THE ASSOCIATION OF 2-YEAR-OLD TRAINING MILESTONES WITH RACING PERFORMANCE IN STANDARDBRED AND THOROUGHBRED HORSES IN NEW ZEALAND

A thesis submitted in partial fulfilment of the requirements of the requirements for the degree Master of Science in Animal Science

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ABSTRACT

This thesis includes epidemiological studies conducted to measure the association between the attainment of training milestones by Standardbred and Thoroughbred horses at two years of age and subsequent racing performance. Additionally, the quantification of racing performance is comprehensively reviewed to identify robust parameters to measure racing success.

Retrospective records of all Standardbred and Thoroughbred horses born in the 2001/2002 season were obtained and analysed separately. The three training milestones used were: registered with a trainer, trialled and raced. Racing performance outcomes were: length of career, in number of years raced and number of race starts, and total earnings.

Horses that were registered with a trainer, trialled, or raced as two-year-olds had more race starts and more years racing than those horses that achieved the milestones at a later age. Additionally, horses that achieved the training milestones as two-year-olds were more likely to win or be placed (first-to-third) in a race, and earned more money than horses that achieved the milestones at a later age. Approximately one-third of the horses born in both the Standardbred and Thoroughbred foal crop failed to achieve the first training milestone indicating high levels of wastage. The results of this thesis suggest that there is a strong association between the attainment of training milestones at two years old with positive career outcomes.

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LIST OF ABBREVIATIONS

HRNZ	Harness Racing New Zealand
NZTR	New Zealand Thoroughbred Racing
IQR	Interquartile range
LRS	Likelihood ratio statistic
OR	Odds Ratio
CI	Confidence interval
MSI	Musculoskeletal injury
DMD	Dorsal metacarpal disease

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INTRODUCTION

BACKGROUND

Horse racing is a global sport and multi-billion dollar industry with large sums of money invested in the production of horses to race. The primary revenue stream for stakes, administration and development of the racing industry is generated from wagering turnover. Therefore, the industry structures the number and the frequency of races to maximise wagering turnover, but this is dependent on the number of horses in training and racing.

Optimally, both the Thoroughbred and Standardbred racing industries require horses that can race many times over a number of seasons. However, a major concern both internationally and domestically is the declining number of foals born and the subsequent effect on the pool of horses available to race. In New Zealand, the number of Thoroughbred and Standardbred foals born has been declining for a number of years. The number of Thoroughbred mares served in 1989/1990 and 2009/2010 was 10,176 (Rogers *et al.* 2009) and 6,488 (Anonymous 2010b), respectively, representing a 36% reduction. The number of Standardbred mares served in 1989/90 and 2009/2010 was 7,261 (Rogers *et al.* 2009) and 3,981 (Anonymous 2010a), respectively, representing a 45% reduction. Furthermore, New Zealand has an excellent reputation for breeding high-class Thoroughbreds, creating a large export demand, particularly for male horses, in the Australian and Asian market (Fennessy 2010; Waldron *et al.* 2011). While exports are economically beneficial to breeders it means fewer horses are available to race in New Zealand.

Another cause for concern is that there are several reasons for loss of potential racehorses before they reach race training. Loss of horses is referred to as wastage, which has both animal welfare and production implications through the loss of horses due to injury, economic factors, or lack of ability. Wastage studies have reported that up to 50% of Thoroughbred foals bred in the United Kingdom fail to race (Jeffcott *et al.* 1982). A report commissioned by the New Zealand Racing Board found approximately 32% of Thoroughbreds and Standardbreds in New Zealand failed to enter training (McCarthy 2009). Musculoskeletal injury appears to be a major contributing factor to wastage and thus has been the focus of many studies. Minimising wastage and in particular musculoskeletal injury should be a priority in all racing jurisdictions.

Recent scientific evidence shows that exercise early in life has a positive effect on growth and development of young horses as this is when the musculoskeletal system is most receptive to stimuli that might optimise tissues and orthopaedic health (Dykgraaf *et al.* 2008a). Early exercise has been shown to have a protective effect against musculoskeletal injury (Barneveld and van Weeren 1999; Firth and Rogers 2005). Therefore, the age at which horses achieve, or fail to achieve, training milestones may influence their future racing performance.

