender, sold, registered with a trainer, trialled, raced, 'won a race', 'won prize money' or 'died'. After the sales, the fate of most (53%; 333/627) horses in the study population was 'registered with a trainer at two years of age', 24% (151/627) were exported and 8% (49/627) were 'unknown'.

Conclusion

The predominant fate of yearlings after the sales was registered with a trainer at two years of age, but the fate of a group of horses remained 'unknown' at the end of the 2-year-old season. The sales cohort in the study population was a good representation of the whole sales cohort, whilst the study population over-represented sales horses and in return horses exported from New Zealand.

INTRODUCTION

The studies conducted at the Hong Kong Jockey Club (Lam *et al.* 2007a; Lam *et al.* 2007b) and the Japan Racing Association (Kasashima *et al.* 2004) represent a gold standard in terms of the sample population used for epidemiological studies of Thoroughbred racehorses, since all the horses were based in one location and allowed the whole population to be studied. This is a rare opportunity and given the structure of racing in other countries, whole population studies are seldom feasible. Therefore, studies of racehorses in training must utilise a sample of the population, which has usually been obtained through a convenience sample (Perkins *et al.* 2004a; Verheyen and Wood 2004b; Cogger *et al.* 2006; Dyson *et al.* 2008; Ely *et al.* 2009; Bolwell *et al.* 2011a; Bolwell *et al.* 2011b [Chapters 2 and 5]; Ramzan and Palmer 2011; Reed *et al.* 2011). Authors have favoured this method due to practical constraints and the need to maintain the accuracy of the data over long observation periods. As convenience samples are not random, such study populations may not be representative of all the Thoroughbred racehorses in training, reducing the external validity of the study (Elwood 2007).

Investigators in the UK (Verheyen and Wood 2004a; Ely *et al.* 2009) have evaluated the external validity of their study population of horses in training against an official publication that lists all horses in training in the UK. Such a publication of horses in training does not exist in New Zealand. However, the online database of New Zealand Thoroughbred Racing (NZTR) does record every horse born and its breeding information, the registered trainer, and racing performance records. Although this information does not provide details of the training population, it does provide the opportunity to compare the distribution of the sample population with the rest of the foal crop born in that year.

A previous analysis of the supply chain in New Zealand Thoroughbred racing highlighted the loss of horses from the industry, estimating 57% of horses 'failed to reach their full potential' (McCarthy 2009); 27% of racehorses were never registered with a trainer. A prospective study identified a cohort of 2- and 3-year-olds in training that did not start in a trial (Perkins *et al.* 2004a). Further losses from the cohort of horses available for racing occur due to the strong international demand for New Zealand horses, with around 30% of horses exported to countries such as Australia, Hong Kong and Singapore (McCarthy 2009; Fennessy 2010). A strength of the prospective design used in this study was that it allowed individual horses to be tracked to the end of the racing season, which provided an opportunity to describe the losses that occurred at each stage from the stud farm to racing as a 2-year-old.

The aims of this paper were to determine the fate of horses after the yearling sales, quantify the loss of horses from sales preparation through to the end of the 2-year-old racing season, and to compare the cohort of yearlings in the study population with the whole foal crop in the same year (2007).

MATERIALS AND METHODS

Sample

Thoroughbred yearlings from the 2007 foal crop were enrolled in a prospective epidemiological study that in Part 1 followed the yearlings from the stud farm through to the end of sales, and in Part 2 tracked from sales to trainers and then through training and racing as 2-year-olds. The recruitment of stud farms and enrolment of horses into Part 1 was described in Chapter 5. The study utilised a convenience sample of eight Thoroughbred stud farms that were exercising yearlings and an additional six stud farms that were not exercising yearlings during the sales preparation. The studmasters also provided details of their yearlings that were not catalogued for the yearling sales (classed as stores), if applicable. All yearlings were then tracked until they entered training with a trainer in New Zealand and followed until the end of their 2-year-old racing season (31st July 2010) or were lost to follow-up. Horses were considered lost to follow-up if they were located in the South Island of New Zealand, sold overseas, and if they were initially registered with, or changed to, a trainer not enrolled in the study.

Data collection

At completion of the study, a data extract was obtained directly from NZTR for the whole 2007 foal crop. Information included horse details such as name, dam, sire, gender and racing information including if and when registered with a trainer, exported, trialled, raced, place in a race and the amount of prize money won. Sales information, such as sale category and whether the yearling was sold or passed-in, was obtained from the online New Zealand Bloodstock (NZB) 2009 sales results[3].

Statistical analysis

The extracts from both NZTR and NZB were entered into an electronic database (Microsoft Access, Microsoft Corporation, Redmond, Washington, USA) and linked together on dam name. The official extracts were also linked to the horses in the study population to allow comparison of the two cohorts: 1) foal crop and 2) study population. Comparisons were also made between the horses that were catalogued for the sales in the foal crop and within the study population. Horses were coded as catalogued or not for the sales, and further subdivided into those that were catalogued for either the Premier, Select or Festival sale and those that were sold, passed in (did not reach the reserve price) or withdrawn from the sales. To avoid excluding horses that did not race and could not earn prize money, a binary variable 'won prize money' was created. Using the official data provided by NZTR, horses were categorised into five groups to describe the fate of the yearlings after the sales: 1) Registered with a trainer at two years of age, 2) Registered with a trainer at three, but not at two, 3) Exported at two, 4) Died and 5) Unknown. Horses that were recorded as 'unknown' were those that had no official information recorded in the extract, and no other information could be determined regarding the fate of these horses. The loss of horses from the study population, as they were followed from the stud farm to the end of the 2-year-old season, was described as the number and percentage of horses that did not reach specific four milestones in training: 1) Registered with a trainer in the study, 2) Entered training, 3) Trialled and 4) Raced.

The sales, fate, trial and race variables were cross tabulated with cohorts 1 and 2 and reported as the number and percentage of horses in each category, stratified by gender. Pearson's Chi-squared test was used to compare the distribution of horses in the whole foal crop with that of the study population and to compare the characteristics of the two cohorts of sales horses. In order to adjust for multiple comparisons a Bonferroni correction was applied and the critical probability for

---

[3] www.nzb.co.nz/sales/index.cfm

assigning significance was P<0.004 and P<0.005, respectively, for comparing the two cohorts and the two sales cohorts. All analyses were conducted in Stata 11 (Statacorp LP, College Station, Texas, USA).

RESULTS

Tracking yearlings from sales preparation to the end of the 2-year-old racing season

Fate after the yearling sales

Most (53%; 333/627) of the horses in the study population were registered with a trainer at two years of age and 24% (151/627) were exported. The most common country of export was Australia (87%; 131/151), followed by 3% each going to Hong Kong, Korea and Singapore. Of the sales horses, 28% were exported compared to 9% of store horses, whilst 40% (92/231), 21% (39/189) and 10% (7/71) of horses catalogued for Premier, Select and Festival sales, respectively, were exported.

After registered with a trainer at two years of age, ‘unknown’ was the second most common destination for store horses (16%; 22/137) and for horses catalogued in the Festival sale (9/71; 13%). Of the horses that were withdrawn from the sales, the same proportions were both ‘unknown’ and registered with a trainer at three years of age (19%, 5/127). Of the horses that were sold or passed in, 4% and 6% were ‘unknown’ and 5% and 8% were registered with a trainer at three years of age, respectively. Of the horses that were sold or passed in, 40% and 15%, respectively, were exported. Fifteen percent of store horses were registered with a trainer at three years of age compared to 7% of sales horses.

Figure 1 shows the fate of the sales (not stores) horses after the sales for the foal crop and for the study population. Most (58% and 59%) sales horses were registered with a trainer at two years of age in both cohorts, but a higher proportion of sales horses were exported in the study population compared to the whole population (28% vs 20%). Few horses died overall, and the fate of 5% of sales horses in the study population was ‘unknown’ at the end of the study period.

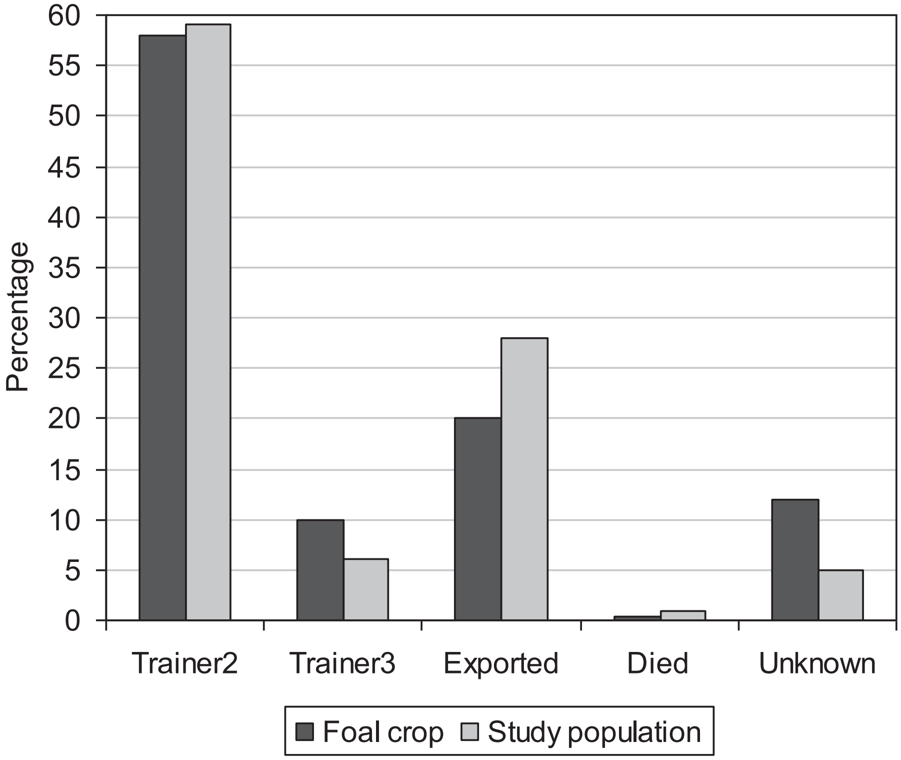


Figure 1: Fate of the sales yearlings after the sales for the foal crop (n=627) and for the study population (n=4,194). Trainer2 = registered with at trainer at two years of age. Trainer3 = registered with a trainer at three but not at two years of age

Registered with a trainer

Although 333/627 horses were officially registered with a trainer at two years of age, there were 364 horses from the study cohort listed as with a trainer after tracking them from the yearling sales. Of these, 208 were with trainers who agreed to take part in the study and 156 were registered with other trainers. The distribution of horses enrolled with trainers in the study was 54% males and 78% sale horses, compared to 57% males and 76% sales horses in the group not enrolled in the study. The proportion of horses that had been withdrawn from the sales was 3% in both cohorts of trainers.

Losses from training

Figure 2 describes the number of horses that were followed from the stud farm to the end of the 2-year-old racing season, and the number of horses that were lost from the study, trialled and raced during that time. Of the horses that were registered with a trainer at two, 43% were registered with a trainer who was not enrolled in the study. Figure 2 shows a number of horses were withdrawn from the study after they had gone to a trainer and been enrolled in the study but before training data were collected, as the trainers withdrew due to time commitments or because the records had not been recorded on a daily basis (indicated by grey arrows between box 2 and 3 in Figure 2).

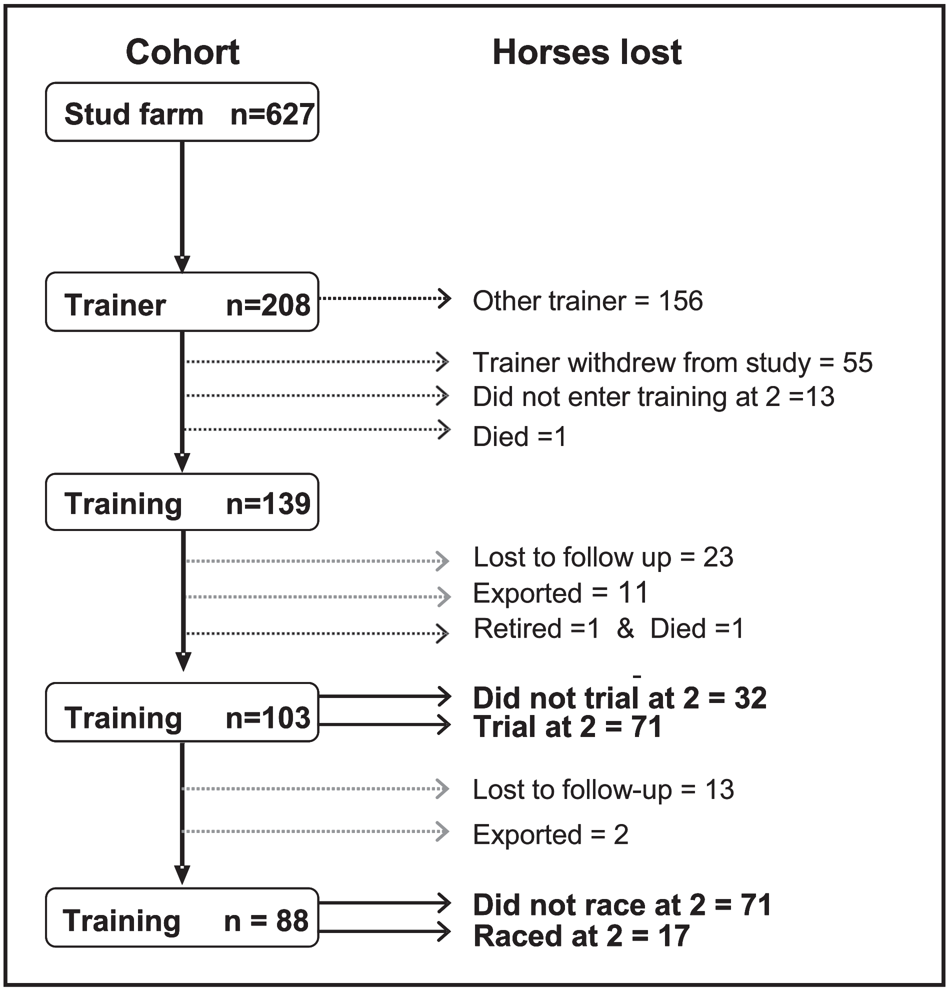


Figure 2: Tracking horses from the enrolment to the study at stud farm to the end of the study period (31st July 2010). The loss of horses before a trial and a race is indicated by grey arrows, whilst the remaining number of horses at each stage is noted in each box.

Of the horses registered with a trainer in the study, 6% had not entered training before the end of the 2-year-old season, 7% were exported before the first trial and there were also losses due to death and retirement from racing: one horse was euthanised as a result of a paddock injury and one horse was retired due to a back injury. After excluding horses that left the study before the first trial, 31% (32/103) did not start in a trial as a 2-year-old and two horses were exported after trialling. Of the 70 horses that raced, 76% were censored (exited the study population) before they raced resulting in only 17 (19%) horses racing during the study period.

Of the horses that trialled and raced, 89% and 82% were from the sales and 65% were male, respectively. Of the 17 horses that raced, 13 horses won total prize money with a median of $5,500 (IQR $850-7,700). Of the sales horses that raced (14), 71% (10/14) were exercised during the sales preparation. The median total exercise during sales preparation for horses that raced was 226mins (IQR 0-1165), compared to 200mins (IQR 0-545) for horses that did not race.

Comparing cohorts

The official extract of the 2007-born foal crop consisted of 4,821 foals, of which 627 (13%) were included in the study population. In the whole foal crop, there was an equal split between males and females whilst the study population had more males than females (55.5% versus 44.5%, respectively), although not significantly (P=0.01). The distribution of horses in the whole foal crop and in the study population, stratified by gender is shown in Table 1. The study population of males and females had a higher proportion from the sales, compared to the foal crop. There was no significant difference between the two cohorts and the proportion of males registered with a trainer, but there was for the proportion of females. The foal crop had a higher proportion of females not registered with a trainer compared to the study population. The total number of horses officially registered with a trainer in the study population was 331; however there were an additional 33 horses that were recorded as being in training in the study population. No difference was seen between the two cohorts for racing, ‘won a race’, ‘won prize money’ or ‘died’. Most of the horses in both cohorts did not trial but there was a significant difference in the proportion of females to trial in the study population compared to the foal crop. There was a significant difference between the two populations and the proportion of horses exported before three years of age. Within the study population, there was a higher proportion of both males and females exported compared to the foal crop (Table 1).

Comparing sales cohorts

There was no difference between the two cohorts of sale horses by gender, sold, registered with a trainer, trialled, raced, ‘won a race’, ‘won prize money’ or ‘died’ (Table 2). Most of the horses in both cohorts were males, sold at the sales, registered with a trainer, and did not trial or race. There was a significant difference in the distribution of horses catalogued for Premier, Select, or Festival sales, between the two cohorts; horses catalogued for Festival sale were underrepresented compared to the entire sales cohort. The horses exported before three years old differed significantly between the two sales cohorts.

Table 1: Distribution of features of horses in the 2007 foal crop and in the study population, stratified by gender.

	Male			**Female**		
	Foal crop N (%)	**Study pop N (%)**	**P-value[a]**	**Foal crop N (%)**	**Study pop N (%)**	**P-value[a]**
Sales			<0.001			<0.001
No	1,338 (64.3)	34 (9.7)		1,663 (77.2)	103 (36.9)	
Yes	741 (35.6)	314 (90.2)		482 (22.7)	176 (63.0)	
Trainer[b]			0.04			<0.001
No	1,120 (53.8)	167 (47.9)		1,232 (58.2)	128 (45.8)	
Yes	959 (46.1)	181 (52.0)		883 (43.7)	151 (54.1)	
Trial			0.006			0.001
No	1,460 (70.2)	219 (62.9)		1,584 (74.8)	184 (65.9)	
Yes	619 (29.7)	129 (37.0)		531 (25.1)	95 (34.0)	
Race			0.06			0.04
No	1,900 (91.3)	307 (88.2)		1,890 (89.3)	238 (85.3)	
Yes	179 (8.6)	41 (11.7)		225 (10.6)	41 (14.7)	
Win race			0.06			0.24
No	2,048 (98.5)	338 (97.1)		2,076 (98.1)	271 (97.1)	
Yes	31 (1.4)	10 (2.8)		39 (1.8)	8 (2.8)	
Won prize money			0.03			0.04
No	1,967 (94.6)	319 (91.6)		1,985 (93.8)	253 (90.6)	
Yes	112 (5.3)	29 (8.3)		130 (6.1)	26 (9.3)	
Exported			<0.001			<0.001
No	1,762 (84.7)	230 (66.0)		1,952 (92.2)	221 (79.2)	
Yes	317 (15.2)	118 (33.9)		221 (7.7)	58 (20.7)	
Died			0.51			0.95
No	2,025 (97.4)	341 (97.9)		2,076 (98.1)	274 (98.2)	
Yes	54 (2.6)	7 (2.0)		39 (1.8)	5 (1.7)	

[a]Pearson's Chi-squared test P-value. [b]Officially registered with a trainer in the 2-year-old season. The critical level for statistical significance P<0.004 (Bonferroni adjustment).

Table 2: Distribution of the horses catalogued for sale in the 2007 foal crop and in the study population.

Variable		Foal crop N (%)	Study population N (%)	P-value[a]
Sex				0.17
	Male	741 (60.5)	314 (64.0)	
	Female	482 (39.4)	176 (35.9)	
Sale category				<0.001
	Premier	271 (22.1)	231 (47.1)	
	Select	495 (40.4)	188 (38.3)	
	Festival	457 (37.3)	71 (14.4)	
Sold				0.04
	Passed in	383 (31.3)	103 (21.0)	
	Sold	840 (68.6)	361 (73.6)	
Registered with a trainer				0.08
	No	495 (40.4)	227 (46.4)	
	Yes	728 (59.5)	263 (53.5)	
Trial				0.08
	No	710 (58.0)	307 (62.6)	
	Yes	513 (41.9)	183 (37.3)	
Race				0.65
	No	1,038 (84.8)	420 (85.7)	
	Yes	185 (15.1)	70 (14.2)	
Win race				0.32
	No	1,182 (96.6)	478 (97.5)	
	Yes	41 (3.3)	12 (2.4)	
Won prize money				0.40
	No	1,097 (89.7)	446 (91.0)	
	Yes	126 (10.3)	44 (8.9)	
Exported				<0.001
	No	939 (76.7)	326 (66.5)	
	Yes	284 (23.2)	164 (33.40)	
Died				0.07
	No	1,216 (99.4)	483 (98.5)	
	Yes	7 (0.5)	7 (1.4)	

[a] Pearson's Chi-squared test P-value. The critical level for statistical significance P<0.005 (Bonferroni adjustment)

DISCUSSION

The aim of this chapter was to describe the distribution of horses in the study population compared to the whole 2007 foal crop and to describe the loss of horses as they were followed from the stud farm to the end of the 2-year-old racing season. The study utilised a convenience sample of stud farms and the yearlings were then followed to trainers. The selection of the study population and any potential bias has been discussed previously (Bolwell *et al.* 2011a [Chapter 5]). Comparison of the horses in training with the wider population of racehorses in training in New Zealand was not possible in this study. Some studies that have utilised convenience samples of racehorses in training have evaluated the population of horses used against all the horses in training (Verheyen and Wood 2004a; Ely *et al.* 2009). Validating the study population is useful when considering the external validity of the study. Since convenience samples are not random they may result in a study population that is an atypical group or a limited sample, which may not be applicable to the wider population. Similarly, a low participation rate or withdrawal of study participants can lead to a lack of external validity as it is less likely that the remaining participants will be representative of the whole population. The official data available from New Zealand Thoroughbred Racing and New Zealand Bloodstock allowed the comparison of the cohort of horses used in the current study, with the whole foal crop born in 2007. After stratifying by gender, the study population was similar to the whole foal crop with respect to the proportion of horses that raced, won a race, won prize money and died. Therefore, with respect to those variables, the initial study population could be considered representative of the horses in the 2007 foal crop.