However, a limitation of all research to date is the lack of consensus in the scientific literature on the best method to quantify racing performance. The racing performance measures that have been used in intervention and genetic studies are many and varied, making comparisons across studies difficult. Thus, it is important that the racing performance literature is reviewed in order to assist the development of standard measures for robust scientific analysis of any intervention which aims to assess or improve racing performance of populations, groups or individual racehorses. Population-based research is the appropriate method to gain understanding of the parameters that are associated with racing performance (More 1999), and to determine the (potential) effect of various influences and interventions which are considered or implemented within the racing industry from time to time. Fortunately, the racing jurisdictions in New Zealand keep accurate and thorough raw data records, enabling epidemiological analysis of entire populations of horses.

The purpose of the epidemiological study recorded in this thesis was thus to critically review the existing literature, to study the associations between the achievement of training milestones and subsequent racing performance in two racing codes, and to determine if the age at which horses first start preparation for training, or training proper, influenced their lifetime athletic performance. Such new knowledge may have practical application in progression of the New Zealand racing industries and in improving equine health and welfare.

LITERATURE REVIEW

This review of the literature investigates the size and scope of the Thoroughbred and Standardbred racing industries in New Zealand, the career profile of horses, and factors that may affect racing career. The areas of wastage that occur in the production of racehorses and the measures of racing performance used to quantify racing success are reviewed, identifying gaps in the current knowledge.

Thoroughbred and Standardbred Industries in New Zealand

The racing industry contributes approximately $1,635 million dollars value added to New Zealand's Gross Domestic Product (GDP) which represents 0.90% of the total GDP (IER 2010). The New Zealand Racing Board administrates racing and wagering in New Zealand and is the parent body for the two horse racing jurisdictions: New Zealand Thoroughbred Racing and Harness Racing New Zealand. In 2010, there were approximately 40,000 participants involved in producing Thoroughbreds and Standardbreds to race in New Zealand (IER 2010). Based on the number of foals born in New Zealand, the Thoroughbred breeding industry is ranked 8th in the world (Fennessy 2010) and the Standardbred breeding industry is ranked 9th (Anon WTC NZ). In the 2009/2010 season, 6,488 Thoroughbred mares were served by 167 stallions resulting in 4,132 foals (Anonymous 2010b), and 3,981 Standardbred mares were served by 92 stallions resulting in 2,801 foals (Anonymous 2010a).

The breeding trend has been in steady decline since 1989 (Rogers *et al.* 2009). However, the export market for New Zealand Thoroughbreds is strong with 1,570 exports in the 2008/2009 season for approximately $130 million, which was an

8% increase on the 2003/2004 season (IER 2010). There is high demand for New Zealand-bred Thoroughbreds from both the Australian and Asian markets (Fennessy 2010; Perkins *et al.* 2004a), with over 60% of the exports for the 2008/2009 season going to Australia (IER 2010). Standardbred horses exported in 2008/2009 generated an estimated $37 million representing a 115% increase on the 2003/2004 season (IER 2010). The main export market for New Zealand-bred Standardbreds is Australia, with approximately 85% of horses sold there and the remainder exported to the United States (IER 2010). Approximately 15% of the Standardbred foals born in a year are exported but only 5% of these are yearlings (McCarthy 2009), most being sold later as "up and going" racehorses.

In 2009/2010, there were 2,791 Thoroughbred breeders and 2,944 Standardbred breeders in New Zealand (IER 2010). Approximately 22-29% of the annual Thoroughbred foal crop is sold through the yearling sales (Bolwell *et al.* 2011a), compared to 19-26% of the annual Standardbred foal crop (Anonymous 2010a). In 2008/2009 the Thoroughbred and Standardbred yearling sales aggregate were $91.9 million and $12.7 million, respectively.

The New Zealand racing season runs from 1st August until 31st July and the governing bodies, New Zealand Thoroughbred Racing and Harness Racing New Zealand, in consultation with the New Zealand Racing Board set the number of race and official trial meetings for each season. The number of race meetings programmed by administrators should attempt to reflect the pool of horses available to race. Ideally, each race run should contain 12 runners for optimum wagering turnover, reducing the field size from 12 to 8 runners decreases wagering revenue by 33% (McCarthy 2009). There were 5,794 Thoroughbred horses that started in a race during the 2009/2010 season that had 33,446 total race starts at 328 race meetings (Anonymous 2010b). In the same season, there were 3,686 individual Standardbred starters that had 32,685 total race starts at 289 race meetings (Anonymous 2010a).

Career profile of the Standardbred and Thoroughbred in New Zealand

Career profile

Thoroughbred horses begin their career at around 15-24 months of age when they are "broken-in" to saddle (Perkins 2005). They then either enter a trainer's stable for education or are sent for a spell (rest period) depending on trainer preference (Bolwell *et al.* 2010; Perkins *et al.* 2004b). After education or pre-training, a horse enters a training preparation of approximately 12 weeks duration with the aim of starting in an official trial (Bolwell *et al.* 2010). During training preparation young horses undergo both education and conditioning to enable them to learn how to race and gain fitness to do so. Thoroughbred horses learn to load in, and jump from, the barrier (starting gate) during training and will have a "jump out" (exiting the barrier and running a short distance at speed either alone or with other horses) (Bolwell *et al.* 2011b) before going to an official trial, and finally to their first race.

There is a lack of literature outlining the early career of the Standardbred racehorse, particularly in New Zealand. However, like Thoroughbreds they are "broken-in" to harness at around 16-24 months of age (Tateo *et al.* 2008), and then either gain some early education with a trainer or are spelled, depending on trainer assessment and preference. However, there is no published literature on the early training of Standardbreds under New Zealand conditions. Standardbred horses will start in unofficial organised workouts prior to going to an official qualifying trial. In a qualifying trial a horse must run over a certain distance within a given time and remain in its correct gait, and once this is achieved the horse is eligible to race.

The career profile of the racehorse creates some important milestones that are recognised by the racing industry and are easy to quantify. These milestones are: being registered with a trainer (when the trainer notifies the governing body that a horse has entered their stable for training), entering an official trial, and competing in a race.

Training regimen

Training racehorses involves a daily exercise routine over a number of weeks to gain the education, conditioning and fitness required to ultimately start in a race. The training regimens described all have the common goal of preparation for an official trial or race start. Training gaits within a Thoroughbred preparation can be described as trot, canter, half-pace, three-quarter pace and gallop (Bolwell *et al.* 2011b; Rogers and Firth 2004), and within a Standardbred preparation, jogging, strong work, and fast work (Shearman and Hopkins 1996). Thoroughbred horses in New Zealand have a training preparation of approximately 12 weeks duration from entering training until running in an official trial (Bolwell *et al.* 2010). Similarly, another study reported a group of 2-year-old horses entering training and undergoing a 13 week preparation for race training (Firth *et al.* 2004). Shearman and Hopkins (1996) reported the total training preparation duration of 13.6 ± 2.8 weeks, when conducting a survey of New Zealand Standardbred trainers. Thoroughbred horses entering training as 2-

and 3-year-olds in New South Wales, Australia had training preparations of 8, 10, and 12 weeks prior to competing in a barrier trial or race (Cogger *et al.* 2008). Perkins (2004b) reported that 2-year-old horses in training were managed more conservatively than older horses as they spent fewer days and less time in training. Another study reported that 2-year-old horses that had fewer days off from training were at less risk of having a voluntary interruption in training (Bolwell *et al.* 2011b).

Horses in training are exercised 6 days a week (Firth *et al.* 2004; Shearman and Hopkins 1996) and an exercise regimen consists of different phases. For Thoroughbred horses in New Zealand, it has been reported that they undergo 4 weeks of slow canter work at the beginning of training (Firth *et al.* 2004). Perkins *et al*. (2004b) reported horses in early training spent the first 4 -5 weeks of preparation at slow work (walk/trot and slow canter). Bolwell *et al*. (2010) reported a median 5-8 weeks in training until the first ¾ pace work, while Rogers and Firth (2004) reported introducing ½ pace (12.5-14.2 m/sec) in the 7th week of training. The introduction of gallop work varies and has been reported to begin from the ninth week of training (Rogers and Firth 2004), from 7-11 weeks of training (Bolwell *et al.* 2010), and from 8 weeks of training (Perkins *et al.* 2004b). In a survey of Thoroughbred racehorse trainers in Sydney the time from entering a stable to starting in a race was reported to be 11 ± 3 weeks but this depended on whether a horse had spent time in pre-training (Bailey *et al.* 1997). Standardbred horses have an initial jogging preparation of 5-6 weeks before a 5 week strong work phase is introduced, followed by a 4 week phase of fast work and jogging on alternate days (Shearman and Hopkins 1996).

Variables that could influence career

Career longevity can be defined as the length of productive racing life of an individual (Burns *et al.* 2006) and career length is measured either as the number of years a horse raced or the number of race starts a horse had. Career length is dictated by factors that influence the beginning and end of a horse's career. However, in order to have a career a horse must first start in a race. Career length may vary depending on a number of factors including, age at which career begins, gender, injury and wastage, early exercise and racing performance.