In the study population, the proportion of males compared to females was significantly higher, highlighting that females were under-represented in the study population compared to the whole foal crop. The difference in the gender distribution was most likely due to the bias towards males in the sales cohorts, which supports the findings of Waldron *et al* (2011). Although there was no difference in the gender distribution in the sales cohorts, both cohorts had a higher proportion of males. The results highlighted that the bias towards males was driven by the industry, given that the distribution of males and females in the foal crop was equal.

However, some significant differences were observed between the distributions of the study population and the 2007 foal crop. A significant difference in the proportion of horses that were registered with a trainer and trialled was apparent for females. The study population over-represented the proportion of females that were registered with a trainer and trialled, compared to the foal crop. Additionally, the proportion of horses exported was greater in the study population, compared to the whole foal crop. This may be because the study population consisted of a higher proportion of horses that were catalogued for the sales, and a higher proportion of sales horses were exported compared to stores.

Overall, the sales cohort of the study population was a good representation of the whole sales cohort as there were no differences seen with respect to gender, and the proportion of horses that were sold, registered with a trainer, raced, won a race, won prize money, or died. There was a significant difference between the two sales cohorts and the type of sale a horse was catalogued for. Although studmasters were asked to provide a random selection of yearlings, horses catalogued in the Festival sales were under-represented and those in the Premier sale were over-represented. As a result, the study population of sales horses may be considered more representative of higher quality horses and the results may not be applicable to the wider population of yearlings catalogued for sale. The difference in the sale type could account for the higher proportion of horses that were exported in the study population, as a higher proportion of horses from Premier and Select sales were exported compared to those from the Festival sale.

In the current study, the fate of most of the horses after the yearling sales time was registered with a trainer at two years of age. Of the 47% of horses not registered with a trainer at two, the most common reason was because they were exported. These results are in agreement with previous a previous report (Fennessy 2010) as most horses were exported to Australia, which further highlights the importance of the export market to the New Zealand breeding industry. However, most of the horses exported were from the Premier sale, indicating that top calibre horses are lost from the pool of horses available for racing in New Zealand. After excluding the horses that were exported, 26% of the study population were not registered with a trainer at two years of age, concurring with an industry-commissioned report of the supply chain wastage within the New Zealand Thoroughbred industry, which reported that 22% of horses were never registered with a trainer (McCarthy 2009). Whilst the proportion of horses not registered was higher in the current study, the industry report considered horses across all ages.

Similarly, the horses whose fate was ‘unknown’ did not reach the milestones of trialling and racing as a 2-year-old. The second most common destination for horses that were stores, withdrawn from the sales or catalogued in the festival sales was ‘unknown’. If horses were withdrawn from the sales due to a veterinary problem, such as an injury, it may have resulted in a delay to the start of training or retirement. The process of cataloguing horses for the sale is a form of pre-selection as horses are selected for each type of sale based on criteria set by NZB. Therefore, horses that are selected for Premier or Select sales may be considered pre-selected based on what is likely to sell and be successful in the industry. Although the fate of the sales horses in both cohorts was similar, more of the horses in the whole foal crop were ‘unknown’ indicating a higher proportion of lost horses in the foal crop. However, some of these horses may belong to the group of horses that enter training but no information is officially recorded by NZTR.

There were discrepancies noted in the number of horses registered with a trainer in the official records of NZTR, compared to the study population. There were horses enrolled in the study that were in work with trainers, but they were not officially registered with a trainer as the trainers had not provided this information to NZTR. These differences highlight the difficulty of monitoring the number of horses with trainers, and calculating the number of horses in training, when the trainers do not always provide the correct information to NZTR. Therefore, it is possible that horses were tried with trainers before they were given a break or retired from training and were never recorded as registered with a trainer; a pattern that has also been observed in the Standardbred racing industry (Tanner *et al.* 2010). Similarly, Perkins *et al* (2004a) highlighted a difference in the proportion of 2-year-old horses that start in a trial or race and the proportion of training days contributed by 2-year-olds, suggesting that a number of 2-year-olds are trained, but do not start in a race. In the current study there were horses that were registered with trainers and did not enter training as a 2-year-old, possibly as a result of trainers assessing a horse's progress and suitability for racing before registering them. Furthermore a previous survey identified horses are often trained as 2-year-olds for education and are not raced until their they are three years old (Bolwell *et al*. 2010) Therefore, using only official records may result in a bias towards horses that are perceived to be more mature or successful during training, resulting in an inability to generalise results to the wider population of horses in training. Therefore, at present, the only way to obtain such information in future work is through prospective studies that can accurately record the horses in training with specific trainers. Official measures to record such information could be implemented, however given the success of current measures utilised by NZTR, stricter monitoring would be needed to ensure accurate information is obtained from trainers.

Comparisons with the trainers that were not enrolled showed the study population had a similar proportion of males and sales horses as those not enrolled. At each stage of the training process, there were losses due to export of horses from New Zealand. Some horses were exported after entering training but before the first trial, indicating that there is a market for horses that have not yet proved themselves, or these horses were bought by overseas buyers but started their training in New Zealand.

Very few horses in the study population were retired from racing due to involuntary events (injury or disease), in contrast to previous reports (Perkins *et al.* 2004b). However, it is possible that some of the horses that were lost to follow-up had involuntary events and this information was not reported. Similarly, some horses that were registered with a trainer did not start training at two, which may reflect a voluntary decision by the trainer to delay the start of training, the occurrence of an injury or other management considerations; further information on why these horses did not enter training was not available.

Despite having an adequate sample size at the start of the data collection, the loss of horses from the study period dictated that few horses which raced remained in the study. These results do not necessarily reflect poor performance in this population as over half the horses that were censored went on to race as a 2-year-old. Although the characteristics of the horses that raced were described, further analysis to determine the effect of early exercise on racing performance outcomes, such as starting in a race, winning a race or winning prize money, was not possible due to low numbers. A difficulty associated with longitudinal studies of racehorses during training and racing is that a commitment is needed from trainers to record detailed data, which can result in studies with small samples sizes that reduce the ability to observe statistically significant associations. Furthermore, it is evident from the results presented in this chapter, and discussed elsewhere (Rosanowski *et al* 2011, personal communication), that racehorse populations in New Zealand are dynamic, making follow-up of individual horses over a number of racing seasons a challenging process.

The sales cohort of the study population was similar to the whole 2007 sales cohort whole sales cohort. The study population over-represented sales horses and in return horses exported from New Zealand. Loss of horses resulted more from trainers leaving the study and exports, than retirements from racing. The predominant fate of yearlings after the sales was registered with a trainer at two years of age, but a number of horses did not subsequently enter training at two and the fate of a cohort of horses remained ‘unknown’ at the end of the 2-year-old season.

REFERENCES

Bolwell, C.F., Russell, L.J. and Rogers, C.W. (2010) A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comp. Exerc. Physiol.* **7**, 37-42.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011a) Exercise in Thoroughbred yearlings during sales preparation: A cohort study. *Equine vet. J.*, no.10.1111/j.2042-3306.2011.00370.x.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011b) Risk factors for interruptions occurring before the first trial start of 2-year-old Thoroughbred racehorses in training. *N.Z. vet. J.* **Submitted**.

Cogger, N., Perkins, N., Hodgson, D.R., Reid, S.W.J. and Evans, D.L. (2006) Risk factors for musculoskeletal injuries in 2-year-old Thoroughbred racehorses. *Preventive Veterinary Medicine* **74**, 36-43.

Dyson, P.K., Jackson, B.F., Pfeiffer, D.U. and Price, J.S. (2008) Days lost from training by two- and three-year-old Thoroughbred horses: A survey of seven UK training yards. *Equine vet. J.* **40**, 650-657.

Elwood, M. (2007) Critical Appraisal of Epidemiological Studies and Clinical Trials: 3rd Edition, Oxford University Press, Oxford, UK. pp 80-81.

Ely, E.R., Avella, C.S., Price, J.S., Smith, R.K.W., Wood, J.L.N. and Verheyen, K.L.P. (2009) Descriptive epidemiology of fracture, tendon and suspensory ligament injuries in National Hunt racehorses in training. *Equine vet. J.* **41**, 372-378.

Fennessy, P.F. (2010) An overview of the New Zealand Thoroughbred Industry. *Proc. N. Z. Soc. Anim. Prod.* **70** 137-139.

Kasashima, Y., Takahashi, T., Smith, R.K., Goodship, A.E., Kuwano, A., Ueno, T. and Hirano, S. (2004) Prevalence of superficial digital flexor tendonitis and suspensory desmitis in Japanese Thoroughbred flat racehorses in 1999. *Equine vet. J.* **36**, 346-350.

Lam, K.H., Parkin, T.D.H., Riggs, C.M. and Morgan, K.L. (2007a) Descriptive analysis of retirement of Thoroughbred racehorses due to tendon injuries at the Hong Kong Jockey Club (1992-2004). *Equine vet. J.* **39**, 143-148.

Lam, K.K.H., Parkin, T.D.H., Riggs, C.M. and Morgan, K.L. (2007b) Evaluation of detailed training data to identify risk factors for retirement because of tendon injuries in Thoroughbred racehorses. *Am. J. vet. Res.* **68**, 1188-1197.

McCarthy, G. (2009) Analysis of supply chain wastage in the Thoroughbred and Harness racing codes. In: *The foundation bulletin. Volumne 14. Number 4*, New Zealand Equine Research Foundation, Palmerston North, New Zealand.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004a) Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *N.Z. vet. J.* **53**, 59-68.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004b) Profiling the New Zealand Thoroughbred racing industry. 2. Conditions interfering with training and racing. *N.Z. vet. J.* **53**, 69-76.

Ramzan, P.H.L. and Palmer, L. (2011) Musculoskeletal injuries in Thoroughbred racehorses: A study of three large training yards in Newmarket, UK (2005-2007). *Vet. J.* **187**, 325-329.

Reed, S.R., Jackson, B.F., Mc Ilwraith, C.W., Wright, I.M., Pilsworth, R., Knapp, S., Wood, J.L.N., Price, J.S. and Verheyen, K.L.P. (2011) Descriptive epidemiology of joint injuries in Thoroughbred racehorses in training. *Equine vet. J.*, 10.1111/j.2042-3306.2010.00352.x.

Tanner, J.C., Rogers, C.W. and Bolwell, C.F. (2010) Preliminary examination of training and racing milestones in a subset of Standardbred horses *Proc. N. Z. Soc. Anim. Prod.* **70**, 148-151.

Verheyen, K.L. and Wood, J.L. (2004a) Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. *Equine vet. J.* **36**, 167-173.

Verheyen, K.L.P. and Wood, J.L.N. (2004b) Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. *Equine vet. J.* **36**, 167-173.

PRELUDE TO CHAPTER 7

Chapter 5 identified that the exposure to exercise during sales preparation differs for each horse, which could have an effect on future performance. In Chapter 6 the destination of the yearlings after the sales and the loss of horses from the study, whilst following them from the stud farm to training, were described. Chapter 7 expands on this and describes how the sales yearlings were followed in Part 2 of the study, which involved enrolling trainers and recording training information.

The manuscript presented in Chapter 7 is the first to describe the association between exposure to exercise during sales preparation and interruptions to race training. Specifically, Chapter 7 measures training performance as the time to voluntary and involuntary interruptions during training occurring before the first trial.

The results of a sensitivity analysis and models diagnostics used in the statistical analysis are presented in the appendix for this Chapter. A manuscript based on Chapter 7 is in press with American Journal of Veterinary Research.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011) Associations between yearling exercise and interruptions to race training in Thoroughbred racehorses.

CHAPTER 7

ASSOCIATIONS BETWEEN YEARLING EXERCISE AND INTERRUPTIONS TO RACE TRAINING IN THOROUGHBRED RACEHORSES

ABSTRACT

Objective

To investigate the effect of exercise during yearling sales preparation on the risk of interruptions during training.

Animals

114 Thoroughbred horses

Sample

Information on the daily exercise of yearlings during a sales preparation was obtained prospectively from a convenience sample of stud farms. Yearlings were followed to the point at which they entered race training and then daily training information was recorded until the end of the racing season.

Procedure

Competing risks survival analysis was used to model the two outcomes: 1) the time to a voluntary interruption (no known condition or disease present) and 2) the time to an involuntary interruption (due to the presence of a condition or disease) occurring before the first trial (practice race for education). Total hand walking time and mechanical walker time accumulated during sales preparation were the main exposures of interest.

Results

A total of 82/114 (71.9%) horses experienced an interruption before the first trial, of which 65 (79%) were voluntary and 17 (21%) were involuntary. Increased total hand walking time was significantly associated with a decreased risk of voluntary interruptions, whilst longer distances accumulated at canter since entering race training were significantly associated with a decreased risk of involuntary interruptions.

Conclusion and clinical relevance

The results identified an association between early exercise during sales preparation and a decreased risk of a voluntary and increased risk of an involuntary interruption during training as a 2-year-old. Whilst further investigation into the effects of early exercise on racing performance is needed, this study has indicated that there may be an opportunity to modify early exercise programs.

INTRODUCTION

Studies in humans show that exercise in young children may result in positive skeletal effects that remain in early adulthood (Hind and Burrows 2007; Gunter *et al.* 2008). As a result, within many sports such as soccer, hockey and gymnastics, coaches have recognised the benefit of developing the appropriate skills early in life, during growth and maturation. In horses, the mechanisms in which the musculoskeletal system responds to early training exercise, has been demonstrated and discussed (Firth and Rogers 2005; Firth 2006). Similarly, different frequencies, intensities and types of exercise during training have been associated with reductions in musculoskeletal injury (MSI) (Parkin 2008) and success during racing (Verheyen *et al.* 2009; Ely *et al.* 2010).

The effects of early exercise in young horses, before the start of race training, to the development of the musculoskeletal system has been reported (Barneveld and van Weeren 1999). Early conditioning exercise of foals in addition to free exercise at pasture did not result in any harmful effects and had a stimulatory effect on components of the musculoskeletal system (Rogers *et al.* 2008a; Meredith *et al.* 2011). Previously conditioned horses had an early training advantage, such as being ready for racing earlier, when compared to unconditioned horses (Rogers *et al.* 2008b; Rogers *et al.* 2010). However, the sample size was too low to identify significant training advantages, suggesting further investigation with a larger number of horses is required.

Within the racing industry, exercising young horses prior to race training occurs during the preparation of yearlings for sale (Gibbs and Cohen 2001; Bolwell *et al.* 2010 [Chapter 4]). Sale preparations last a median of 12 (Interquartile range (IQR) 12-16) weeks, and studmasters use exercise modalities such as hand walking and walking or trotting on mechanical horse walkers, to educate yearlings and to stimulate muscle development (Bolwell *et al.* 2010 [Chapter 4]). The differences observed in the type and amount of exercise during sales preparation (Bolwell *et al.* 2010; Bolwell *et al.* 2011a [Chapters 4 and 5]), suggest that because the exposure to exercise varies among young horses, these differences in early exercise could impact future athletic performance.

Performance during the early years of training has been associated with better racing success and longevity (Bailey *et al.* 1999; More 1999). Recent work in Standardbred racehorses (Tanner *et al.* 2011) has placed further importance on having horses in training for the first time as 2-year-olds rather than later, suggesting that the identification of training factors that can advance the horses' capabilities to train and race, such as exercise and horse age, is beneficial.

Given the increasing body of evidence to support early conditioning exercise, an epidemiological study following a cohort of yearlings into training as 2-year-olds was designed, in order to quantify the exercise and management of yearlings and the effect of this on future training and racing performance. If an effect of industry exercise programs on future athletic ability could be demonstrated, there may be an opportunity to intervene earlier by modifying exercise programs. Development of such programs could help to reduce losses during training and racing, whilst meeting the goals of the stud master and buyers at the yearling sales.

The aim of this paper was to investigate the effect of exercise during sales preparation on the risk of interruptions occurring before the first recognised industry milestone (trial) during training, for a cohort of Thoroughbred racehorses. We hypothesised that hand walking and walker exercise time accumulated during sales preparation would be associated with interruptions during training as a 2-year-old.

MATERIALS AND METHODS

Data were collected as part of a recent prospective epidemiological study to investigate the effect of early exercise on future training and racing performance. The study was conducted in two parts 1) during yearling sales preparation and 2) during training as a 2-year-old, of which Part 1 has been described in detail (Bolwell *et al.* 2011a [Chapter 5]). Briefly, information on the daily exercise of yearlings during a sales preparation was obtained from a convenience sample of eight Thoroughbred stud farms, from September 2008 until 25th January 2009. Studmasters recorded the type and duration of exercise and the number of hours spent in pasture. An additional six stud farms that were not exercising horses as part of preparation, provided the sire and dam names of their sales yearlings so those horses could be tracked to trainers. The studmasters also provided a list of non-sale horses (classified as stores), but these horses were not included in any analysis of this paper.

The yearlings enrolled in Part 1 were then tracked to determine if they were registered with a trainer (by New Zealand Thoroughbred Racing (NZTR)), and several methods were used to determine the location of the horses. The sire and dam names of the enrolled horses were checked against the export lists of named and unnamed horses published by NZTR. Additionally, bloodstock agencies and purchasers who had bought yearlings and stud farms that were vendors of the yearlings at the sales were contacted to identify the current location of the yearlings. Lastly, online searches of the NZTR database provided information about whether the horse was currently registered with a trainer. These methods were used until all the horses enrolled in Part 1 were located or until the study ended on the 31st July 2010, whichever came sooner. Horses that were exported overseas or registered with trainers in the South Island of New Zealand were not tracked any further.

After a horse enrolled in Part 1 was identified as being registered with a trainer, the trainer was contacted and invited to participate in the next stage of the project. Some trainers were already recording data for horses enrolled in an ongoing study (Bolwell *et al.* 2011b [Chapter 2]), whilst new trainers were contacted by phone or email. Data on the daily training activity were recorded from the first day the horse entered the trainer's yard until the 31st July 2010 (end of the 2010 racing season), or until the horse was lost to follow-up. Horses that were sold overseas or changed to trainers not already enrolled in the study were considered lost to follow-up. The type of data recorded and the methods of data collection were described as part of a prospective study investigating race training risk factors for interruptions in a different cohort of horses (Bolwell *et al.* 2011b [Chapter 2]). Briefly, the daily training activity, including the distances worked at canter (>15s/200m) and fast speeds (15s/200m (15s), 13s/200m (13s), 12s/200m (12s)), and reasons for not working were recorded on standardized forms or were provided directly through copies of the trainers' records. Data were collected in paper format, except for one trainer who provided copies of an electronic spreadsheet (Microsoft Excel, Microsoft Corporation, Redmond, WA, USA) and a second trainer who provided information from their records by phone, on a weekly basis. Information on reasons for horses not working was provided by the trainer and not a veterinarian.

Statistical analysis

Data were entered into a customized database (Microsoft Access, Microsoft Corporation, Redmond, WA, USA) and random subsamples of the dataset were checked for data entry errors. Once all the data were entered, a customized checklist was followed to look for outliers and inconsistencies within the data. Data were changed only when the entry in the database deviated from the paper records.

Competing risks survival analysis was used to model the two outcomes: 1) time from entering training to the first voluntary interruption occurring before the first trial (no known condition or disease present) and 2) time from entering training to the first involuntary interruption occurring before the first trial (due to the presence of a condition or disease). Horses that were away from the training yard, or not in work for >7 consecutive days were considered not at risk and these periods were classed as an interruption (any type) to the training program (Perkins *et al.* 2004).