Age

Age at first start has a significant association with career length (Thiruvenkadan *et al.* 2009a). Thoroughbred horses that begin their race career as 2-year-olds appear to race longer than horses that start their career later in life (More 1999; Sobczynska 2007), and this is also the case with Standardbreds (Physick-Sheard 1986a; Saastamoinen and Ojala 1994). Bailey (1999a) found Thoroughbred horses that first raced as 2-year-olds had more race starts and more years racing than horses that first raced as 3- or 4-year-olds. Standardbred horses in Australia that first raced as 2-year-olds had more years racing and more race starts than those that began racing at a later age (Knight and Thomson 2011). However, these studies focussed on factors affecting career length rather than the effect of the 2-year-old year on career length.

Gender

Gender has an effect on career length, as males have a higher probability of a longer career than females (Bailey *et al.* 1999a; Sobczynska 2007). More (1999) found that male Thoroughbred horses were less likely to cease racing during the 2 years following their first start than their female counterparts. In a study on the Canadian Standardbred population, Physick-Sheard (1986b) showed that not only did female horses have fewer years racing than males, but they also had fewer race starts per racing year. Similarly, male Standardbreds in Australia had more career starts than females (Knight and Thomson 2011). Perkins (2004b) found that male Thoroughbreds aged 2 and 3 years spent proportionally more time in training and less time spelling than did the females in the same cohort. Similarly, a study in New South Wales found well-performed horses were more likely to be male (Cogger *et al.* 2008).

Wastage

Wastage can be defined as horses purpose-bred for racing which failed to race or participate to their full potential (McCarthy 2009). The effect of wastage on the racing industry can be measured through days lost in training, early retirement from racing or death, the cost of diagnosis and treatment of injuries, opportunity cost of investment (Bailey *et al.* 1997; Dyson *et al.* 2008). Wastage is a broad term describing loss from all areas of the supply chain from conception through to racing.

A study in the United Kingdom reported an overall figure for wastage at 72.8% from conception through to 4 years of age in Thoroughbred racehorses (Jeffcott *et al.* 1982). In New Zealand, approximately 22% and 33% of the Thoroughbred and Standardbred foal crop, respectively, fail to be registered with a trainer in a given year (McCarthy 2009). This figure is similar to the 38% of Thoroughbred horses that failed to enter training by their 4-year-old year in the United Kingdom (Jeffcott *et al.* 1982). Another UK study followed a cohort of 1,022

Thoroughbred foals until the end of their third year (Wilsher *et al.* 2006); 52% (537/1022) of the cohort entered training as 2-year-olds but 39% (210 /537) did not race in their 2-year-old year and, overall, 55% of the horses in this study entered training (Wilsher *et al.* 2006). Thus, a higher percentage of horses in the latter study failed to enter training than those reported by Jeffcott *et al*. (1982) and McCarthy (2009). In a cohort of 762 registered Standardbreds in Canada, 33.5% of failed to compete in a race (Physick-Sheard 1986a). In New Zealand, a study following an entire annual crop of Standardbred foals reported that 51.9% (1,575/3,032) failed to start in a race (Tanner *et al.* 2010). In a longitudinal study of Thoroughbred horses in training in New Zealand only 16.6% (262/1,571) failed to start in an official trial or a race (Perkins *et al.* 2004b). However, as the latter study followed horses already in training most wastage might have occurred prior to being registered with a trainer.

One of the main causes of wastage in the racing industry is musculoskeletal injury (MSI) (Parkin 2008; Stover 2003); other causes include lack of talent (Saastamoinen and Ojala 1994), temperament (Wilsher *et al.* 2006), other diseases (Hamlin and Hopkins 2003; Jeffcott *et al.* 1982), or financial decisions made by owners. Musculoskeletal injury is often acute and in some cases life-threatening (Firth and Rogers 2005) and may lead to a horse not fulfilling its career potential (McCarthy 2009). Musculoskeletal injury was responsible for 83.3% of involuntary interruptions to training in a cohort of 2-year-old Thoroughbred racehorses in New Zealand (Bolwell *et al.* 2011b). Similarly, Perkins *et al*. (2004c) reported MSI was responsible for 78.8% of involuntary interruptions in a cohort of Thoroughbreds in New Zealand. In contrast, a survey investigating trainer-reported health and training-related problems in Standardbred horses in

New Zealand found that horses were more likely to suffer from infections and illness than MSI problems (Hamlin and Hopkins 2003).

Lameness is the most commonly reported sign of the manifestation of musculoskeletal injury (Dyson *et al.* 2008; Jeffcott *et al.* 1982; Lindner and Dingerkus 1993; Perkins *et al.* 2004c) and is the most important cause of modified training days (Bailey *et al.* 1999b). For instance, dorsal metacarpal disease (DMD), often referred to as shin soreness, is a common complaint in horses entering training and racing, with incidence reported from 9% in the UK (Jeffcott *et al.* 1982), 24% in Australia (Cogger *et al.* 2006), and 24% in the UK (Verheyen *et al.* 2005)to 42% in Australia (Bailey *et al.* 1999b). Other major causes of lameness include fetlock joint injury (Cogger *et al.* 2006), carpal injuries (Dyson *et al.* 2008), tendon and ligament injuries (Lam *et al.* 2007; Perkins *et al.* 2004c; Perkins *et al.* 2005), and fracture (Dyson *et al.* 2008; Ramzan and Palmer 2011). Reducing wastage, and in particular musculoskeletal injuries, is an industry-wide goal.

Early Exercise

Musculoskeletal tissue responds to exercise through adaptive change (Kim *et al.* 2009) and scientific evidence suggests that exercise early in life has a protective effect on the musculoskeletal system (Barneveld and van Weeren 1999; Firth 2006; Rogers *et al.* 2008b). A 30% increase in cumulative workload applied to Thoroughbred foals kept at pasture from 3 weeks to 19-21 months of age had little adverse effect on musculoskeletal health or future 2- and 3-year-old racing career (Rogers *et al.* 2008a; Rogers *et al.* 2008b). The attrition rate in the study was low, with only one horse failing to complete 2- and 3-year-old training. Thus exercise early in life appears to be not harmful. A study of bone development in early growth in Warmblood foals separated foals into 3 groups: confined to stall, confined to stall with additional exercise, and kept at pasture (Barneveld and van Weeren 1999). The foals confined to stalls with additional exercise, worked up to a sprint at gallop, had enhanced bone mineral density of the trabecular bone at 5 months of age but the exercise with box rest was considered detrimental as tissue vitality was lower at 11 months of age than the other groups:. The foals kept at pasture had the highest glycosaminoglycan (GAG) content in both articular cartilage and tendon when compared to the box rest and box rest with exercise groups. Withholding exercise (box rest group) had a lasting effect on lower GAG-content in articular cartilage (Barneveld and van Weeren 1999). Van Weeren *et al.* (2008) found that additional exercise in horses kept at pasture had no deleterious effects on articular cartilage. Thus it appears that horses kept at pasture and those at pasture with additional exercise have more healthy articular cartilage than horses raised in box stalls.

Racing performance

A horse's performance on the racetrack is probably associated with the length of its racing career. However, racing performance is a complex trait and there is no single parameter used to quantify success. Within the equine literature, the measures of performance used to evaluate the success of interventions, or manipulations, are varied. The variation in the measures and in their robustness greatly limits the ability of the scientific community to successfully compare across studies or racing jurisdictions. Traditional measures of performance either censor data or present data with a heavily skewed distribution that does not reflect the distribution of the underlying athletic ability.

A measure of racing performance is available for only those horses that start in a race. However, it is well documented that a large percentage of foals bred never race (Bailey *et al.* 1997; Jeffcott *et al.* 1982; Wilsher *et al.* 2006), and many horses in training do not go on to race (Perkins *et al.* 2004b). Performance measures need to account for the opportunity to perform. It has been proposed that some factors that may affect racing performance are age, nutrition, skill of the trainer, starting position, track condition, handicap weight, sex, and level of competition (van Vleck 1990). Some of these factors may need to be accounted for when considering the optimal outcome measure of performance.

Performance measures often do not reflect the underlying biological variation of a trait, because the racing industry seeks to identify the exception (the good racehorse) rather than defining the normal population. This results in performance measures that are heavily skewed and lack the sensitivity required to reflect the underlying normally distributed variation in athletic ability, particularly at the lower end of the performance spectrum. Therefore, transformations of these data become necessary to normalise the data for analysis. Population-based research allows understanding of the average horse's career (More 1999), but there is a lack of data on the natural trends of populations of Thoroughbred and Standardbred racehorses (Cheetham *et al.* 2010). This is in direct contrast to other animal production industries where measurements of performance of the normal population are considered important production indices which provide a reference point for the evaluation of between-animal, or herd, or year variation.