The data were arranged as multiple records per horse, each representing a training day, and in each model the other outcome event was censored on the day that the event took place. Only the first interruption that occurred was considered for inclusion in the analysis. The main exposures of interest were the total hand walking time and mechanical horse walker (walker) exercise time during yearling sales preparation, which was calculated for each horse. The number of hours spent at pasture during yearling preparation could not be used in the models as this information was not provided by the stud farms that were not exercising horses. The training exposure variables consisted of the exercise distances (canter, 15s, and 13s), the number of exercise events (high speed events (12s), swim (horse was swum in equine pool) water walker), the number of jump outs (practice out of the starting gates at speed) and the number of days off (out of training) accumulated since entering training. The units of the yearling and training exercise variables were converted to hours and furlongs (1 furlong = 201.168m), respectively, to allow better interpretation of the hazard ratios. The other exposure variables investigated were age (months) at the start of training and gender. Stud farm was modelled as a fixed effect, whilst trainer was modelled as a shared frailty term to adjust for potential clustering of horse within trainers.

Exposure variables were considered for inclusion in multivariable models at a cut-off of $P<0.20$. As hand walking and walker exercise time were the main exposures of interest, these variables were forced into the multivariable models if the Wald test P-value was greater than the cut-off. A backwards selection procedure was followed, retaining exposure variables in the model based on a combination of Wald test and Likelihood ratio statistic (LRS) P-values of $P<0.05$. The functional form of continuous variables was investigated by visually assessing the martingale residuals as described in Dohoo *et al*. (2003a) The proportional hazards assumption was tested for each of the final models and the model fits were visually assessed through plots of Cox-Snell residuals (Collett 2003; Dohoo *et al.* 2003b). A sensitivity analysis was performed to investigate informative censoring whereby all censored observations were recoded and assumed to have experienced the event on the day of censoring. All analyses were conducted in intercooled Stata 11.1 (Statacorp LP, College Station, Texas, USA) and the critical *p*robability for assigning statistical significance was set at P<0.05.

RESULTS

Of the 490 yearlings that were officially catalogued for the sales in Part 1 of the study, information obtained from one farm misclassified 11 horses as stores and so no exercise information was recorded during the sales preparation. These 11 horses were excluded from further analysis, leaving 479 horses in the population of sales horses recorded in Part 1. Of which, 258 horses were officially recorded by NZTR as registered with a trainer as a 2-year-old and an additional 25 horses were reported by the trainer as being in training. Thirty-four trainers agreed to take part, recording information for 135/283 horses that were registered with trainers. On the first visit to three trainers, data had not been accurately recorded on a daily basis and so information from these trainers (10 horses) was excluded from further analysis. A further four horses that were with trainers enrolled in the study were excluded as the trainers did not want to record information. One horse was registered with a trainer but it died from a paddock accident before entering training, and six horses did not enter training before the study ended.

In total, data were recorded by 26 trainers on 114 horses enrolled in both Part 1 and 2 of the study, which provided 6,788 days at risk. Over half the horses were males (64% 74/114) and 59% (67/114) of horses were exercised as part of the yearling preparation. The median age at the start of training was 21 months (IQR 19-23). Twenty-four horses had short (12 (IQR 11-15) days) pre-training preparations before entering training; the first start date for these horses was when they entered the training stable for the second time after their pre-training preparation.

A total of 82 horses experienced an interruption before the first trial, of which 65 (79%) were voluntary and 17 (21%) were involuntary. Most (51%, 33/65)) voluntary interruptions did not have a specific reasons cited, rather they were a break between exercise preparations classed as “part of the program”. Of the specific reasons cited by trainers for voluntary interruptions, 22% were “to grow and strengthen”. A little over half (53% 9/17) of the involuntary interruptions were due to shin soreness. The median time from entering training to a voluntary interruption was 60 days (95% confidence interval [CI] 52-77), whilst the median time to involuntary interruptions could not be calculated as more than 50% of the cohort survived. Twenty-eight horses reached their first trial without an interruption, three horses were lost to follow-up before their first trial, and one horse was censored at the end of the study. Descriptive statistics for the continuous exercise variables considered in the competing risks analysis are shown in Table 1.

Table 1: Descriptive statistics of total walker and hand walking yearling exercise and race training exercise accumulated since entering training for a cohort of 2-year-old Thoroughbred racehorses in training

Variable	Median	Interquartile range	Minimum	Maximum
Total walker (hours)	0	0-0	0	19
Total hand walk (hours)	0.8	0-10	0	24
Cumulative distance at canter (furlongs)	321	134-690	0	2,400
Cumulative distance at 15s (furlongs)[a]	0	0-3	0	26
Cumulative distance at 13s (furlongs)[b]	0	0-0	0	18
Cumulative high speed events at 12s (furlongs)[c]	0	0-0	0	26
Cumulative days off	5	2-11	0	37
Cumulative swim events	0	0-0	0	9
Cumulative jump outs	0	0-0	0	3
Cumulative water walker events	0	0-0	0	26

[a] 15s/200m. [b] 13s/200m [c] 12s/200m. Exercise variables represent the distances accumulated since entering training

Voluntary interruptions

The type of yearling exercise, gender, age at the start of training, number of water walker days and high speed events at 12s accumulated were not associated with voluntary interruptions in the univariable analysis. The exposure variables significant at the cut-off of $P<0.20$ are shown in Table 2. Each additional hour of hand walking and walker time significantly decreased the risk of voluntary interruptions. After adjusting for the distances accumulated at canter, the number of days off, stud farm and trainer in the final multivariable model, the total walker time was no longer associated with the chance of voluntary interruptions. The final multivariable model for voluntary interruptions is shown in Table 3. After adjusting for the other variables in the model, total hand walking time was significantly associated with a decreased risk of voluntary interruptions. The risk of voluntary interruptions decreased as the distance accumulated at canter increased, but increased significantly with each additional day off accumulated. Stud farm was significantly associated with voluntary interruptions and there was significant clustering at the trainer level.

Involuntary interruptions

The exposure variables associated with involuntary interruptions at P<0.20 are shown in Table 2. The type of yearling exercise, gender, number of water walker days, high speed events at 12s, swim events and jump outs accumulated were not associated with involuntary interruptions in the univariable analysis. Although the P-values for total hand walking and walker time were above the cut-off, these were the main exposures of interest and were considered for inclusion in multivariable models.

Table 2: Variables significantly associated with voluntary and involuntary interruptions in univariable analysis. The critical level for assigning statistical significance P<0.20

Variable	Coefficient	Hazard Ratio	95% CI [a]	Wald P-Value	LRS[b] P-value
Voluntary interruption					
Hand walk (hours)	-0.05	0.94	0.91-0.99	0.01	0.008
Walker (hours)	-0.08	0.91	0.82-1.01	0.08	0.04
Cumulative days off	0.10	1.11	1.04-1.19	0.002	0.002
Cumulative distance at canter[c]	-0.003	0.99	0.99-0.99	0.004	0.002
Cumulative distance at 15s[cd]	0.05	1.05	1.00-1.11	0.05	0.06
Cumulative swim events	0.11	1.12	0.97-1.30	0.11	0.14
Cumulative jump outs	0.43	1.54	0.98-2.42	0.05	0.08
Stud farm (19 df)					0.01
Involuntary interruption					
Age at start of training[e]	0.09	1.09	0.96-1.25	0.16	0.17
Hand walk (hours)[f]	-0.02	0.97	0.90-1.05	0.52	0.51
Walker (hours) [f]	0.05	1.05	0.95-1.16	0.31	0.35
Cumulative distance at canter[c]	-0.005	0.99	0.99-0.99	0.01	0.01
Cumulative distance at 15s[cd]	0.11	1.11	1.02-1.22	0.01	0.03
Stud farm (19 df)					0.01

[a]95% confidence interval. [b]Likelihood ratio statistic P-value. [c]Distance in furlongs (1 furlong = 201.168m). [d]15s/200m. [e]At the start of training (months). [f]Considered for multivariable analysis as *a priori* variables of interest.

The variables included in the final model for involuntary interruptions are shown in Table 3. After adjusting for the distance accumulated at canter, total walker time and trainer, the total hand walking time was no longer associated with involuntary interruptions. Increasing total walker time was associated with an increased risk of involuntary interruptions (Wald test P-value only). Although the LRS P-value indicated only a trend for improving the model fit, there was a stronger association of canter distance accumulated and the clustering within trainer increased with the inclusion of this variable in the final model. As the distance accumulated at canter increased, horses were less likely to have an involuntary interruption. The frailty term for trainer was significant, indicating clustering at the trainer level.

Table 3: Final competing risks models for voluntary and involuntary interruptions occurring before the first trial for 2-year-old Thoroughbred racehorses in training

Variable	Coefficient	Hazard Ratio	95% CI[a]	Wald P-Value	LRS[b] P-value
Voluntary interruption					
Hand walking (hours)	-0.59	0.55	0.42-0.73	<0.001	0.003
Cumulative days off	0.31	1.37	1.18-1.58	<0.001	<0.001
Cumulative distance at canter[c]	-0.008	0.99	0.98-0.99	<0.001	<0.001
Stud farm (19 df)					0.003
Trainer [d]					<0.001
Involuntary interruption					
Walker (hours)	0.12	1.13	1.01-1.27	0.04	0.06
Cumulative distance at canter[c]	-0.007	0.99	0.98-0.99	0.008	0.005
Trainer [e]					0.006

[a]95% confidence interval. [b]Likelihood ratio statistic P-value. [c]Distance in furlongs (1 furlong = 201.168m). [d]Variance estimate for the trainer shared frailty term = 2.63 (Standard error = 0.94). [e]Variance estimate for the trainer shared frailty term e = 2.37 (Standard error = 1.72)

Model fit

The assumption of proportion hazards was met in both the final models. The plots of the Cox-Snell residuals showed slight deviation. Refitting the final voluntary interruption model without stud farm produced a slightly better fit, indicating that the lack of fit might be due to the increased degrees of freedom with the inclusion of stud farm. The sensitivity analysis for informative censoring showed little change in the hazard ratios for the voluntary interruption model. Total walker time was no longer significant in the final involuntary model, indicating that some informative censoring may have been present.

DISCUSSION

The aim of this paper was to investigate the effect of early exercise during yearling sales preparation on the risk of interruptions during race training. An earlier study (Bolwell *et al.* 2011b [Chapter 2]) demonstrated an association between race training exercise and interruptions during training. This study expands on that work by investigating the effect of exposure to exercise earlier in life, before entering race training, on performance later in life. The results showed an association between hand walking and walker exercise with voluntary and involuntary interruptions during training.

Increased hand walking exercise during sales preparation was associated with a reduced likelihood of a voluntary interruption. Hand walking during sales preparation is most often given to educate and improve the behaviour of the yearlings (Bolwell *et al.* 2010 [Chapter 4]), whilst some stud managers use it for fitness purposes. Yearlings that have been exercised may be, or appear to be, more developed than those doing less hand walking and be better able to withstand training without any voluntary interruptions. A recent study showed both voluntary and involuntary interruptions increase the time to, and reduce the likelihood of, a trial and race start (Bolwell *et al.* 2011c [Chapter 3]), and there is an association between trialling and racing at two years of age and future racing performance and success (Bailey *et al.* 1999; More 1999; Tanner *et al.* 2011). Elements within exercise programs during sales preparations represent factors that could be modified in order to reduce the proportion of horses with interruptions before their first trial. Before this could be done, possible associations between early exercise programs and racing success should be investigated.

Conversely, a greater amount of walker exercise accumulated during sales preparation was associated with an increased risk of an involuntary interruption. However, caution should be applied when interpreting this finding as the LRS P-value indicated only a trend that the inclusion of this variable improved the model fit. The lack of significance in the final model may be due to a lack of power as a result of few involuntary interruptions. Data on the effect of horse walkers on the benefits or potential negative effects on the musculoskeletal system, in a horse of any age, are limited. A retrospective study in dressage horses reported that increased time on the walker was associated with the risk of lameness (Murray *et al.* 2010), although the authors state that this may be due to an effect of rehabilitation for lameness, rather than a cause. However, studmasters' observations of yearlings on the horse walker have previously resulted in a reduction in exercise time, due to caution over the use of the walker (Bolwell *et al.* 2011a [Chapter 5]). Different strains on the distal limb bones of horses, and changes in kinematics, have been observed during tight turns or circles (Davies and Merritt 2004; Hobbs *et al.* 2011). Whether the use of the walker resulted in any underlying problems that led to involuntary interruptions to training, cannot be determined from the current study. It is possible that the trainers perceived these yearlings as being more forward and developed for training, in terms of musculoskeletal tissues, movement, and temperament, which resulted in imposition of a higher training load than other horses that had done less walker exercise and were less forward. The most common reason for involuntary interruptions was shin soreness, and increasing distances at high speed within short time periods has been identified as a risk factor for dorsal metacarpal disease (Verheyen *et al.* 2005). However, no association of high speed events and involuntary interruptions was established by the analysis in the current study.

It has been hypothesised that the associations with interruptions during training and gender may be a reflection of the difference between colts and fillies in the amount of exercise accumulated during a sales preparation (Bolwell *et al.* 2011a; Bolwell *et al.* 2011b [Chapters 5 and 2]). However, the current study did not find any significant associations between gender and either involuntary or voluntary interruptions.

The second most common specific reason cited by trainers for voluntary interruptions was so the horse could "grow and strengthen". The data show that there was a significant association between the accumulated number of days off and a voluntary interruption. It is speculated that horses that are perceived as not coping well or are not strong enough would be given more days off, but are still kept in training. Similarly, increasing canter distance was associated with a reduced risk of voluntary interruptions suggesting that horses that are accumulating longer canter distances may be performing well for the trainer, either through showing co-operation during training and/or through an indication of progression or improved fitness, and continue to remain in work. However, this association could be a result of being in training longer than horses with an interruption, rather than a cause of accumulating longer canter distances.

The percentage of horses reaching their first trial without an interruption to training was less than the 30% previously reported (Bolwell *et al.* 2011b [Chapter 2]). These and other discrepancies, such as no association of high speed events or age with interruptions, may be due to differences in the sample population of the two studies and the inclusion of the early exercise exposures in the current study.

Stud farm was associated with voluntary interruptions in the final model and there was significant clustering in both final models at the trainer level. Unmeasured effects at the stud farm level such as management and feeding practices, not recorded in this study, and the production focus of the farm (for instance, sprinters versus long distance) may have contributed to the association with stud farm. The unmeasured factors and clustering present at the trainer level is common in studies of training and racing performance (Verheyen *et al.* 2009; Ely *et al.* 2010; Bolwell *et al.* 2011b [Chapter 3]), and whilst it may represent management differences, such as the reasons cited for voluntary interruptions, the level of involvement from the owner should also be considered.

This paper reported on findings that linked two parts of the whole study. Part 1 used a convenience sample of stud farms, the implications of which have been discussed (Bolwell *et al.* 2011a [Chapter 5]). The sample of trainers in this paper was determined by the horses enrolled in Part 1 (Bolwell *et al.* 2011a [Chapter 5]), and trainers were enrolled in the study based on the horses being registered with them. As trainers were not being recruited based only on their willingness to participate, loss to follow-up from yearling sales to the trainer was expected. As shown in our study, even with enthusiasm and willingness to participate, the amount of work required to record training exercise can and did result in withdrawal of trainers, and subsequent loss or exclusion of data; a common problem in other studies of this kind (Ely *et al.* 2009; Reed *et al.* 2011). Withdrawal of trainers reduced the size of the sample of horses followed, so the study may have lacked statistical power to investigate multiple risk factors and identify subtle effects. Furthermore, exclusions can result in selection bias as those trainers that did not participate may have differed in various ways from those that remained in the study. Giving preference to trainers that already have recording systems in place may introduce selection bias by favouring trainers that are highly organised or have more horses in work (Reed *et al.* 2011), but would improve compliance and the accuracy of the data. Although trainers could not be selected in this way in the current study, several trainers already had recording systems in place. Movement in the direction of a central training database, as developed by The Jockey Club for racetrack injuries (Anonymous 2007), would assist future studies and allow investigators to utilize larger, random samples of trainers.

Although the plots of the Cox-Snell residuals showed some lack of model fit, some departure is expected towards the right hand tail as a result of a reduced sample due to the occurrence of events or censoring. Additionally, these plots can indicate a lack of model fit when there is a substantial proportion of censoring (Dohoo *et al.* 2003a) as seen in the involuntary model. The sensitivity analysis for informative censoring did not indicate any changes in the hazard ratios for the voluntary interruption model, suggesting that the occurrence of an involuntary event did not inform a voluntary interruption. There was some indication of informative censoring in the involuntary model, but it should be noted that this analysis is a worst case scenario that is unlikely to represent reality; given the reasons cited for voluntary interruptions it is doubtful that all the horses censored for voluntary events would have experienced an involuntary event the next day, had they not been censored.

CONCLUSION

An association between early exercise during a sales preparation and the hazard of a voluntary or involuntary interruption during training as a 2-year-old was identified. Whilst further investigation into the effects of early exercise on racing performance is needed, this study has indicated there may be potential benefits to training of 2-year-old Thoroughbreds through modifications to optimize the effect of early exercise programs.

REFERENCES

Anonymous (2007) Equine injury reporting system debuts at racetracks. Journal American Veterinary Medical Association News. http://www.avma.org/onlnews/javma/jul07/070715h.asp Accessed 4th April 2011.

Bailey, C.J., Reid, S.W., Hodgson, D.R. and Rose, R.J. (1999) Factors associated with time until first race and career duration for Thoroughbred racehorses. *Am. J. vet. Res.* **60**, 1196-1200.

Barneveld, A. and van Weeren, P.R. (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine. vet. J., Suppl.* **31**, 112-119.

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2010) Management and exercise of Thoroughbred yearlings during preparation for yearling sales in North Island of New Zealand. *Proc. N. Z. Soc. Anim. Prod.* **70**, 157-161.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011a) Exercise in Thoroughbred yearlings during sales preparation: A cohort study. *Equine vet. J.*, no.10.1111/j.2042-3306.2011.00370.x.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011b) Risk factors for interruptions to training occurring before the first trial start of 2-year-old Thoroughbred racehorses. *N.Z. vet. J.* **In press**.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011c) The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses. *Pre. vet. Med.* **Submitted**.

Collett, D. (2003). In: *Modelling Survival Data in Medical Research* 2nd Edition edn., Chapman & Hall/CRC Press, Boca Raton. p 122.

Davies, H.M.S. and Merritt, J.S. (2004) Surface strains around the midshaft of the third metacarpal bone during turning. *Equine vet. J.* **36**, 689-692.

Dohoo, I., Martin, W. and Stryhn, H. (2003a) Modelling survival data. In: *Veterinary Epidemiologic Research*, Eds: I. Dohoo, W. Martin and H. Stryhn, AVC Inc, Charlottetown, Canada. p 439.

Dohoo, I., Martin, W. and Stryhn, H. (2003b) Validity in observational studies. In: *Veterinary Epidemiologic Research*, Eds: I. Dohoo, W. Martin and H. Stryhn, AVC Inc, Charlottetown, Canada. p 213.

Ely, E.R., Avella, C.S., Price, J.S., Smith, R.K.W., Wood, J.L.N. and Verheyen, K.L.P. (2009) Descriptive epidemiology of fracture, tendon and suspensory ligament injuries in National Hunt racehorses in training. *Equine vet. J.* **41**, 372-378.

Ely, E.R., Price, J.S., Smith, R.K., Wood, J.L.N. and Verheyen, K.L.P. (2010) The effect of exercise regimens on racing performance in National Hunt racehorses. *Equine vet. J.* **42**, 624-629.

Firth, E.C. and Rogers, C.W. (2005) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. Conclusions. *N.Z. vet. J.* **53**, 377-383.

Firth, E.C. (2006) The response of bone, articular cartilage and tendon to exercise in the horse. *J. Anat.* **208**, 513-526.

Gibbs, P.G. and Cohen, N.D. (2001) Early management of race-bred weanlings and yearlings on farms. *J. Equine vet. Sci.* **21**, 279-283.

Gunter, K., Baxter-Jones, A.D.G., Mirwald, R.L., Almstedt, H., Fuchs, R.K., Durski, S. and Snow, C. (2008) Impact Exercise Increases BMC During Growth: An 8-Year Longitudinal Study. *J. Bone Miner. Res.* **23**, 986-993.

Hind, K. and Burrows, M. (2007) Weight-bearing exercise and bone mineral accrual in children and adolescents: A review of controlled trials. *Bone* **40**, 14-27.

Hobbs, S.J., Licka, T. and Polman, R. (2011) The difference in kinematics of horses walking, trotting and cantering on a flat and banked 10 m circle. *Equine vet. J.*, 10.1111/j.2042-3306.2010.00334.x.

Meredith, K., Bolwell, C.F., Rogers, C. and Gee, E.K. (2011) The use of allied health therapies on competition horses in the North Island of New Zealand. *N.Z. vet. J.* **59**, 123-127.

More, S.J. (1999) A longitudinal study of racing Thoroughbreds: performance during the first years of racing. *Aust. vet. J.* **77**, 105-112.

Murray, R.C., Walters, J.M., Snart, H., Dyson, S.J. and Parkin, T.D.H. (2010) Identification of risk factors for lameness in dressage horses. *Vet. J.* **184**, 27-36.

Parkin, T.D.H. (2008) Epidemiology of Racetrack Injuries in Racehorses. *Vet. Clin. N. Am.: Equine Pract.* **24**, 1-19.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004) Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *N.Z. vet. J.* **53**, 59-68.

Reed, S.R., Jackson, B.F., Mc Ilwraith, C.W., Wright, I.M., Pilsworth, R., Knapp, S., Wood, J.L.N., Price, J.S. and Verheyen, K.L.P. (2011) Descriptive epidemiology of joint injuries in Thoroughbred racehorses in training. *Equine vet. J.*, 10.1111/j.2042-3306.2010.00352.x.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008a) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine vet. J.* **40**, 111-118.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008b) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2 and 3 year old racing careers. *Equine vet. J.* **40**, 119-127.

Rogers, C.W., Kidd, L. and Firth, E.C. (2010) Linear and temporal changes in the trot of 2-year-old Thoroughbred racehorses in relation to early exercise and race training. *Comp. Exerc. Physiol.* **7**, 65-71.

Tanner, J.C., Rogers, C.W. and Firth, E.C. (2011) The relationship of training milestones with racing success in a population of Standardbred horses in New Zealand. *N.Z. vet. J.* **59**, 331-336.

Verheyen, K.L., Henley, W.E., Price, J.S. and Wood, J.L. (2005) Training-related factors associated with dorsometacarpal disease in young Thoroughbred racehorses in the UK. *Equine vet. J.* **37**, 442-448.

Verheyen, K.L.P., Price, J.S. and Wood, J.L.N. (2009) Exercise during training is associated with racing performance in Thoroughbreds. *Vet. J.* **181**, 43-47.

APPENDIX E

This appendix presents the results of the sensitivity analysis for informative censoring (Table A1) and plots of Cox-Snell residuals for the final competing risks model (Figures A1 and A2). A plot of the final voluntary interruption model with the fixed effect for stud farm excluded is also presented.

Table A1: Results of the final voluntary and involuntary interruption competing risks models and of a sensitivity analysis for informative censoring.

	Final model		Informative censoring model	
Variable	**Hazard Ratio**	**95%CI[a]**	**Hazard Ratio**	**95%CI[a]**
Voluntary interruption				
Hand walking (hours)	0.55	0.42-0.73	0.58	0.45-0.74
Cumulative days off	1.37	1.18-1.58	1.32	1.17-1.49
Cumulative distance at canter[b]	0.99	0.98-0.99	0.99	0.98-0.99
Involuntary interruption				
Walker (hours)	1.13	1.01-1.27	1.02	0.95-1.10
Cumulative distance at canter[b]	0.99	0.98-0.99	0.99	0.99-0.99

[a]CI = Confidence interval. [b]Distance in furlongs.

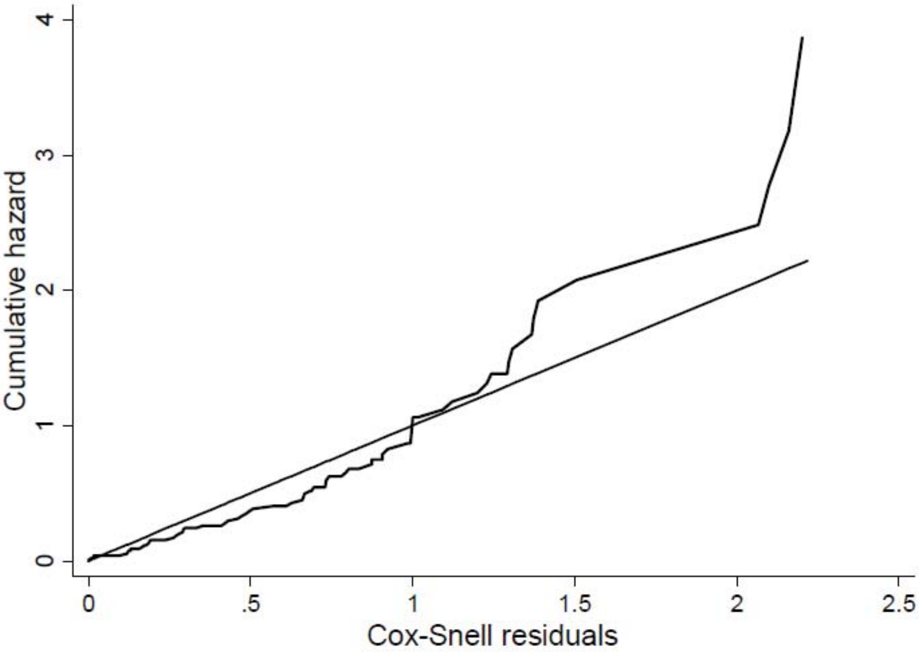


Figure A1: Plot of the Cox-Snell residuals against the cumulative hazard for the final multivariable model for voluntary interruptions. A reference line with a slope=1 is also displayed.

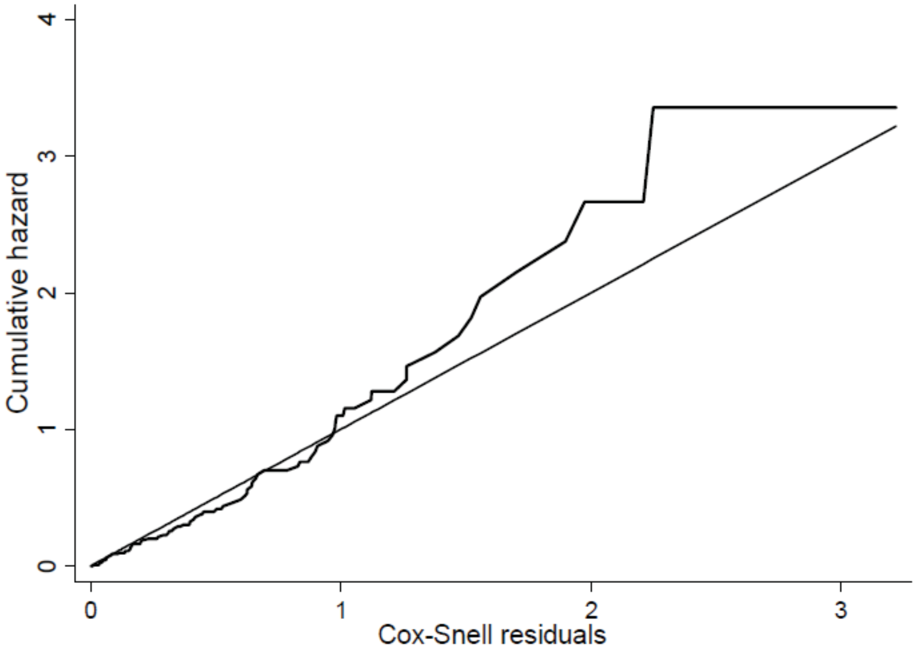


Figure A2: Plot of the Cox-Snell residuals against the cumulative hazard for the final multivariable model for voluntary interruptions, excluding the fixed effect for stud farm. A reference line with a slope=1 is also displayed.

PRELUDE TO CHAPTER 8

Chapter 3 identified that interruptions to training, and the high speed distance accumulated during training, were associated with time to the first trial and race. Both the first trial and race are important milestones used by trainers to measure a horse's progress.

The results of Chapter 6 showed that due to losses from the study population, few of the horses raced during the study period. As a result, the effect of early exercise on racing performance outcomes could not be investigated in this cohort of horses. Therefore, Chapter 7 reported the associations between exercise during sales preparation and the time to interruptions occurring before the first trial.

Chapter 8 expands on the results presented in Chapter 3 and follows on from Chapter 7 by investigating the effect of exercise during sales preparation on the time to the first trial

Supplementary information on the model diagnostics used in the statistical analysis is presented in the appendix to this chapter. This chapter has not been submitted for publication

.

CHAPTER 8

EFFECT OF EARLY EXERCISE IN THOROUGHBRED RACEHORSES ON THE TIME TO THE FIRST TRIAL

ABSTRACT

Aim

To investigate the effect of exercise during sales preparation on the time to first trial during race training.

Method

Data on the daily exercise of yearlings during sales preparation were recorded on eight Thoroughbred stud farms, from September 2008 until January 2009. Twenty-six trainers provided information on the daily training activity, and trial dates for each horse until the end of the 2010 racing season. The main exposures of interest were the total hand walking and walker time accumulated during sales preparation, and other horse and race training variables. Cox regression survival analysis was used to investigate associations between the exposure variables and the time from entering training to the first trial.

Results

A total of 112 horses spent 119,710 days at risk of trialling. Overall, 62 (55%) horses trialled at least once, whilst 54% (27/50) of those that did not trial were lost to follow-up and 46% (23/50) were right censored at the end of the study period. The median time to the first trial for the whole cohort was 155 days (95% CI 110-173). There were no significant association between hand walking and walker time and the time to first trial. Increasing age at the start of training (months) and longer distances accumulated at 15s/200m, was associated with an increased chance of starting in a trial (P=0.04 and P=0.001, respectively).

Conclusion

The exercise distances accumulated during race training had a greater effect on the time to the first trial than the hand walking and walker exercise recorded during sales preparations.

INTRODUCTION

Wastage in the Thoroughbred racing industries worldwide is an ongoing issue that has resulted in research initiatives that aim to reduce musculoskeletal injury (MSI). A large scale study was conducted by the Global Equine Research Alliance that aimed to reduce MSI through the use of conditioning regimens in juvenile horses (McIlwraith 2000).

As part of this alliance, Rogers *et al* (2008a) investigated the effect of early conditioning exercise in foals on training workload and on training and racing milestones when they were 2- and 3-year-old racehorses. All the foals were reared at pasture and one group received an additional 30% increase in exercise from three weeks up to 19-21 months of age. Although there were no signs of negative effects of the early exercise on the ability of horses to train and race, a significant early training advantage could not be demonstrated, possibly because a respiratory disease outbreak disrupted the training programmes and there was not enough statistical power to detect a difference. However, these results, combined with potential benefits of early exercise on the development of the musculoskeletal system (Barneveld and van Weeren 1999; van Weeren *et al.* 2000; Dykgraaf *et al.* 2008; Nicholson and Firth 2010), suggested further investigation of early exercise programmes on training performance was warranted.

The effect of early exercise on the progression of horses through training, specifically whether they experienced an interruption to training before the first trial, has been described (Bolwell *et al.* 2011a [Chapter 7]). The first trial has been considered as a milestone by trainers for assessing a horse's performance (Bolwell *et al.* 2010) and as such, other studies have investigated trial starts as an important training milestone (Perkins *et al.* 2004a; Perkins *et al.* 2004b; Cogger *et al.* 2008; Tanner *et al.* 2010). This chapter links Part 1 and 2 of the study, and aims to investigate the effect of early exercise in Thoroughbred yearlings on training performance, specifically the time to first trial. The general hypothesis was that hand walking and walker exercise would be associated with the time to the first trial.

MATERIALS AND METHODS

Full details on the sample population, the methods of data collection, and the type of exercise data collected were described in detail in Chapters 5 and 7. Briefly, a prospective cohort study followed Thoroughbred yearlings born in 2007 through sales preparation to the point at which they entered training, and then until the end of the 2-year-old racing season. Data on the daily exercise (hand walking and mechanical walker) of yearlings during sales preparation were recorded on eight Thoroughbred stud farms, from September 2008 until January 2009. Twenty-six trainers recorded information on the daily training activity from the first day a horse entered their stable to begin training until 31st July 2010 (end of the 2010 racing season), or until the horse was lost to follow-up. The trial dates were provided by the trainers and compared with those officially recorded in the New Zealand Thoroughbred Racing online database; if there were any discrepancies in the dates the official date was used.

Statistical analysis

The total hand walking and walker time accumulated during the sales preparation were the main exposures of interest. The units of these variables were converted from minutes to hours to improve the interpretation of the hazard ratios. Variables for the distances accumulated since entering training at canter (>15s/200m) and speeds of 15s/200m (15s), 13s/200m (13s) and 12s/200m (12s) were calculated and presented as furlongs. Other training components accumulated since entering training were: the number of days off, high speed events at 12s, jump outs (a practice start out of gates at high speed), swimming days, water walker days, and days off. Additional exposure variables investigated were daily walking time (on a mechanical walker), age (months) at the start of training, gender, the type of interruption to training that occurred before the first trial (none, voluntary and involuntary), and trainer.

Kaplan Meier survival analysis (Kaplan and Meier 1958) was used to plot the time from entering training to the first trial for the whole cohort, and to calculate the median time and 95% confidence interval (CI) to the first trial for the whole cohort and by gender, the type of interruption and trainer. The total number of trials and the days at risk were obtained and incidence rates of a trial (per 1,000 training days) by gender, type of interruption, and trainer were calculated.

A Cox proportional hazards regression model was developed to investigate associations between the exposure variables and the time from entering training to the first trial. Investigation of the functional form of continuous variables, the use of fractional polynomials and the process of univariable selection and model building were described in Chapter 3. Age at the start of training and total hand walking and walker time during sales preparation were *a priori* variables of interest and were forced into the multivariable modelling. Trainer was modelled as a shared frailty term to adjust for potential clustering of horses within trainers, and stud farm was modelled as a fixed effect. As discussed previously (Chapter 3), the proportional hazards assumption was tested for non-time dependant variables and Cox-Snell residuals were plotted to visualise the model fit. Influential observations were investigated through plots of likelihood displacement and LMAX values against time (Cleves *et al.* 2010). The critical probability for assigning statistical significance was set at P<0.05 and all analyses were conducted in intercooled STATA 11 (Statacorp LP, College Station, Texas, USA).

RESULTS

Sale preparation exercise and training activity were recorded for 114 sales horses, but due to missing data that included the first trial date, two horses were excluded from the analysis. A total of 112 horses, across 26 trainers, spent 119,710 days at risk of trialling. Overall 62 horses trialled at least once, resulting in an incidence rate of 5.17 (95% CI 4.03-6.64) per 1,000 training days. Of the horses that did not trial, 52% (26/50) were lost to follow-up, 46% (23/50) were right censored at the end of the study period, and one horse died.

The median time to the first trial for the whole cohort was 155 days (95% CI 110-173) (Figure1), but horses without an interruption to training had a shorter median time of 72 days (95% CI 58-114). Horses with an involuntary or voluntary interruption took longer than the median time for the whole cohort, with 162 (95% CI 97-193) and 196 (95%CI 163-267) days respectively.

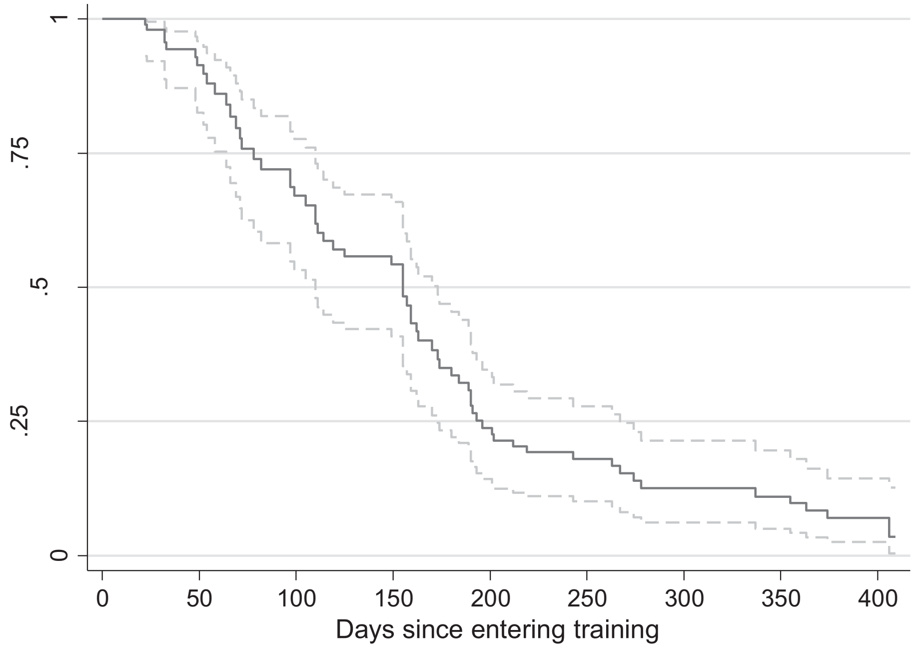


Figure 1: Kaplan Meier 'survival' curve of the time since entering training to the first trial for a cohort of 2-year-old Thoroughbred racehorses in training.

The distribution of horses that trialled, days at risk and incidence rates (per 1,000 training days) for gender, type of interruption and trainer are shown in Table 1. The incidence rate of trials was similar for males and females, whilst the rate was higher in horses that did not have an interruption compared to those that had an interruption of either type.

Table 1: Total number, number of horses that trialled, days at risk and incidence rate of a first trial by gender, type of interruption and trainer

Variable	Total horses	Number trialled	Days at risk	Rate per 1,000 training days	95% CI[a]
Gender					
Male	73	42	80, 660	5.20	3.8-7.0
Female	39	20	39,050	5.12	3.3-7.9
Type of interruption					
None	31	27	26,670	10.1	6.9-14.7
Involuntary	16	12	15,310	7.8	4.4-13.8
Voluntary	65	23	77,730	2.9	1.9-4.4
Trainer					
1	3	2	1,910	10.4	2.6-41.8
2	1	1	230	43.4	6.1-310
3	4	2	5,210	3.8	0.9-15.3
4	1	0	400	0	N/A
5	1	1	720	13.8	1.9-98.5
6	4	1	5,550	1.8	0.2-12.7
7	1	0	1,350	0	N/A
8	10	0	9,990	0	N/A
9	1	0	1,150	0	N/A
10	3	0	910	0	N/A
11	1	0	770	0	N/A
12	1	0	1170	0	N/A
13	5	5	5460	9.1	3.8-22
14	8	3	7960	3.7	1.2-11.6
15	5	4	5170	7.7	2.9-20.6
16	9	5	13,060	3.8	1.5-9.1
17	1	1	920	10.8	1.5-77.1
18	4	1	4,910	2.0	0.2-14.4
19	2	0	520	0	N/A
20	11	10	9,580	10.4	5.6-19.4
21	1	1	970	10.3	1.4-73.1
22	3	1	1,640	6.1	0.8-43.2
23	14	12	11,630	10.3	5.8-18.1
24	8	5	10,850	4.6	1.9-11.1
25	7	5	12,040	4.1	1.7-9.9
26	3	2	5,640	3.5	0.8-14.1

[a] CI = Confidence interval, calculated using the quadratic approximation to the Poisson log-likelihood for the log-rate parameter

Univariable analysis

Table 2 shows the results of the univariable screening of horse and exercise exposures with the time to first trial. Increasing hand walking and walker time were associated with an increased chance of a trial start, but not significantly.

Table 2: Results of univariable Cox regression of variables associated with time to first trial for 2-year-old Thoroughbred racehorses in training

Variable	β coefficient	Standard error	Hazard ratio	95%CI[a]	Wald test P-value	LRS[b] P-value
Interruption						<0.001
None	Ref	-	Ref	-		
Involuntary	-0.99	0.40	0.36	0.16-0.81	0.01	
Voluntary	-2.02	0.35	0.13	0.06-0.26	<0.001	
Age at start of training (months)	0.03	0.04	1.03	0.93-1.13	0.52	0.64
Gender						
Colts	Ref	-	Ref	-		
Fillies	-0.05	0.27	0.94	0.55-1.62	0.84	0.84
Hand walking (hours)	0.01	0.01	1.01	0.98-1.05	0.32	0.33
Walker (hours)	0.03	0.03	1.03	0.97-1.10	0.26	0.29
Canter distance[c]	0.001	0.003	1.00	1.00-1.00	<0.001	<0.001
Distance at 15s/200m$^{c\ \wedge 0.5}$	1.79	0.29	6.04	3.41-10.7	<0.001	<0.001
Distance at 13s/200m$^{c\wedge -0.5}$	-0.49	0.07	0.61	0.52-0.70	<0.001	<0.001
Distance at 12s/200m$^{c\wedge -2}$	-0.003	0.006	0.99	0.99-0.99	<0.001	<0.001
High speed events$^{c\wedge -2}$	-0.01	0.002	0.98	0.98-0.99	<0.001	<0.001
Number of jump outs$^{c\wedge -2}$	-2.18	0.36	0.11	0.05-0.23	<0.001	<0.001
Number of days off[c]	-0.003	0.01	0.99	0.96-1.02	0.82	0.82
Number of swim days[c]	0.13	0.04	1.14	1.05-1.24	0.001	0.002
Number of water walker days[c]	-0.41	0.74	0.66	0.15-2.83	0.57	0.15

[a]CI = confidence interval. [b]LRS = Likelihood ratio statistic P-value. [c]Exercise distances (furlongs)/events accumulated since entering training. Ref = Reference level for comparison.