Within the scientific literature there has been no consensus on effective outcome measures to quantify the success of equine medical or surgical intervention (Cheetham *et al.* 2010). Various parameters have been investigated, reflecting the difficulty in defining racing performance (Reardon *et al.* 2008), and many authors have tried to define an optimal measure (Barnes *et al.* 2004; Cheetham *et al.* 2010; Hawkins *et al.* 1997; Woodie *et al.* 2005). Most clinical intervention studies have small sample sizes, which significantly limits the parameters available and the conclusions that can be drawn. The lack of uniformity in the outcome measures has also made comparison between studies difficult (Stover 2003).

Methods of quantifying racing performance

Various parameters are used to quantify racing performance, but not all performance measures are capable of becoming outcome measures. An acceptable outcome measure must be sensitive enough to distinguish between-horse variation and permit analysis in statistical models. Several racing performance measures have been widely investigated as suitable candidates for the evaluation of genetic merit, and to a lesser extent as an outcome measure for clinical intervention trials. The performance measures described below are methodologies used in genetic evaluation, clinical intervention, and by the racing industry.

Earnings and race starts

Prize money in racing is allocated to horses that are "placed" in a race with prize money being allocated proportionally (Tavernier 1991), the greatest proportion is awarded to the winner and then incremental reductions back to fourth or fifth or even lower placing, depending on jurisdiction. As a measure of performance, "all individuals have an equal opportunity, but not ability, to win; earnings is a better indicator of what an individual can do in actual competition" (Tolley *et al.* 1985). However, earnings may be affected by the opportunities to earn in regard to amount of prize money on offer (Hintz 1980). It is also difficult to compare between countries using earnings, as each country has independent policies regarding prize money (Bokor *et al.* 2005). Raw earnings are generally heavily skewed and require transformation to normalise data for statistical analysis. The number of race starts per season describe a horse's ability to perform annually, whilst lifetime starts quantifies the length of a horse's career.

Lifetime or total earnings and annual earnings

The horse's total career prize money is a measure of lifetime performance. Annual earnings are the total earnings of a horse in a year and reflect the performance of that horse in relation to all the horses that raced in that year (Thiruvenkadan *et al.* 2009a).

Log of earnings

Log transformation of earnings is proposed as a method of normalising earning distribution and is often applied when estimating genetic merit (Langlois and Blouin 2004).

Racing status

Racing status is expressed as an all or none trait (Arnason 1999), and is useful for separating a population of horses into raced or not raced groups. It may also be the first step in measuring success or part of an outcome measure, as a horse has to race in order to attain a performance measure.

Race starts

The number of race starts a horse has during its life can be used as a measure of career longevity. Number of starts has been proposed as a correction factor for earnings (Langlois and Blouin 2008), rather than the use of earnings alone. Comparison of performance in a number of race starts before and after a medical or surgical intervention is commonplace (Barakzai and Dixon 2005; O'Meara *et al.* 2010; Woodie *et al.* 2005). However, the number of starts measured across different studies is a matter of some discussion, with differing opinion on the optimal number of pre- and post-intervention starts for accurate assessment; the number of subjects is often small and less than well controlled.

Earnings per start and average earnings per start

Earnings per start is considered a more precise measure of performance than earnings alone because the number of starts are accounted for (Ojala 1987; Ricard *et al.* 2000). Average earnings per start is a commonly used measure of merit as it reflects a horse's level in relation to other horses (Ojala 1989). Langlois and Blouin (2007) justified log of earnings per start as a performance criteria by showing that the regression coefficient of log of earnings with log of number of starts was close to one, meaning horses that earn more have more starts. They also outlined the problem that many horses cannot attain a measurement of performance as earnings is a continuous variable, meaning that horses with zero earnings are excluded.

Average Earnings Index (AEI) and Standard Starts Index (SSI)

The Average Earnings Index (AEI) is based on the average earnings per start of a sire's progeny. The AEI was further developed into the Standard Starts Index (SSI) in1977 (also known as the Racing Index (RI)) by separating colts and geldings from fillies' earnings, and by ranking 2-year-olds separately from older horses. The SSI takes all the foals in one year and calculates that crop's average earnings per start; once the average is determined it is assigned an index of 1.00 and horses in that crop are then compared to the average index. These indexes are predicted for all Thoroughbred horses racing in North America so are useful within that jurisdiction, but do not translate outside of this population. However, it would be possible to use a method such as AEI or SSI to calculate an index for other populations of racehorses.