Age at the start of training was not significantly associated with the time to first trial, but as this and hand walking and walker time were *a priori* factors of interest they were included in the multivariable modelling. Gender, the number of days off and stud farm (P=0.30) were not significant, whilst all other training variables were significantly associated with time to first trial and were considered for multivariable analysis.

Multivariable analysis

Results of the final multivariable model are shown in Table 3. There was no significant association between hand walking and walker time and the time to first trial. Increasing age at the start of training (months) was associated with an decreased chance of starting in a trial, and horses with a voluntary or involuntary interruption were significantly less likely to start in a trial. The distance accumulated at 15s was significantly associated with the time to first trial (Figure 2), and was modelled as a fractional polynomial as ((15s+0.24)/10)^0.5. As the distance accumulated at 15s increased, horses were more likely to start in a trial.

Table 3: Multivariable Cox regression results of variables associated with the time to first trial for 2-year-old racehorses in training

Variable	β coefficient	Standard error	Hazard ratio	95%CI[a]	Wald test P-value	LRS[b] P-value
Interruption						<0.001
None			Ref			
Involuntary	-1.47	0.56	0.22	0.07-0.68	0.009	
Voluntary	-1.91	0.48	0.14	0.05-0.37	<0.001	
Age at start of training (months)	-0.13	0.06	0.87	0.76-0.99	0.04	0.04
Distance at 15s/200m $^{\wedge 0.5}$	1.30	0.39	3.68	1.69-7.99	0.001	0.005
Distance at 13s/200m $^{\wedge -0.5}$	-0.51	0.11	0.60	0.47-0.75	<0.001	<0.001
Distance at 12s/200m $^{\wedge -2}$	-0.003	0.0009	0.99	0.99-0.99	<0.001	<0.001
Trainer[c]						0.008

[a]CI = confidence interval. [b]LRS = Likelihood ratio statistic P-value. Exercise variables represent the distance (furlongs) accumulated since entering training. [c]Trainer modelled as a frailty term, within-group correlation= 0.47 (standard error 0.33).

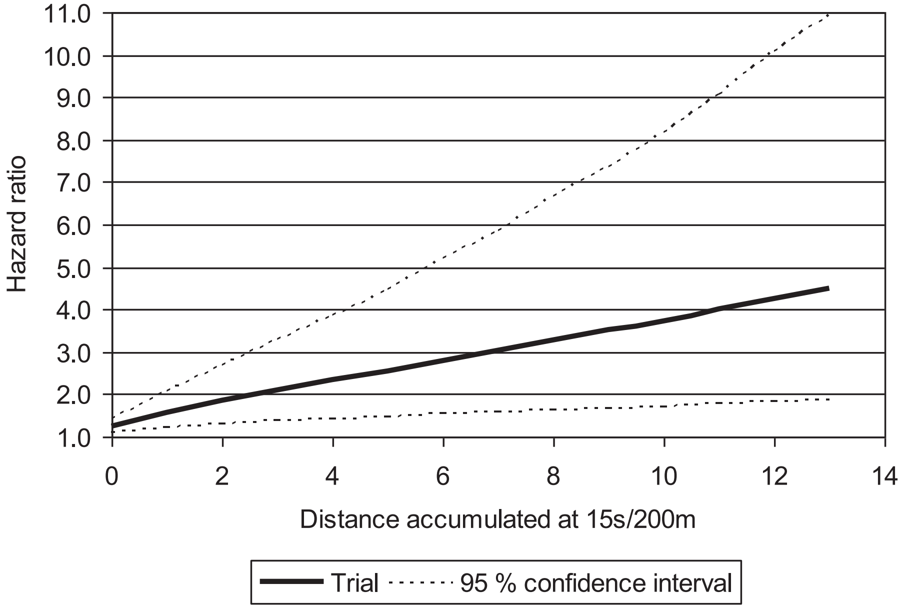


Figure 2: Association between the distance (furlongs) accumulated at 15s/200m (15s) since entering training and the likelihood of a trial. Distance at 15s modelled as a fractional polynomial transformation ((15s+0.24)/10)^0.5

The shape of the association between the distances accumulated at 13s and 12s and the likelihood of a trial was best modelled as fractional polynomials as ((13s+0.24)/10)^-0.5 and ((12s+0.49)/10)^-0.2, respectively. The relative hazard of starting in a trial increased with longer distances accumulated at 13s and 12s (Figures 3 and 4). The frailty term for trainer was significant in the final model, indicating the presence of clustering within trainer; the estimate of frailty for trainer was 0.44 (standard error 0.33). No statistically significant interactions were present in the final model.

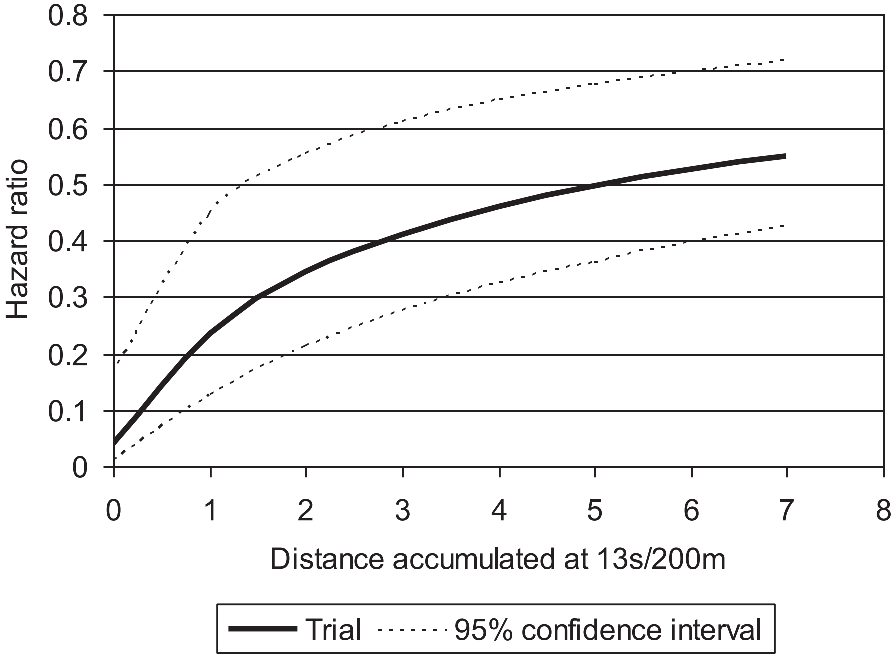


Figure 3: Association between the distance (furlongs) accumulated at 13s/200m (13s) since entering and the likelihood of a trial. Distance at 13s modelled as a fractional polynomial transformation ((13s+0.24)/10)^-0.5.

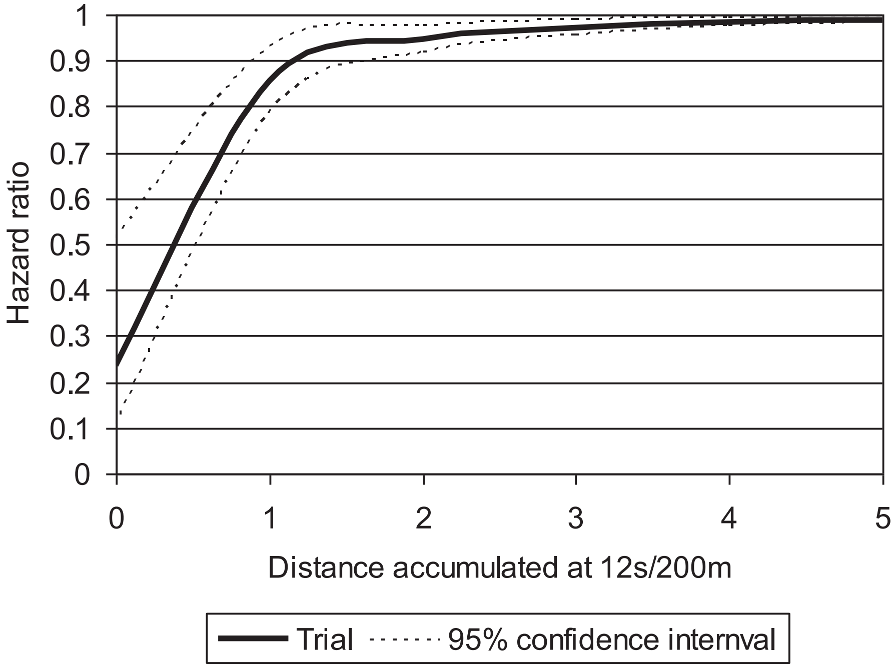


Figure 4: Association between the distance (furlongs) accumulated at 12s/200m (12s) since entering and the likelihood of a trial. Distance at 12s modelled as a fractional polynomial transformation ((12s+0.49)/10)^-2.

The final model did not violate the proportional hazards assumption (P=0.26) and there were no influential observations identified. A plot of the Cox-Snell residuals suggested there was some indication of poor fit at larger time values due to censoring. Plots of likelihood displacement values and influential observations indicated that two horses were outliers and influential in the final model. Investigation of these horses indicated that they had relatively long survival time and accumulated long distances at 15s and 13s with little or no distances at 12s. Removal of these horses reduced the effect of age and clustering at trainer-level, but as the overall fit of the model did not change they were not excluded from the dataset.

DISCUSSION

This study aimed to investigate the effect of early exercise in Thoroughbred yearlings on training performance. Specifically the effect of hand walking and walker time as a yearling, along with horse and race training exposures on the time to the first trial, were investigated. The selection of the study population, the process of tracking horses to training and the potential bias that may have occurred have been described previously (Bolwell *et al.* 2011a; Bolwell *et al.* 2011b [Chapter 5 and 7]).

Just over half the horses in the study population trialled, but 46% of those that did not trial remained in the study population until the end of the 2-year-old season. Therefore, these results support the findings of Perkins *et al* (2004b), which indicated there was a group of horses that were in training at two years of age but did not trial. Although for a number of trainers the purpose of having 2-year-olds in work is to provide education (Bolwell *et al.* 2010), the first trial has been reported as an indicator of how a horse is progressing through training (Bolwell *et al.* 2010).

This study focussed on the first trial since entering training, and the average time to the first trial was longer (155 days) than the ~70 days that is believed to be the industry norm in New Zealand (Perkins *et al.* 2004b). However, in the study by Perkins *et al* (2004b) the time to first trial was investigated from the start of each training preparation and was not restricted to only 2-year-olds. In the current study, the average time to the first trial was similar (~70 days) to that reported in other studies (Perkins *et al.* 2004b; Cogger *et al.* 2008; Bolwell *et al.* 2009; Bolwell *et al.* 2011c [Chapter 3]), when it was stratified by voluntary and involuntary interruptions. Horses with an involuntary or voluntary interruption took over twice as long to start in a trial than horses without an interruption. A recent study (Bolwell *et al.* 2011c [Chapter 3]) indicated that horses with either voluntary or involuntary interruptions to training were less likely to trial, a finding that was supported by the results in this cohort of 2-year-old racehorses.

Results of this study did not support the hypothesis that hand walking and walker exercise time during sales preparation were associated with the time to the first trial. Although hand walking and walker time were considered in the multivariable models, there were no associations observed between yearling exercise and the time to the first trial after adjusting for the exercise accumulated since entering training. Previously, a large scale study was designed to investigate the effects of an early conditioning programme imposed on Thoroughbred foals raised at pasture (McIlwraith 2000). Specifically, the effect of the conditioning programme on the workload and injury during race training at two and three years of age was investigated (Rogers *et al.* 2008a). Although significant advantages of early conditioning on future training and racing performance could not be confirmed, conditioned horses preformed more training sessions as 2-year-olds and there was an indication that they started in competitive events earlier, than unconditioned foals (Rogers *et al.* 2008a); although the analysis did not adjust for the potential confounding effects of training exercise.

However, the exercise observed during the sale preparations predominantly consisted of hand walking and walker exercise (Bolwell *et al.* 2011b [Chapter 5]). It is more likely that the sprint exercise, utilised by Rogers *et al* (2008b), could be likened to the future training environment more than the exercise regimens currently used by stud farms. Similarly, previous studies that reported changes to the musculoskeletal system as a result of early exercise (Barneveld and van Weeren 1999) used exercise protocols that could be considered a greater exercise load than hand walking or walker exercise. In light of these findings, further work is required to identify if early exercise that is more strenuous is associated with future training and racing performance.

Horses that were older at the start of training were less likely to trial, and this association was not confounded by either hand walking or walker exercise time, in the current study. This association may be due to the trainers' management decisions and reasons why they enter training when they are older. The trainers' focus might be on preparing older horses for their 3-year-old campaign, as opposed to a trial and race start as a 2-year-old. In a survey of trainers in the North Island of New Zealand, one of the reasons cited for having horses in training at two years of age was 'in preparation for racing as a 3-year-old' (Bolwell *et al.* 2010).

The distances accumulated at faster speeds than canter were associated with the time to the first trial. Longer distances accumulated at 15s were associated with an increased chance of a trial start. Additionally, the results showed horses accumulating less than three furlongs at 13s or 12s were less likely to start in a trial, possibly reflecting the trainer's decision to build up fast work before competitive events. Conversely, the number of high speed events and the number of jump-outs accumulated were not associated with the time to the first trial start. Given that the hazard of starting in a trial increased at short accumulated distances of high speed, these distances were probably accumulated within very few events at high speed and may account for the lack of association observed. In contrast, a reduced chance of a starting in a trial for horses accumulating fewer high speed events and jump-outs, respectively, was previously reported in this project with a different cohort of horses (Bolwell *et al.* 2011c [Chapter 3]). The differences reported with these associations, and the lack of an association with exercise during a sales preparation and the time to the first trial, may be due to a lack of statistical power to identify multiple risk factors and associations in this population of horses.

There was some indication that two horses were influential in the model and these horses were investigated further, and had accumulated long distances at fast speeds and had long survival times. The main effect of removing these horses was to reduce the effect of age and the clustering at trainer level. However, the values for these horses were not considered errors or outside those expected within the study population and removing the observations did not alter the overall model fit. In order to maintain the validity of the model (Dohoo *et al.* 2003) these horses were not removed from the analysis.

Overall, the age at the start of training and the occurrence of an interruption during training were associated with a reduced chance of a trial start. Hand walking and walker exercise time during sales preparation were not associated with the time from entering training to the first trial. The exercise distances accumulated during race training had a greater effect on the time to the first trial than the exercise recorded during sales preparations.

REFERENCES

Barneveld, A. and van Weeren, P.R. (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine. vet. J., Suppl.* **31**, 112-119.

Bolwell, C.F., Rogers, C.W., Firth, E.C. and French, N.P. (2009) Identification of three distinct sub-populations of 2-year-old racehorses in training. In: *Proceedings of the 12th symposium of the International Society for Veterinary Epidemiology and Economics*. p 635.

Bolwell, C.F., Russell, L.J. and Rogers, C.W. (2010) A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comp. Exerc. Physiol.* **7**, 37-42.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011a) Associations between yearling exercise and interruptions to race training in Thoroughbred racehorses. *Am. J. vet. Res.* **Submitted**.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011b) Exercise in Thoroughbred yearlings during sales preparation: A cohort study. *Equine vet. J.*, no.10.1111/j.2042-3306.2011.00370.x.

Bolwell, C.F., Rogers, C.W., French, N.P. and Firth, E.C. (2011c) The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses. *Pre. vet. Med.* **Submitted**.

Cleves, M., Gould, W., Gutierrez, R.G. and Marchenko, Y.V. (2010) The Cox model:Diagnostics. In: *An Introduction to Survival Analysis Using Stata*, Stata Press, Texas. pp 223-227.

Cogger, N., Perkins, N., Hodgson, D., Reid, S. and Evans, D. (2008) Profiling training preparation in young Australian Thoroughbred racehorses. *Aust. vet. J.* **86**, 419-424.

Dohoo, I., Martin, W. and Stryhn, H. (2003) Veterinary Epidemiologic Research, AVC Inc, Charlottetown, Canada. p 309.

Dykgraaf, S., Firth, E.C., Rogers, C.W. and Kawcak, C.E. (2008) Effects of exercise on chondrocyte viability and subchondral bone sclerosis in the distal third metacarpal and metatarsal bones of young horses. *Vet. J.* **178**, 53-61.

Kaplan, E.L. and Meier, P. (1958) Nonparametric estimation from incomplete observations. *J. Amer. Statistical. Assoc.* **53**, 457-481.

McIlwraith, C.W. (2000) Global Equine Research Alliance to reduce musculoskeletal injury in the equine athlete. *Equine. vet. Educ.* **12**, 260-262.

Nicholson, C.L. and Firth, E.C. (2010) Assessment of bone response to conditioning exercise in the radius and tibia of young Thoroughbred horses using pQCT. *J. Musculoskelet. Neuron. Interact.* **10**, 199-206.

Perkins, N., Reid, S. and Morris, R. (2004a) Effect of training location and time period on racehorse performance in New Zealand. 1. Descriptive analysis. *N.Z. vet. J.* **52**, 236-242.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004b) Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *N.Z. vet. J.* **53**, 59-68.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008a) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2 and 3 year old racing careers. *Equine vet. J.* **40**, 119-127.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008b) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine vet. J.* **40**, 111-118.

Tanner, J.C., Rogers, C.W. and Bolwell, C.F. (2010) Training and racing milestones in a subset of standardbred horses. In: *Proceedings Australian Equine Science symposium*. p 74.

van Weeren, P.R., Brama, P.A.J. and Barneveld, A. (2000) Exercise at Young Age May influence the final quality of the equine musculoskeletal system. *Proc. Am. Ass. equine Practnrs.* **40**, 29-35.

APPENDIX F

In this appendix supplementary information on the model diagnostics used for the final multivariable model of the time to the first trial is presented. Additionally, the results of investigating influential observations are shown.

Fit of the final multivariable model for time to first trial

A plot of the Cox-Snell residuals that provided a visual assessment of the model fit is shown in Figure A1. If the model fits the data well, the plot of the Cox-Snell residuals versus the cumulative hazard will be close to the reference line. However, the Cox-Snell residuals plot is of limited use in assessing model fit when there are a large number of censored points.

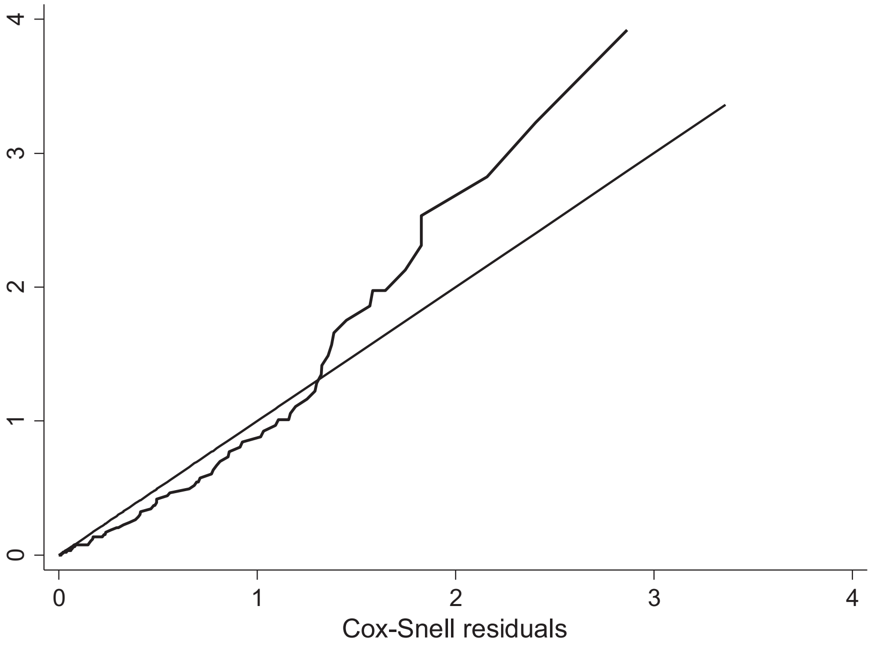


Figure A1: Plot of the Cox-Snell residuals against the cumulative hazard for the final multivariable model for time to first trial (bold line). A reference line with a slope=1 is also displayed.

Investigation of influential horses

Two horses that were influential in the model were identified from plots of the likelihood displacement values and LMAX values (Figure A2 and A3). The data were reanalysed with these two horses excluded from the dataset. The final model for the time to first trial excluding the two horses is shown in Table A1 and a plot of the Cox-Snell residuals is shown in Figure A3. When the two horses were removed from the analysis, age was no longer significantly associated with the time to first trial and there was no significant clustering at the trainer level. None of the estimates for the other variables in the model changed and the plot of Cox-Snell residuals did not show an improved fit to the data (Figure A3), compared to the model with the two horses included. The data for these horses were checked and as they were not considered to be errors in the data, these horses remained in the final model presented in the manuscript for Chapter 8.