Time

Time elapsed over a certain distance is a direct measure of speed (Tolley *et al.* 1985) and variations of time have been proposed as a candidate measure in European Standardbreds and trotter horses, as well as Thoroughbreds. Time taken to run over a distance is recorded for all races run and the best time run over a particular distance is often used as a measure of performance within the harness racing industry. The harness racing industry records the time taken for horses to run over the distance of one mile (with the exception of European harness racing which records time in seconds per kilometre).

Final time or Race time

Final time, or race time, is the time taken to run over a certain distance and is a direct measure of speed (Thiruvenkadan *et al.* 2009b). Race time is usually only measured for the winner of the race and the times of the other competitors in the race are estimated from the number of lengths behind the winner they finish. Time is influenced by all circumstances that occur within that race (Tolley *et al.* 1985), for example, track conditions, pace set during the race, and ambient temperature (Hintz 1980).

Best time and Average time

Best time is the horse's fastest time over a distance and can indicate a horse's level of performance compared to all those that raced (Ojala 1987). Average race time is the average of all a horse's performances over a particular distance (Hintz 1980).

Handicap or Performance Rating

The purpose of handicapping is to theoretically provide each horse with an equal chance of success in the given race, which improves betting participation and horse opportunity, and hence return of money to industry stakeholders. Handicappers are appointed within each racing jurisdiction and attempt to correct for previous racing success, horse gender and age. Methods of handicapping vary between Thoroughbred and Standardbred (or Trotter horses) due to the differences in gait, racing style, and method of start. Thoroughbreds are handicapped by weight whereas Standardbreds are handicapped by starting at a distance behind lesser rated horses in the case of standing start, or from a wider draw in mobile starts.

Timeform

Timeform ratings were established in 1948 where Thoroughbred horses are ranked annually, or rated by handicap weight, to express their relative performance. Timeform ratings express racing performance as weight in pounds, the most successful horses being given the highest weight (Arnason and van Vleck 2000).

Racing Post Rating (RPR)

The Racing Post Rating (RPR) is a handicap rating that is determined by a horse's overall performance[1]. The rating is based on finish time, handicap weight, quality of the field, and race level and is calculated per race run by a horse.

Beyer Speed Figure (BSF)

The Beyer Speed Figure (BSF) is a numerical measure of a horse's performance. It is based on final time and inherent speed over the track on which the race is run[1]. The BSF is calculated per race run by a horse and is interchangeable over distance and track.

Whilst the preceding three rating systems are robust, they are relevant to only a particular country or jurisdiction. In all cases the higher the horse's rating the better the horse is considered to be.

Rank at finish/Finish position

Finish position or rank at the finish measures the horse's performance compared to other horses within a particular race. Finishing position is the most common measure of performance within the racing industry. The finishing position of each

[1] http://www.thoroughbredink.com/files/Download/DRF_PP_Guide.pdf

horse in a race generates “form” for each horse and this is one of the major variables taken into account by punters and handicappers.

Wins and Placings

The ability to have a win or the number of wins and placings (first-to-third) are conventional measures of success within the racing industry, with the temporal reference being either season or lifetime. The percentage of wins to starts and the percentage of placings have been used in the breeding evaluation of Standardbreds (Arnason 1999). The percentage of placings may describe a horse’s “rating” compared to its peers whilst percentage of wins describes a horse’s temperament or will to win (Ojala 1987). As only a small percentage of horses that race go on to win a race, an acceptable outcome measure is unlikely to be based around wins.

Distance behind winner

The distance behind the winner is measured as the number of lengths a horse finishes behind the winner, or as the time behind winner. As such, the distance behind the winner is only a measure of a horse’s performance in relation to the other horses in that race.

Performance Index (PI)

A Performance Index (PI) first created by Hawkins *et al*.(1997) assigns points to race finish position: first place, 5 points; second place, 4 points; third place, 3 points; fourth place, 2 points; and unplaced, 1 point. The point value awarded for an individual race was then multiplied by a scaler (between 0.4 and 1) based on official race ratings to adjust for race class. Various modifications of this PI have been created by different authors. Strand *et al.* (2000) assigned points for first, second and third on a 3, 2, 1 basis, adding total points together and dividing by total number of races run within the given period to generate the PI. Another version used mean PI in a number of race starts pre- and post-intervention (Woodie *et al.* 2005).

Qualifying status

Qualification status is related to harness racing as horses must run over a certain distance in a certain time before they are allowed to race. This is a binary measure of performance similar to racing status described previously. As horses must qualify before they race it may be considered as a pre-performance measure.