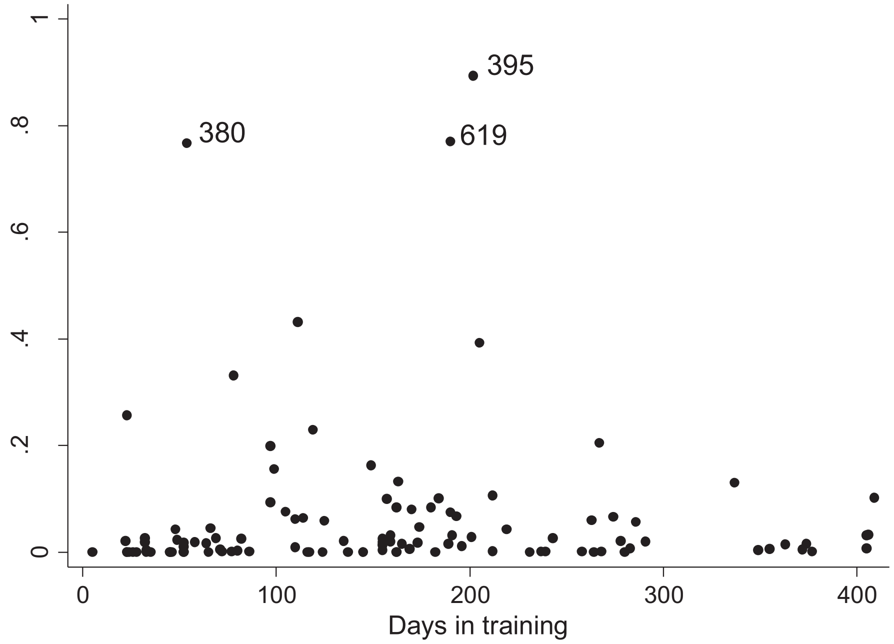


Figure A2: Plot of likelihood displacement values against time. The three numbered points are the horses that were considered to be influential.

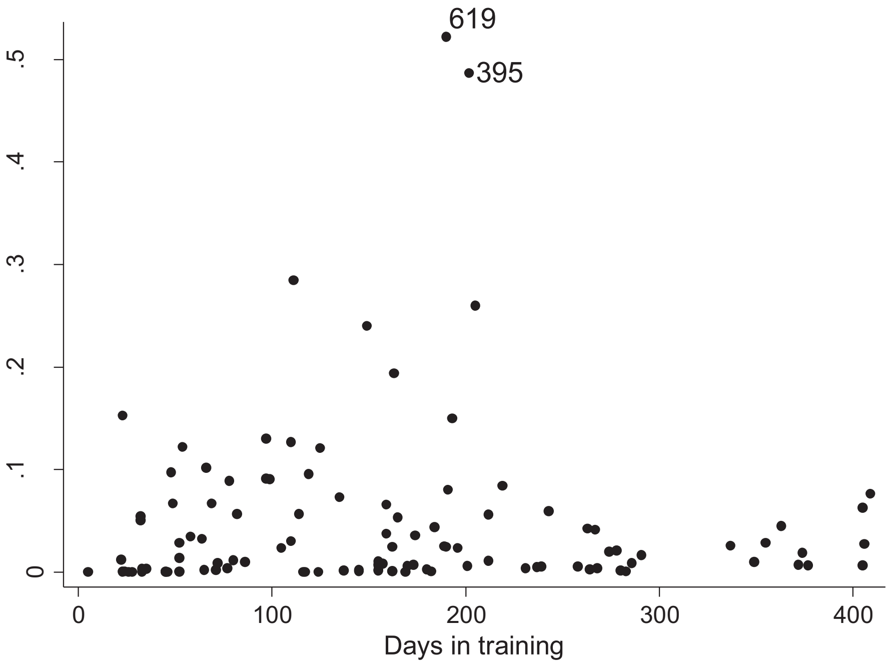


Figure A3: Plot of LMAX values against time, with the numbers representing the horses that were considered influential.

Table A1: Results of multivariable Cox regression results of variables associated with the time to first trial for 2-year-old racehorses in training, with two influential horses excluded from the analysis

Variable	**β coefficient**	**Standard error**	**Hazard ratio**	**95%CI**[a]	**Wald test P-value**
Interruption					
None			Reference		
Involuntary	-1.15	0.55	0.31	0.10-0.93	0.03
Voluntary	-2.07	0.45	0.12	0.05-0.30	<0.001
Age start training (months)	-0.10	0.06	0.89	0.78-1.02	0.10
Distance at 15s/200m$^{\wedge 0.5}$	1.24	0.38	3.46	1.62-7.35	0.001
Distance at 13s/200m$^{\wedge -0.5}$	-0.50	0.10	0.60	0.48-0.74	<0.001
Distance at 12s/200m$^{\wedge -2}$	-0.003	0.009	0.99	0.99-0.99	<0.001
Trainer[c]					0.12

[a]CI = confidence interval. [b]LRS = Likelihood ratio statistic P-value. Exercise variables represent the distance (furlongs) accumulated since entering training. [c]Trainer modelled as a frailty term, within-group correlation= 0.26 (standard error 0.30).

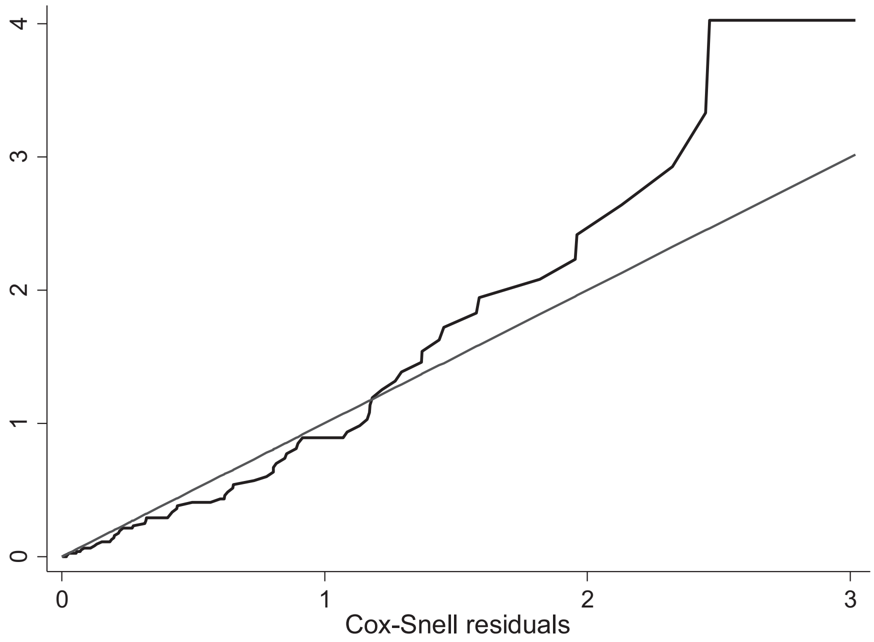


Figure A4: Plot of the Cox-Snell residuals against the cumulative hazard for the time to the first trial with two influential horses removed from the model.

CHAPTER 9

GENERAL DISCUSSION AND CONCLUDING REMARKS

This thesis presents the results of a series of epidemiological studies which aimed to quantify the exercise regimens of Thoroughbred yearlings during their sales preparation and during their 2- and 3-year-old race training in New Zealand, and to establish if there were significant associations between the early exercise and future training and racing performance.

In **Chapter 2** a competing risks analysis was used to investigate risk factors for two types of interruption occurring before the first trial. This analysis identified different risk factors for voluntary and MSI interruptions. Although not a modifiable risk factor, gender was associated with MSI interruptions, in agreement with a previous study of risk factors for MSI (Perkins *et al.* 2005a). Our results showed that females had a lower risk of MSI interruptions compared to males. Accumulating more days off during training and shorter distances at canter were associated with an increased likelihood of voluntary interruptions, which most likely reflected the reasons cited by trainers for voluntary interruptions and the ability of the horse to continue training. For example, the common reasons for voluntary interruptions related to the physical maturity of the horse. Furthermore, horses that were older at the start of training were less likely to have a voluntary interruption.

The use of multivariable analysis showed the importance of adjusting for multiple risk factors, particularly factors such as the exercise accumulated during training. Failure to adjust for potential confounding variables may lead to incorrect conclusions about apparent associations, or lack thereof, which may be affected by other variables. Using the appropriate study design and statistical analysis reduces potential bias and the possibility of erroneous conclusions, and results in studies that are internally valid.

A competing risks analysis was used as it allowed the two types of events to compete to end the time in training for each horse (Singer and Willet 2003), with only the first occurrence of an interruption before a trial, for each horse, being considered. Furthermore, competing risks survival analysis included censored horses that did not experience any interruption. Inclusion of the same variables in each model allowed direct comparison of the effects of the horse and exercise variables for the two types of interruptions, whilst aiming to reduce the potential for noninformative censoring.

The noninformative assumption is an important consideration when using a competing risks analysis, as one event should not provide any information about the risk of the other events occurring (Singer and Willet 2003). A sensitivity analysis identified that informative censoring may have been present, suggesting the results presented in Chapter 2 should be interpreted with some caution. However, the sensitivity analysis represented an extreme scenario and the same exposure variables were used to model each of the two events in order to reduce informative censoring (Singer and Willet 2003). Overall, the competing risks analysis allowed the identification of different underlying relationships between horse and exercise exposure variables and the two types of interruption occurring during training. For example, there was no association observed with age, days off and canter distance accumulated and MSI interruptions, whilst these associations were observed with voluntary interruptions.

Whilst voluntary interruptions may be unsurprising because they are typically the result of common training decisions or practices, the potential positive or negative effects of interruptions on starting in a trial or race were unknown and were investigated in **Chapter 3**. The results showed that the occurrence of a voluntary or involuntary interruption, before a horse had started in a trial, increased the time to a trial or race and significantly decreased the chance of starting in trial at all. Although there was no direct association found between an interruption to training and the chance of starting in a race, competing in a trial was associated with greater likelihood of starting in a race. Therefore, presumably, the effect of an interruption on starting in a trial would consequently affect the likelihood of starting in a race. Understanding the risk factors for interruptions, as identified in Chapter 2, is important given the delay that involuntary interruptions cause in horses reaching training and racing milestones, because the delay results in elevated costs. The association between interruptions during training and starting in a trial was present after adjusting for exercise during training; accumulation of shorter distances and less high speed events were associated with a reduced chance of a trial or race start.

The survival analysis allowed the investigation of time to event data for both trial and race outcomes, and allowed exercise variables to vary over time. Additionally, survival analysis accounted for horses that left the study, or the study ended, before experiencing a trial or race event (censored horses), which was an important consideration given the number of horses in training that did not trial or race during the study period. Including only the horses that remained in the study until the end of the observation period and those that experienced a trial or race would have reduced the number of horses available for analysis, potentially limiting the opportunity to consider the trial and race outcomes. In Chapter 3 a multiple imputation method was used to identify if missing data (due to trainers not recording information) resulted in biased estimates of the survival data and the result was that such bias was highly unlikely. This was a useful tool and an essential one, for identifying the effect of missing data, which is always likely to be a factor in the interpretation of longitudinal collection of training and racing (or other biological) information.

Chapter 4 utilised a retrospective cross-sectional survey to collect data on the management and exercise of yearlings during sales preparations. Data were collected at the farm-level since the actual exercise workload each horse had undertaken was unlikely to have been easily recalled. Exercising yearlings was found to be a common practice, which was not significantly associated with other farm management factors or the type of sale horses to which horses were destined. Hand walking or walking on a mechanical walker were the common types of exercise reported, but average duration and frequency of exercise varied between horses as a result of horse-level factors, such as gender or behaviour.

The farm-level findings of Chapter 4 indicated that detailed data at the horse-level were required in order to accurately describe the exposure to exercise during a sales preparation, which led to the prospective cohort study described in **Chapter 5**. At the horse-level, the type and amount of exercise varied significantly between and within stud farms. Specifically, males accumulated more exercise on average than females, total exercise varied by the month of preparation, and daily exercise varied between horses on the same farm, confirming that the type and amount of exercise in sales preparation is often tailored to individual horses. Therefore, whilst exercise during a sales preparation was a common practice in that year, the level of exposure was not the same for all horses, which may have positive, negative or no implications for future training and racing performance.

Chapter 6 described the fate of the yearlings followed in Chapter 5, and compared the study cohort with the whole 2007 foal crop. Overall, the study population was representative of the horses in the 2007 foal crop with respect to racing outcomes, but it had an over-representation of males, sales horses and horses exported. The study cohort of sales horses was a good representation of all the horses catalogued for the sales, indicating that findings may be extrapolated to the wider population of sales yearlings in New Zealand.

Most yearlings had been registered with a trainer by two years of age, but a group of these horses did not subsequently enter training. Of the horses not registered with a trainer at two years of age, most were either exported or not registered until three years of age. As the horses were followed from stud farm to the end of the 2-year-old racing season, horses were lost from the study as they were exported, changed trainers or, most commonly, due to a trainer leaving the study. Few horses were lost due to involuntary retirements or death.

Chapter 7 combined the data on exposure to exercise as a yearling with data collected during two year old race training. The results showed that after adjusting for exercise accumulated during training and for trainer, increasing total hand walking time was strongly associated with a reduced chance of a voluntary interruption. This result indicates that hand walking exercise may have better prepared yearlings to withstand the demands of training, or the trainers perceived them to be more developed than yearlings doing less hand walking exercise. Increasing total walker time was associated with an increased chance of an involuntary interruption, although less strongly than the association between hand walking and voluntary interruptions. However, whether the accumulation of walker exercise resulted in any underlying problems that led to involuntary interruptions during training can not be concluded. Overall, these results show that the amount and type of exercise accumulated during sales preparation affected progress during race training as a 2-year-old.

To further explore the effect of exercise on future training, **Chapter 8** investigated an important milestone during training. The results of Chapter 8 disproved the hypothesis that hand walking and walker exercise would be associated with the time to the first trial, and instead found no statistically significant association between hand walking or walker time and the time to the first trial. Longer distances accumulated at fast speeds during training were associated with a shorter time to the first trial, indicating that exercise during race training had a greater effect on the time to the first trial, than the exercise accumulated during sales preparation in this cohort. The findings of Chapter 8, and Chapters 2, 3 and 7, provide further evidence of the association between exercise regimens during early training and future racing performance, as previously described using different outcomes of racing success in flat and jump racehorses (Verheyen *et al.* 2009; Ely *et al.* 2010).

Although the lack of association between yearling exercise and the time to the first trial may be due to insufficient numbers of horses with complete records in the study cohort (i.e. statistical power) to detect multiple risk factors, these results suggest that the possible benefits of current industry exercise regimens did not result in a shorter time taken to start in a trial. However, it should be noted that hand walking and walker time could not be adjusted for the effect of free exercise at pasture, as the time at pasture was not recorded for horses on stud farms that were not using exercise programmes. As free exercise at pasture has been shown to induce musculoskeletal changes in previous intervention studies (Barneveld and van Weeren 1999; Rogers *et al.* 2008b), pasture exercise may be an confounding factor that should be adjusted for. Whilst the inclusion of stud farm as a fixed effect adjusted for unmeasured factors at the stud farm level, such as pasture exercise, direct associations between free exercise at pasture and indicators of racing performance could not be quantified.

IMPLICATIONS FOR THE THOROUGHBRED INDUSTRY

This thesis highlighted that a trainer's decision to give a horse a voluntary interruption before the first trial results in delays in reaching the trial and race milestones. These results place further importance on the trainers' decisions, suggesting it may be better to keep horses in training until after the first trial. These findings would likely need much consideration by trainers. For instance, it may be impractical for trainers to keep horses in training until the first trial, due to owners' decisions, rotation of horses within the training stables, especially those with large numbers of horses in work, or it may not be economically viable. Furthermore, the most common reason for voluntary interruptions was to 'grow and strengthen', highlighting that these interruptions may be necessary to allow development of the musculoskeletal system as the horses are not yet able to withstand the demands of training. These results were supported by the finding that older horses were less likely to experience an interruption before the first trial, suggesting that they have already had time to mature before entering training. Perhaps trainers could consider waiting until a horse was deemed mature enough to progress through training to a trial, before they started the horse's training programme. It should be noted, however, that this thesis did not consider the effect of interruptions at different points in training (for example after the first interruption or starting in a trial or race) or multiple occurrences of interruptions. Furthermore, no assessment was made of the effects of keeping horses in training, when they would usually be assessed by trainer as needing an interruption, on musculoskeletal development or the risk of injury. Therefore, further information is required to establish if these findings are plausible modifications that could be implemented by trainers to increase the proportion of horses starting in a trial or race.

Alternatively, trainers could use their identification that a horse required an interruption as an early indicator of poor performance, detecting the horses that take longer and have less chance of reaching important milestones. The plans for such a horse could be adjusted accordingly, and the trainers' focus could be directed to those horses that are more likely to succeed. These findings need to be expanded, and future data-gathering studies should aim to establish the reasons behind voluntary interruptions, and at what stage the trainer decides a voluntary interruption is needed. Additionally, the thesis identified that a number of terms were used by trainers to describe the types of voluntary interruptions; however, whilst this has not been previously described, clarification of the specific terms, and potential overlap of terms, used by different trainers was not sought. Therefore, there is a need to determine how trainers make decisions regarding voluntary interruptions and their role in the training programme. For example, a trainer may already know that a horse will not race as a 2-year-old but the horse is in training for education. In support of this, trainers in New Zealand have previously indicated that one of the commonly reported reasons young horses were in training was for education (Bolwell *et al.* 2010).

With this in mind, future studies should collaborate with social scientists with the aim of understanding the reasons behind trainers' decisions and actions, and in assisting them with understanding that although some horses may require time, the effect of early exercise appears to be positive not negative. Developing an understanding of the biology, through increased communication of the research results, would help reduce the barriers to openness for change in training practice. Similarly, this information would provide further understanding of the clustering at trainer level, that was present in Chapters 2, 3 7 and 8 of this thesis, in agreement with other studies (Perkins *et al.* 2005a; Cogger *et al.* 2006). Much of the unexplained variance at the trainer-level has previously been attributed to differences in management and other factors not captured by the studies. With outcomes such as interruptions, trials and race starts, the trainers' decisions are likely to play a large role. Whilst a trial is an important milestone for a trainer, and performance during the early years has indicated longer racing careers in both Thoroughbred and Standardbred racehorses (Bailey *et al.* 1999; Tanner *et al.* 2011), epidemiological studies are required to determine the significance of reaching a trial or race at two years of age on career longevity and success.

Lastly, given the observed association between exercise during sales preparation and interruptions during training, any modifications aimed at reducing interruptions during training may lie with those responsible for the management of the horses before they reach the trainers. Recognition of the role studmasters could play is essential given that exercise in early life is apparently beneficial for horses, and if care and skill are practised, no harm is likely and has not been observed (Rogers *et al.* 2008a, b).

This thesis identified that the exercise regimens utilised within the breeding industry in New Zealand would be considered less strenuous than those employed in previous exercise intervention studies in foals (van Weeren and Barneveld 1999; Rogers *et al.* 2008b). The results of Chapter 5 indicated that studmasters were already tailoring preparations, which suggests that they may be willing to consider recommendations for modifications in order to enhance musculoskeletal development. Furthermore, these results highlighted large variation in the amount of exercise given to yearlings at the stud farms in the study. Therefore, there may be an opportunity to work with specific farms to modify their current regimen to increase or reduce the exercise that is being given, in order standardise exercise regimens across the industry.

However, the successful implementation of any changes would rely on not compromising the goal of the studmaster, which is clearly to raise and educate yearlings to produce a marketable sales yearling of high value. Furthermore, on some stud farms the use of exercise regimens may be labour intensive, which has implications for space and time to implement new protocols. However, given the role early management appears to play in the ability of a horse to train and race, the focus of production would need to alter to include long-term objectives that would improve the success of the Thoroughbred racing industry overall. There is clearly an opportunity to disseminate these research findings, in order to raise awareness the potential importance of incorporating exercise into sales preparations. Ensuring that the results of this thesis are widely disseminated would help to raise awareness of the various regimens utilised in the industry during sales preparation, so that practices may be altered or new practices adopted. As a result, there may be an increasing appreciation for a bigger goal of producing not only yearlings that are of high value, but that may go on to be more capable of training and racing in the future.

FUTURE DIRECTIONS

Before the traditions, beliefs and current practices of exercising young horses can be altered to design programmes that minimise wastage, further epidemiological studies are required to determine the extent of the effect of current industry regimens on different measures of racing success. Future studies of this nature should aim for larger sample populations, to ensure enough horses race, to enable analysis with enough power to detect statistically significant associations. The cohort of 2006 born horses utilised in Chapters 2 and 3 had sufficient horses to investigate the time to the first race, but this cohort of horses were followed only during one stage of their career, i.e. during race training. To enhance participation in the study and maintain interest over the period of data collection, the aims, recruitment process and progress of the project were disseminated to studmasters and trainers through industry media. Despite these attempts, following the 2007 born horses over two stages in their career inevitably led to more opportunities for losses from the study population, which resulted in few horses within the study population that reached the milestone of racing.

Alternative study designs that employ retrospective analysis of race records would allow larger numbers of horses to be studied, and various measures of racing performance and outcome measures of career longevity could be used. However, as there is currently no official record of training exercise within New Zealand, such studies would not be able to adjust for the confounding effects of training exercise or the unmeasured effects at trainer-level. The importance of adjusting for the exercise accumulated during training, when investigating other horse-level factors that affect racing performance, has been highlighted by the results of this thesis. Similarly, significant clustering at the trainer-level was present in a number of Chapters in this thesis, highlighting the need for future studies to consider enrolling more trainers rather than more horses within the same trainer. This would allow a better representation of the variation in training practices and would reduce the clustering of horses within trainers.

As highlighted by this thesis, there is a need to better understand the variations in management practices that occur between trainers. By including shared frailty terms in the models, trainers that were more or less likely to have horses with interruptions or horses starting in a trial or race (more or less likely to fail for each outcome) could be identified. Therefore, future studies that focus on specific trainers may provide more insight into training or management factors that are associated with injuries or indicators of performance. For example, it may be possible to determine the effects of the location of the trainer and the tracks the horses are trained on, the structure of the training programme and reasons behind training decisions. Such studies may be on a smaller scale, due to the high involvement of trainers that may be required, but they could employ explorative techniques such as multiple correspondence analysis (Fox 1993) to further explore the decision processes of trainers.

In an ideal world, information on the training programmes, such as exercise, interruptions and details of injuries, of horses in New Zealand would be officially recorded and entered into a database that, whilst maintaining confidentiality, would allow future research questions to be answered using accurate and detailed training information. Further, such a database would allow large, random samples of horses that would be representative of the wider population of racehorses in training. Given the increasing use of global positioning systems (GPS) for recording distances and speed in horses (Fonseca *et al.* 2010; Hampson *et al.* 2010) and the willingness of trainers that participated in this research, such a database would seem possible. However, given the discrepancies highlighted between this study and official databases of studbooks and racing data, it would seem that current methods used to collect information from trainers may not always be accurate, casting doubt on the potential success of a trainer-driven database of exercise data. A similar recommendation was stated in a previous epidemiological study of the health and performance of racehorses in New Zealand (Perkins 2005), for an official standardised record of training and racing injuries. It is likely that the success of such a database would rely on incentives for trainers to participate, perhaps through research extension to highlight the benefits of research and the potential gains to trainers as a result of becoming part of such projects. Previous studies have utilised the database maintained by the Hong Kong Jockey Club that contains information on all the horses in training (Lam *et al.* 2007a; Lam *et al.* 2007b) and although the Jockey Club in the USA are now officially capturing racing injury data (Anon 2007) and the injuries diagnosed on British racecourses are recorded in a database maintained by the British Horseracing Authority, such a database is yet to be implemented in New Zealand.

In New Zealand the critical factor is most likely the recording of data by trainers and studmasters in a consistent and longer-term manner. Although the data collected for this thesis could not be validated against another source, the need to record data as part of this project was met with enthusiasm by all those in the industry that were invited to take part. Throughout this project, a high level of interest, willingness, and competence to record detailed information was apparent, indicating that the members of the Thoroughbred industry are committed to be actively involved in finding answers to reduce its problems. As such, a high level of confidence should be placed in the capability of those in the industry that are willing to participate in such projects to collect its own data reliably, which can be used for the good of the industry.

This thesis identified that the type and amount of exercise yearlings were given during sales preparations varied and was associated with the occurrence of interruptions during training. There are several questions that arise from this thesis, which future studies should seek to answer. The most appropriate time to introduce exercise, such as during a sales preparation or whether exercise could be implemented (much) earlier, should be investigated. Intervention studies to determine the effects of implementing exercise regimens earlier on stud farms to the development of the yearling for sales, and the practicalities of such interventions, would be useful. Such studies would need to address the potentially limiting factor of studmasters willingness to take part in interventions, potential ethical considerations and the need for enough power to quantify the effects of the interventions. Further, this thesis highlighted a negative association with longer durations on the mechanical horse walker during sales preparation. There appears to be a lack of scientific data examining the effects of horse walkers on the development of the musculoskeletal system, for horses of any age, and this is an area that should be addressed. Further observational work should be directed towards quantifying the exercise distances that are accumulated by foals and yearlings whilst at pasture, and comparing yearlings that are destined for sales with those that remain at the stud farm until they begin race training; a question that was beyond the scope of the current thesis, but one that could be addressed through using GPS systems to record data whilst horses are at pasture.

This thesis did not attempt to identify what type of exercise and regimen is correct, and could be implemented on stud farms, to ensure yearlings are both educated for the sales and prepared for the future demands of training and racing. The results provide key data on the current industry practices, allowing comparison with previous experimental studies. The results of this thesis lay the foundation for further observational and intervention studies to investigate if exercise protocols can be developed and successfully implemented, as a proactive approach to reducing losses in the Thoroughbred racing industry.

REFERENCES

Anon (2007) Equine injury reporting system debuts at racetracks. Journal American Veterinary Medical Association News. http://www.avma.org/onlnews/javma/jul07/070715h.asp Accessed 4th April 2011.

Anon (2008) Wastage Discussion Paper. New Zealand Thoroughbred Racing. http://www.nzracing.co.nz/Documents/2475/Wastage%20Discussion%20Paper%202008.pdf. Accessed on 27th August 2008.

Anon (2010a) Return of mares press release. Irish Thoroughbred Breeders Association. http://www.itba.info/news.php?id=485 Accessed 4th March 2011.

Anon (2010b) *New Zealand Thoroughbred Racing Fact Book 2010*, New Zealand Thoroughbred Racing Inc., Welllington.

Anon (2011a) Karaka 2011 Sales Series - The Ups And Downs. In: *New Zealand Thoroughbred Breeders' Bulletin, Autumn 2011*, New Zealand Thoroughbred Breeders' Association. p 3.

Anon (2011b) Annual North American Registered Foal Crop. The Jockey Club 2011 Online Fact Book. http://www.jockeyclub.com/factbook.asp?section=2 Accessed 3rd March 2011.

Anon (2011c) Size of field and starts per horse. The Jockey Club 2011 Online Fact Book. http://www.jockeyclub.com/factbook.asp?section=1. Accessed on 4th March 2011.

Anon (2011d) International Cataloguing Standards and International Statistics 2011. The Jocky Club Information Systems Inc, in association with International federation of Horseracing Authorities. Kentucky, USA. www.ifhaonline.org/standardsBook.asp.

Anon (2011e) Amended Rules of Racing. New Zealand Thoroughbred Racing Inc. Wellington, New Zealand. www.nzracing.co.nz/About/RulesDirectivesPolicies.aspx.

Anthenill, L.A., Stover, S.M., Gardner, I.A. and Hill, A.E. (2007) Risk factors for proximal sesamoid bone fractures associated with exercise history and horseshoe characteristics in Thoroughbred racehorses. *Am. J. vet. Res.* **68**, 760-771.

Arrighi, H.M. and Hertz-Picciotto, I. (1994) The Evolving Concept of the Healthy Worker Survivor Effect. *Epidemiology* **5**, 189-196.

Bailey, C.J., Reid, S.W., Hodgson, D.R., Suann, C.J. and Rose, R.J. (1997a) Risk factors associated with musculoskeletal injuries in Australian thoroughbred racehorses. *Pre. vet. Med.* **32**, 47-55.

Bailey, C.J., Rose, R.J., Reid, S.W.J. and Hodgson, D.R. (1997b) Wastage in the Australian Thoroughbred racing industry: A survey of Sydney trainers. *Aust. vet. J.* **75**, 64-66.

Bailey, C.J., Reid, S.W., Hodgson, D.R., Bourke, J.M. and Rose, R.J. (1998) Flat, hurdle and steeple racing: risk factors for musculoskeletal injury. *Equine vet. J.* **30**, 498-503.

Bailey, C.J., Reid, S.W., Hodgson, D.R. and Rose, R.J. (1999) Factors associated with time until first race and career duration for Thoroughbred racehorses. *Am. J. vet. Res.* **60**, 1196-1200.

Barneveld, A. and van Weeren, P.R. (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine. vet. J., Suppl.* **31**, 112-119.

Bathe, A.P. (1994) 245 fractures in Thoroughbred racehorses: results of a 2year prospective study in Newmarket. . *Procc. Am. Assoc. Eq. Prac.* **40**, 275-276.

Bell, R.A., Nielsen, B.D., Waite, K., Rosenstein, D. and Orth, M. (2001) Daily access to pasture turnout prevents loss of mineral in the third metacarpus of Arabian weanlings. *J. Anim. Sci.* **79**, 1142-1150.

Birch, H.L., McLaughlin, L., Smith, R.K. and Goodship, A.E. (1999) Treadmill exercise-induced tendon hypertrophy: assessment of tendons with different mechanical functions. *Equine. vet. J., Suppl.* **30**, 222-226.

Boden, L.A., Charles, J.A., Slocombe, R.F., Sandy, J.R., Finnin, P.J., Morton, J.M. and Clarke, A.F. (2005) Sudden death in racing thoroughbreds in Victoria, Australia. *Equine vet. J.* **37**, 269-271.

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Slocombe, R.F. and Clarke, A.F. (2006) Risk of fatality and causes of death of Thoroughbred horses associated with racing in Victoria, Australia: 1989-2004. *Equine vet. J.* **38**, 312-318.

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Clarke, A.F. and Slocombe, R.F. (2007a) Risk factors for Thoroughbred racehorse fatality in flat starts in Victoria, Australia (1989-2004). *Equine vet. J.* **39**, 430-437.

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Clarke, A.F. and Slocombe, R.F. (2007b) Risk factors for Thoroughbred racehorse fatality in jump starts in Victoria, Australia (1989-2004). *Equine vet. J.* **39**, 422-428.

Bolwell, C.F., Russell, L.J. and Rogers, C.W. (2010) A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comp. Exerc. Physiol.* **7**, 37-42.

Boston, R.C. and Nunamaker, D.M. (2000) Gait and speed as exercise components of risk factors associated with onset of fatigue injury of the third metacarpal bone in 2-year-old Thoroughbred racehorses. *Am. J. vet. Res.* **61**, 602-608.

Boyle, G., Guthrie, G.A. and Gorton, l. (2007) My Kingdom for a Horse: Resolving Conflicts of Interest in Asset Management.

http://papers.ssrn.com/sol3/papers.cfm?abstract_id=938550 (accessed June 2008). Social Science Electronic Publishing, Inc.

Brama, P.A.J., Tekoppele, J.M., Bank, R.A., Barneveld, A., Firth, E.C. and Weeren, P.R.v. (2000a) The influence of strenuous exercise on collagen characteristics of articular cartilage in Thoroughbreds age 2 years. *Equine vet. J.* **32**, 551-554.

Brama, P.A.J., Tekoppele, J.M., Bank, R.A., Barneveld, A. and Van Weeren, P.R. (2000b) Functional adaptation of equine articular cartilage: the formation of regional biochemical characteristics up to age one year. *Equine vet. J.* **32**, 217-221.

Brama, P.A.J., Holopainen, J., van Weeren, P.R., Firth, E.C., Helminen, H.J. and Hyttinen, M.M. (2009) Influence of exercise and joint topography on depth-related spatial distribution of proteoglycan and collagen content in immature equine articular cartilage. *Equine vet. J.* **41**, 557-563.

Buckingham, S. and Jeffcott, L.B. (1990) Shin soreness: A survey of Thoroughbred trainers and racetrack veterinarians. *Aust. equine Vet.* **8**, 148.

Carrier, T.K., Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Read, D.H. and Ardans, A.A. (1998) Association between long periods without high-speed workouts and risk of complete humeral or pelvic fracture in Thoroughbred racehorses: 54 cases (1991-1994). *J. Am. vet. med. Ass.* **212**, 1582-1587.

Cherdchutham, W., Becker, C., Smith, R.K.W., Barneveld, A. and van Weeren, P.R. (1999) Age-related changes and effect of exercise on the superficial molecular composition of immature equine superficial digital flexor tendons. *Equine. vet. J., Suppl.* **31**, 86-93.

Cogger, N., Perkins, N., Hodgson, D.R., Reid, S.W.J. and Evans, D.L. (2006) Risk factors for musculoskeletal injuries in 2-year old Thoroughbred racehorses. *Pre. vet. Med.* **74**, 36-43.

Cogger, N., Evans, D.L., Hodgson, D.R., Reid, S.W. and Perkins, N. (2008a) Incidence rate of musculoskeletal injuries and determinants of time to recovery in young Australian Thoroughbred racehorses. *Aust. vet. J.* **86**, 473-480.

Cogger, N., Perkins, N., Hodgson, D., Reid, S. and Evans, D. (2008b) Profiling training preparation in young Australian Thoroughbred racehorses. *Aust. vet. J.* **86**, 419-424.

Cohen, N.D., Mundy, G.D., Peloso, J.G., Carey, V.J. and Amend, N.K. (1999) Results of physical inspection before races and race-related characteristics and their association with musculoskeletal injuries in Thoroughbreds during races. *J. Am. Vet. Med. Assoc.* **215**, 654-661.

Cohen, N.D., Berry, S.M., Peloso, J.G., Mundy, G.D. and Howard, I.C. (2000) Association of high-speed exercise with racing injury in thoroughbreds. *J. Am. vet. med. Ass.* **216**, 1273-1278.

Cornelissen, W., van Weeren, P.R., Ederveen, A.G.H. and Barneveld, A. (1999) Influence of exercise on bone mineral density of immature cortical and trabecular bone of the equine metacarpus and proximal sesamoid bone. *Equine. vet. J., Suppl.* **31**, 79 - 85.

Cruz, A.M., Poljak, Z., Filejski, C., Lowerison, M.L., Goldie, K., Martin, S.W. and Hurtig, M.B. (2007) Epidemiologic characteristics of catastrophic musculoskeletal injuries in Thoroughbred racehorses. *Am. J. vet. Res.* **68**, 1370-1375.

Doube, M., Firth, E.C. and Boyde, A. (2007) Variations in articular calcified cartilage by site and exercise in the 18-month-old equine distal metacarpal condyle. *Osteoarthr. Cartilage* **15**, 1283-1292.

Dykgraaf, S., Firth, E.C., Rogers, C.W. and Kawcak, C.E. (2008) Effects of exercise on chondrocyte viability and subchondral bone sclerosis in the distal third metacarpal and metatarsal bones of young horses. *Vet. J.* **178**, 53-61.

Dyson, P.K., Jackson, B.F., Pfeiffer, D.U. and Price, J.S. (2008) Days lost from training by two- and three-year-old Thoroughbred horses: A survey of seven UK training yards. *Equine vet. J.* **40**, 650-657.

Ely, E.R., Verheyen, K.L. and Wood, J.L. (2004) Fractures and tendon injuries in National Hunt horses in training in the UK: a pilot study. *Equine vet. J.* **36**, 365-367.

Ely, E.R., Avella, C.S., Price, J.S., Smith, R.K.W., Wood, J.L.N. and Verheyen, K.L.P. (2009) Descriptive epidemiology of fracture, tendon and suspensory ligament injuries in National Hunt racehorses in training. *Equine vet. J.* **41**, 372-378.

Ely, E.R., Price, J.S., Smith, R.K., Wood, J.L.N. and Verheyen, K.L.P. (2010) The effect of exercise regimens on racing performance in National Hunt racehorses. *Equine vet. J.* **42**, 624-629.

Estberg, L., Gardnerb, I.A., Stoverc, S.M., Johnsona, B.J., Case, J.T. and Ardansa, A. (1995) Cumulative racing-speed exercise distance clusteras a risk factor for fatal musculoskeletal injury:in Thoroughbred racehorses in California. *Pre. vet. Med.* **24** 253-263.

Estberg, L., Stover, S.M., Gardner, I.A., Drake, C.M., Johnson, B. and Ardans, A. (1996a) High-speed exercise history and catastrophic racing fracture in Thoroughbreds. *Am. J. vet. Res.* **57**, 1549-1555.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Case, J.T., Ardans, A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J. and Woods, L.W. (1996b) Fatal musculoskeletal injuries incurred during racing and training in thoroughbreds. *J. Am. vet. med. Ass.* **208**, 92-96.

Estberg, L., Gardner, I.A., Stover, S.M. and Johnson, B.J. (1998a) A case-crossover study of intensive racing and training schedules and risk of catastrophic musculoskeletal injury and lay-up in California thoroughbred racehorses. *Pre. vet. Med.* **33**, 159-170.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Jack, R.A., Case, J.T., Ardans, A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J. and Woods, L. (1998b) Relationship between race start characteristics and risk of catastrophic injury in thoroughbreds: 78 cases (1992). *J. Am. vet. med. Ass.* **212**, 544-549.

Fennessy, P.F. (2010) An overview of the New Zealand Thoroughbred Industry. *Proc. N. Z. Soc. Anim. Prod.* **70** 137-139.

Firth, E.C., van Weeren, P.R., Pfeiffer, D.U., Delahunt, J. and Barneveld, A. (1999) Effect of age, exercise and growth rate on bone mineral density (BMD) in third carpal bone and distal radius of Dutch Warmblood foals with osteochondrosis. *Equine. vet. J., Suppl.* **31**, 74 - 78.

Firth, E.C. (2004) Problems in quantifying bone response to exercise in horses: a review. *N.Z. vet. J.* **52**, 216-229.

Firth, E.C., Rogers, C.W., Perkins, N.R., Anderson, B.H. and Grace, N.D. (2004) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 1. Study design, and clinical, nutritional, radiological and histological observations. *N.Z. vet. J.* **52**, 261-271.

Firth, E.C. and Rogers, C.W. (2005a) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 7. Bone and articular cartilage response in the carpus. *N.Z. vet. J.* **53**, 113-122.

Firth, E.C. and Rogers, C.W. (2005b) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. Conclusions. *N.Z. vet. J.* **53**, 377-383.

Firth, E.C., Rogers, C.W., Doube, M. and Jopson, N.B. (2005) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 6. Bone parameters in the third metacarpal and third metatarsal bones. *N.Z. vet. J.* **53**, 101-112.

Firth, E.C. (2006) The response of bone, articular cartilage and tendon to exercise in the horse. *J. Anat.* **208**, 513-526.

Fonseca, R.G., Kenny, D.A., Hill, E.W. and Katz, L.M. (2010) The association of various speed indices to training responses in Thoroughbred flat racehorses measured with a global positioning and heart rate monitoring system. *Equine vet. J.* **42**, 51-57.

Fox, M.F. (1993) A Multi-dimensional Exploration of the Decision Process Using Correspondence Analysis. *Marketing Bulletin* **4**, 30-42.

Gibbs, P.G. and Cohen, N.D. (2001) Early management of race-bred weanlings and yearlings on farms. *J. Equine vet. Sci.* **21**, 279-283.

Goodship, A.E. (1993) The pathophysiology of flexor tendon injury in the horse. *Equine Vet. Educ.* **5**, 23-29.

Gunter, K., Baxter-Jones, A.D.G., Mirwald, R.L., Almstedt, H., Fuchs, R.K., Durski, S. and Snow, C. (2008) Impact Exercise Increases BMC During Growth: An 8-Year Longitudinal Study. *J. Bone Miner. Res.* **23**, 986-993.

Hampson, B. and Pollitt, C. (2008) GPS analysis of activity of domestic mares and new born foals. *6th International Conference on Equine Locomotion*, 17.

Hampson, B.A., Morton, J.M., Mills, P.C., Trotter, M.G., Lamb, D.W. and Pollitt, C.C. (2010) Monitoring distances travelled by horses using GPS tracking collars. *Aust. vet. J.* **88**, 176-181.

Helminen, H.J., Hyttinen, M.M., Lammi, M.J., Arokoski, J.P.A., Lapvetelainen, T., Jurvelin, J., Kiviranta, I. and Tammi, M.I. (2000) Regular joint loading in youth assists in the establishment and strengthening of the collagen network of articular cartilage and contributes to the prevention of osteoarthrosis later in life: a hypothesis. *J. Bone Miner. Metab.* **18**, 245-257.

Hernandez, J., Hawkins, D.L. and Scollay, M.C. (2001) Race-start characteristics and risk of catastrophic musculoskeletal injury in Thoroughbred racehorses. *J. Am. vet. med. Ass.* **218**, 83-86.

Hill, A.E., Gardner, I.A., Carpenter, T.E. and Stover, S.M. (2004) Effects of injury to the suspensory apparatus,exercise, and horseshoe characteristics on the risk of lateral condylar fracture and suspensory apparatus failure in forelimbs of Thoroughbred racehorses. *Am. J. vet. Res.* **65**, 1508.

Hind, K. and Burrows, M. (2007) Weight-bearing exercise and bone mineral accrual in children and adolescents: A review of controlled trials. *Bone* **40**, 14-27.

Hiney, K.M., Nielsen, B.D., Rosenstein, D., Orth, M.W. and Marks, B.P. (2004) High-intensity exercise of short duration alters bovine bone density and shape. *J. Anim. Sci.* **82**, 1612-1620.

Hoekstra, K., Nielsen, B., Orth, M.W., Rosenstien, D., Schott, H.C. and Shelle, J.E. (1999) Comparision of bone mineral content and bone metabolism in stall-versus pasture-reared horses. *Equine. vet. J., Suppl.* **30**, 601-604.

Jeffcott, L.B., Rossdale, P.D., Freestone, J., Frank, C.J. and Towers-Clark, P.F. (1982) An assessment of wastage in Thoroughbred racing from conception to 4 years of age. *Equine vet. J.* **14**, 185-198.

Kawcak, C.E., McIlwraith, C.W. and Firth, E.C. (2010) Effects of early exercise on metacarpophalangeal joints in horses. *Am. J. vet. Res.* **71**, 405-411.

Kim, W., Kawcak, C.E., McIlwraith, C.W., Firth, E.C., McArdle, B.H. and Broom, N.D. (2009) Influence of early conditioning exercise on the development of gross cartilage defects and swelling behavior of cartilage extracellular matrix in the equine midcarpal joint. *Am. J. vet. Res.* **70**, 589-598.

Kingston, J.K., Soppet, G.M., Rogers, C.W. and Firth, E.C. (2006) Use of a global positioning and heart rate monitoring system to assess training load in a group of Thoroughbred racehorses. *Equine vet. J.* **38**, 106-109.

Knowles, T.G. and Broom, D.M. (1990) Limb bone strength and movement in laying hens from different housing systems. *Vet. Rec.* **126**, 354-356.

Kurvers, C.M.H., van Weeren, P.R., Rogers, C.W. and van Dierendonck, M.C. (2006) Quantification of spontaneous locomotion activity in foals kept in pastures under various management conditions. *Am. J. vet. Res.* **67**.

Lam, K.H., Parkin, T.D.H., Riggs, C.M. and Morgan, K.L. (2007a) Descriptive analysis of retirement of Thoroughbred racehorses due to tendon injuries at the Hong Kong Jockey Club (1992-2004). *Equine vet. J.* **39**, 143-148.

Lam, K.K.H., Parkin, T.D.H., Riggs, C.M. and Morgan, K.L. (2007b) Evaluation of detailed training data to identify risk factors for retirement because of tendon injuries in Thoroughbred racehorses. *Am. J. vet. Res.* **68**, 1188-1197.

Lepeule, J., Bareille, N., Robert, C., Ezanno, P., Valette, J.P., Jacquet, S., Blanchard, G., Denoix, J.M. and Seegers, H. (2009) Association of growth, feeding practices and exercise conditions with the prevalence of Developmental Orthopaedic Disease in limbs of French foals at weaning. *Pre. vet. Med.* **89**, 167-177.

Lindner, A. and Dingerkus, A. (1993) Incidence of training failure among Thoroughbred horses at Cologne, Germany. *Pre. vet. Med.* **16**, 85-94.

Marchant, J.N. and Broom, D.M. (1996) Effects of dry sow housing conditions on muscle weight and bone strength. *Anim. Sci.* **62**, 105-113.

McCarthy, G. (2009) Analysis of supply chain wastage in the Thoroughbred and Harness racing codes. In: *The foundation bulletin. Volumne 14. Number 4*, New Zealand Equine Research Foundation, Palmerston North, New Zealand.

McIlwraith, C.W. (2000) Global Equine Research Alliance to reduce musculoskeletal injury in the equine athlete. *Equine. vet. Educ.* **12**, 260-262.

McKay, H. and Smith, E. (2008) Winning the battle against childhood physical inactivity: The key to bone strength? *J. Bone Miner. Res.* **23**, 980-985.

Mckee, L. (1995) Update on racing fatalities in the UK. *Equine. vet. Educ.* **7**, 202-204.

Moffat, P.A., Firth, E.C., Rogers, C.W., Smith, R.K.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., McIlwraith, C.W. and van Weeren, P.R. (2008) The influence of exercise during growth on ultrasonographic parameters of the superficial digital flexor tendon of young thoroughbred horses. *Equine vet. J.* **40**, 136-140.

More, S.J. (1999) A longitudinal study of racing Thoroughbreds: performance during the first years of racing. *Aust. vet. J.* **77**, 105-112.

Murray, R.C., Branch, M.V., Dyson, S.J., Parkin, T.D.H. and Goodship, A.E. (2007) How does exercise intensity and type affect equine distal tarsal subchondral bone thickness? *J. Appl. Physiol.* **102**, 2194-2200.

Nicholson, C.L. and Firth, E.C. (2010) Assessment of bone response to conditioning exercise in the radius and tibia of young Thoroughbred horses using pQCT. *J. Musculoskelet. Neuron. Interact.* **10**, 199-206.

Nielsen, B., Potter, G.D., Morris, R.S., Odom, T.W., Senor, D.M., Reynolds, J.A., Smith, W.B. and Martin, M.T. (1997) Changes in the third metacarpal bone and frequency of bone injuries in young quarter horses during race training - Observations and theoretical considerations. *J. Equine vet. Sci.* **17**.

Nordstrom, A., Karlsson, C., Nyquist, F., Olsson, T., Nordstrom, P. and Karlsson, M. (2005) Bone Loss and Fracture Risk After Reduced Physical Activity. *J. Bone Miner. Res.* **20**, 202-207.

Nugent, G.E., Law, A.W., Wong, E.G., Temple, M.M., Bae, W.C., Chen, A.C., Kawcak, C.E. and Sah, R.L. (2004) Site- and exercise-related variation in structure and function of cartilage from equine distal metacarpal condyle. *Osteoarthr. Cartilage* **12**, 826-833.

O'Brien, E., Stevens, K.B., Pfeiffer, D.U., Hall, J. and Marr, C.M. (2005) Factors associated with the wastage and achievements in competition of event horses registered in the United Kingdom. *Vet. Rec.* **157**, 9-13.

Olivier, A., Nurton, J.P. and Guthrie, A.J. (1997) An epizoological study of wastage in Thoroughbred racehorses in Gauteng, South Africa. *J. S. Afr. vet. Ass.* **68**, 125-129.

Otterness, I., Eskra, J., Bliven, M., Shay, A., Pelletier, J. and Milici, A. (1998) Exercise protects against articular cartilage degeneration in the hamster. *Arthritis Rheum.* **41**, 2068-2076.

Parkin, T.D., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004a) Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine vet. J.* **36**, 521-526.

Parkin, T.D., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004b) Horse-level risk factors for fatal distal limb fracture in racing Thoroughbreds in the UK. *Equine vet. J.* **36**, 513-519.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004c) Risk of fatal distal limb fractures among thoroughbreds involved in the five types of racing in the United Kingdom. *Vet. Rec.* **154**, 493-497.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.M., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004d) Risk factors for fatal lateral condylar fracture of the third metacarpus/metatarsus in UK racing. *Equine vet. J.* **37**, 192-199.

Parkin, T.D.H. and Rossdale, P.D. (2006) Epidemiology of equine performance wastage: importance of analysing facts and implementing their message in management. *Equine vet. J.* **38**, 98-100.

Parkin, T.D.H. (2007) Havemeyer workshop report - Epidemiology of training and racing injuries. *Equine vet. J.* **39**, 466-469.

Parkin, T.D.H. (2008) Epidemiology of Racetrack Injuries in Racehorses. *Vet. Clin. N. Am.: Equine Pract.* **24**, 1-19.

Patterson-Kane, J.C., Parry, D.A.D., Goodship, A.E. and Firth, E.C. (1997a) Exercise modifies the age-related change in crimp pattern in the core region of the equine superficial digital flexor tendon. *N.Z. vet. J.* **45**, 135-139.

Patterson-Kane, J.C., Wilson, A.M., Firth, E.C., Parry, D.A. and Goodship, A.E. (1997b) Comparison of collagen fibril populations in the superficial digital flexor tendons of exercised and nonexercised thoroughbreds. *Equine vet. J.* **29**, 121-125.

Patterson-Kane, J.C. and Firth, E.C. (2009) The pathobiology of exercise-induced superficial digital flexor tendon injury in Thoroughbred racehorses. *Vet. J.* **181**, 79-89.

Peloso, J.G., Mundy, G.D. and Cohen, N.D. (1994) Prevalence of, and factors associated with, musculoskeletal racing injuries of thoroughbreds. *J. Am. Vet. Med. Assoc.* **204**, 620-626.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004a) Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *N.Z. vet. J.* **53**, 59-68.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2004b) Profiling the New Zealand Thoroughbred racing industry. 2. Conditions interfering with training and racing. *N.Z. vet. J.* **53**, 69-76.

Perkins, N.R. (2005) *Epidemiology of health and performance in New Zealand racehorses*, PhD Thesis, Massey University, Palmerston North.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2005a) Risk factors for injury to the superficial digital flexor tendon and suspensory apparatus in Thoroughbred racehorses in New Zealand. *N.Z. vet. J.* **53**, 184-192.

Perkins, N.R., Reid, S.W.J. and Morris, R.S. (2005b) Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *N.Z. vet. J.* **53**, 171-183.

Pinchbeck, G.L., Clegg, P.D., Proudman, C.J., Stirk, A., Morgan, K.L. and French, N.P. (2004) Horse injuries and racing practices in National Hunt racehorses in the UK: the results of a prospective cohort study. *Vet. J.* **167**, 45-52.

Ramzan, P.H.L. and Palmer, L. (2011) Musculoskeletal injuries in Thoroughbred racehorses: A study of three large training yards in Newmarket, UK (2005-2007). *Vet. J.* **187**, 325-329.

Raub, R.H., Jackson, S.G. and Baker, J.P. (1989) The effect of exercise on bone growth and development in weanling horses. *J. Anim. Sci.* **67**, 2508-2514.

Reed, S.R., Jackson, B.F., Mc Ilwraith, C.W., Wright, I.M., Pilsworth, R., Knapp, S., Wood, J.L.N., Price, J.S. and Verheyen, K.L.P. (2011) Descriptive epidemiology of joint injuries in Thoroughbred racehorses in training. *Equine vet. J.*, 10.1111/j.2042-3306.2010.00352.x.

Rietbroek, N.J., Dingboom, E.G., Schuurman, S.O., Wiel, E., Eizema, K. and Everts, M.E. (2007) Effect of exercise on development of capillary supply and oxidative capacity in skeletal muscle of horses. *Am. J. vet. Res.* **68**, 1226-1231.

Rogers, C.W. and Firth, E.C. (2004) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 2. Measurement error and effect of training stage on the relationship between objective and subjective criteria of training workload. *N.Z. vet. J.* **52**, 272 - 279.

Rogers, C.W., Gee, E.K. and Firth, E.C. (2007) A cross-sectional survey of Thoroughbred stud farm management in the North Island of New Zealand. *N.Z. vet. J.* **55**, 302-307.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008a) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2 and 3 year old racing careers. *Equine vet. J.* **40**, 119-127.

Rogers, C.W., Firth, E.C., McIlwraith, C.W., Barneveld, A., Goodship, A.E., Kawcak, C.E., Smith, R.K.W. and van Weeren, P.R. (2008b) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine vet. J.* **40**, 111-118.

Rogers, C.W., Kidd, L. and Firth, E.C. (2010) Linear and temporal changes in the trot of 2-year-old Thoroughbred racehorses in relation to early exercise and race training. *Comp. Exerc. Physiol.* **7**, 65-71.

Rossdale, P.D., Hopes, R., Digby, N.J. and offord, K. (1985) Epidemiological study of wastage among racehorses 1982 and 1983. *Vet. Rec.* **116**, 66-69.

Ruab, R.H., Jackson, S.G. and Baker, J.P. (1989) The effect of exercise on bone growth and development in weanling horses. *J. Anim. Sci.* **67**, 2508-2514.

Shipov, A., Sharir, A., Zelzer, E., Milgram, J., Monsonego-Ornan, E. and Shahar, R. (2010) The influence of severe prolonged exercise restriction on the mechanical and structural properties of bone in an avian model. *Vet. J.* **183**, 153-160.

Singer, J.D. and Willet, J.B. (2003) *Applied Longitudinal Data Analysis: Modeling Change and Event Occurence*, Oxford University Press, Inc, Oxford, New York.

Smith, R.K., Birch, H., Patterson-Kane, J., Firth, E.C., Williams, L., Cherdchutham, W., van Weeren, W.R. and Goodship, A.E. (1999) Should equine athletes commence training during skeletal development?: changes in tendon matrix associated with development, ageing, function and exercise. *Equine. vet. J., Suppl.* **30**, 201-209.

Smith, R.K.W. and Goodship, A.E. (2008) The Effect of Early Training and the Adaptation and Conditioning of Skeletal Tissues. *Vet. Clin. N. Am.: Equine Pract.* **24**, 37-51.

Stanley, R.L., Edwards, L.J., Goodship, A.E., Firth, E.C. and Patterson-Kane (2008) Effects of exercise on tenocyte cellularity and tenocyte nuclear morphology in immature and mature equine digital tendons. *Equine vet. J.* **40**, 141-146.

Stephen, J.O., White, N.A., McCormick, W.H., Cowles, R.R. and Corley, K.T.T. (2003) Risk factors and prevalence of injuries in horses during various types of steeplechase races. *J. Am. vet. med. Ass.* **223**, 1788-1790.

Stowers, N.L., Rogers, C.W. and Hoskin, S.O. (2009) Management of weanlings on commercial Thoroughbred studs farms in the North Island of New Zealand. *Proc. N. Z. Soc. Anim. Prod.* **69**, 4-9.

Tabar-Rodriguez, J.J., Cruz, A.M., Monteith, G., Gordon, K. and Hurtig, M.B. (2009) Use of quantitative ultrasonography for noninvasive surveillance of the third metacarpal bone in racing and training Thoroughbreds. *Am. J. vet. Res.* **70**, 1484-1493.

Takahashi, T., Kasashima, Y. and Ueno, Y. (2004) Association between race history and risk of superficial digital flexor tendon injury in Thoroughbred racehorses. *J. Am. Vet. Med. Assoc.* **225**, 90-93.

Tanner, J.C., Rogers, C.W. and Firth, E.C. (2011) The relationship of training milestones with racing success in a population of Standardbred horses in New Zealand. *N.Z. vet. J.* **59**, 331-336.

van de Lest, C.H.A., Brama, P.A.J. and van Weeren, P.R. (2002) The influence of exercise on the composition of developing equine joints. *Biorheology* **39**, 183-191.

van den Hoogen, B.M., van den Lest, C.H.A., van Weeren, P.R., van Golde, L.M.G. and Barneveld, A. (1999) Effect of exercise on the proteoglycan metabolism of articular cartilage in growing foals. *Equine. vet. J., Suppl.* **31**, 62-66.

van Weeren, P.R. and Barneveld, A. (1999) Study design to evaluate the influence of exercise on the development of the musculoskeletal system of foals up to age 11 months. *Equine. vet. J., Suppl.* **31**, 4-8.

van Weeren, P.R., Brama, P.A.J. and Barneveld, A. (2000) Exercise at Young Age May influence the final quality of the equine musculoskeletal system. *Proc. Am. Ass. equine Practnrs.* **40**, 29-35.

van Weeren, P.R., Firth, E.C., Brommer, H., Rogers, C.W., DeGroot, J. and Brama, P.A.J. (2008) Early exercise advances the maturation of glycosaminoglycans and collegen in the extracellular matrix in the horse. *Equine vet. J.* **40**, 128-135.

Verheyen, K., Price, J., Lanyon, L. and Wood, J. (2006a) Exercise distance and speed affect the risk of fracture in racehorses. *Bone* **39**, 1322-1330.

Verheyen, K.L. and Wood, J.L. (2004) Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. *Equine vet. J.* **36**, 167-173.

Verheyen, K.L., Henley, W.E., Price, J.S. and Wood, J.L. (2005) Training-related factors associated with dorsometacarpal disease in young Thoroughbred racehorses in the UK. *Equine vet. J.* **37**, 442-448.

Verheyen, K.L., Newton, J.R., Price, J.S. and Wood, J.L. (2006b) A case-control study of factors associated with pelvic and tibial stress fractures in Thoroughbred racehorses in training in the UK. *Pre. vet. Med.* **74**, 21-35.

Verheyen, K.L.P., Price, J.S. and Wood, J.L.N. (2007) Fracture rate in Thoroughbred racehorses is affected by dam age and parity. *Vet. J.* **174**, 295-301.

Verheyen, K.L.P., Price, J.S. and Wood, J.L.N. (2009) Exercise during training is associated with racing performance in Thoroughbreds. *Vet. J.* **181**, 43-47.

Warden, S.J., Fuchs, R.K., Castillo, A.B., Nelson, I.R. and Turner, C.H. (2007) Exercise when young provides lifelong benefits to bone structure and strength. *J. Bone Miner. Res.* **22**, 251-259.

Weiler, U., Salloum, B.A. and Claus, R. (2006) Influence of short term confinement and exercise on tibia development in growing pigs. *J. vet. Med. A* **53**, 450 - 455.

Williams, R.B., Harkins, L.S., Hammond, C.J. and Wood, J.L. (2001) Racehorse injuries, clinical problems and fatalities recorded on British racecourses from flat racing and National Hunt racing during 1996, 1997 and 1998. *Equine vet. J.* **33**, 478-486.

Wilsher, S., Allen, W.R. and Wood, J.L. (2006) Factors associated with failure of thoroughbred horses to train and race. *Equine vet. J.* **38**, 113-118.

Wilson, J.H., Jensen, R.C. and Robinson, R.A. (1996) Racing injuries of two year old Thoroughbreds and Quarter horses. *Pferdeheilk.* **12**, 582-587.

Wood, J.L., Eastment, J., Harkins, L. and Rogers, K. (2002) Towards better welfare of Racehorses. Final Report. Animal Health Trust, Newmarket. pp1-15.

Yates, J., Mellor, D.J., Reid, S.W.J. and Parkin, T.D.H. (2009) Identifying the major causes of loss in the Thoroughbred breeding industry. In: *ISVEE 12: Proceedings of the 12th Symposium of the International Society for Veterinary Epidemiology and Economics*, Durban, South Africa.

APPENDIX G

Statements of contribution to doctoral thesis containing publications.

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Charlotte Bolwell…………………………………………………

Name/Title of Principal Supervisor: Dr Chris Rogers……………………………

Name of Published Paper: Risk factors for interruptions occurring before the first trial start of 2-year-old Thoroughbred racehorses in training……….

In which Chapter is the Published Work: Chapter 2……………………………….

What percentage of the Published Work was contributed by the candidate: 80%

C Bolwell
Candidate's Signature

22/06/2011
Date

Principal Supervisor's signature

22/06/2011
Date

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Charlotte Bolwell……………………………………………………

Name/Title of Principal Supervisor: Dr Chris Rogers……………………………

Name of Published Paper: The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses………

In which Chapter is the Published Work: Chapter 3……………………………

What percentage of the Published Work was contributed by the candidate: 80%

CBolwell
____
Candidate's Signature

22/06/2011
Date

____
Principal Supervisor's signature

22/06/2011
Date

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Charlotte Bolwell…………………………………………………

Name/Title of Principal Supervisor: Dr Chris Rogers……………………………

Name of Published Paper: Management and exercise of Thoroughbred yearlings during preparation for yearling sales: a cross-sectional study…..

In which Chapter is the Published Work: Chapter 4…………………………….

What percentage of the Published Work was contributed by the candidate: 80%

CBolwell
Candidate's Signature

22/06/2011
Date

Principal Supervisor's signature

22/06/2011
Date

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Charlotte Bolwell…………………………………………………

Name/Title of Principal Supervisor: Dr Chris Rogers……………………………

Name of Published Paper: Exercise in Thoroughbred yearlings during sales preparation: A cohort study…………………………………………………………………..

In which Chapter is the Published Work: Chapter 5……………………………

What percentage of the Published Work was contributed by the candidate: 80%

CBolwell

Candidate's Signature

22/06/2011

Date

Principal Supervisor's signature

22/06/2011

Date

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Charlotte Bolwell…………………………………………………

Name/Title of Principal Supervisor: Dr Chris Rogers……………………………

Name of Published Paper: Associations between yearling exercise and interruptions to race training in Thoroughbred racehorses…………………….

In which Chapter is the Published Work: Chapter 7……………………………

What percentage of the Published Work was contributed by the candidate: 80%

CBolwell

Candidate's Signature

22/06/2011
Date

Principal Supervisor's signature

22/06/2011
Date