Measures of Performance used for Genetic Evaluation

The primary focus of most studies quantifying racing performance has been breeding evaluation; namely the estimation of heritability (separation of genetic and environmental variation) and the repeatability of performance traits (Langlois 1980; Thiruvenkadan *et al.* 2009a, b; Tolley *et al.* 1985). The optimal outcome measure provides the best description of the desired phenotype. The inheritance of performance in Thoroughbreds, harness horses, and sport horses has been the subject of a number of comprehensive reviews (Hintz 1980; Langlois 1980; Thiruvenkadan *et al.* 2009a, b; Thorén Hellsten *et al.* 2006; Tolley *et al.* 1985). The general trend across these reviews has been that racing performance is moderately heritable (h^2 .20-.40), although there has been little consensus as to the best measure of racing performance.

Measures of Performance Used in the Sport Horse Industry for Breeding Evaluation

The largest volume of data produced for breeding evaluation has originated from the Western European sport horse population. The structure of European sport horse industry permits this, as it is well regulated and organised, and thus analogous to the racing industries with a structured approach to keeping records. Nationally, most countries record a variety of measures including placings, points and earnings which have been summarised in the review of Koenen and Aldridge (2002). Score, ranking, and number of placings reflect a sport horse's performance but as a function of competition level and number of starts (Hintz 1980), and therefore require additional correction factors to account for these. Possibly because of the need for additional correction factors, points-based systems appear to be used only within the Netherlands for genetic evaluation of competition data (Huizinga and van der Meij 1989). The use of earnings and transformation of earnings are more commonly used, such as log earnings in Germany (Bruns 1981) and log of annual earnings per start in France (Langlois and Blouin 2007). Rankings have been proposed as an accurate and valid candidate to measure relative performance, but logistical difficulties and industry reception to this has meant lack of wider uptake by industry (Tavernier 1990). Since 2004, the International Equestrian Federation (FEI) and World Breeding Federation of Sport Horses (WBFSH) have produced world rankings for sport horses and stud books based on cumulative points. However, the rankings are subject to significant bias as they are dependent on population size and the number, and access, of the respective horses to the international ranking competitions and therefore are biased towards the larger European stud books.

Measures of Performance used in the Racing Industries for Breeding Evaluation

The criteria used to measure performance for heritability estimation is heavily influenced by the ability of the measure to reflect the underlying genetic variation and the availability of measures on most of the population of interest. Race time has been the most frequently reported measure of racing performance used in early heritability estimation. Reported heritability estimates of performance for time and best time, were 0.04 to 0.29 and 0.10 to 0.18, respectively, for Thoroughbreds, and 0.04 to 0.48 and 0.18 to 0.36, respectively, in trotting horses (Thiruvenkadan *et al.* 2009a, b). The repeatability of race time based measures are generally high (0.15-0.63) (Thiruvenkadan *et al.* 2009a), but the objective of racing is to beat the other horses, not necessarily run the fastest time. The lower heritability estimates for race time in Thoroughbreds is due to the variability of race distance and track surface; by contrast Standardbred racing is conducted over more uniform distances and track surfaces.

Earnings and variations of earnings have been common performance measures for breeding evaluation. Heritability estimates for log of earnings are generally higher (range 0.11 – 0.39) in both Thoroughbreds and harness horses. Most authors agree that some transformation of earnings is required with the most common being log transformation, although square root transformation (Minkema 1975), fourth root transformation (Saastamoinen and Nylander 1996) and log of earnings corrected by starts (Langlois and Blouin 2007) are further variations. To account for the opportunity to earn prize money, the log of earnings is often reported as ‘earnings per start’ (Bugislaus *et al.* 2005a; Bugislaus *et al.* 2005b; Langlois and Vrijenhoek 2004). Ekiz *et al.* (2005) reported higher repeatability for earnings per start and for log of earnings per start than for annual earnings and log of earnings, implying it is a more accurate reflection of the true ability of the horse (Langlois and Blouin 2007).

Racing status is a measure of whether or not a horse has raced. Racing status is highly heritable in harness horses and Thoroughbred horses both on the flat and over jumps (Langlois and Blouin 2008). Racing status provides the mechanism to account for the qualification of horses to race and quantifies the initial milestone of qualifying to race. However, these authors appear to be the only ones to consider racing status.

Timeform ratings have been used to estimate the genetic trend of racing performance (Field and Cunningham 1976; Gaffney and Cunningham 1988; More O'Ferrall and Cunningham 1974). Based on that series of studies the authors reported that race times in English Classic races had not improved in a 50 year period and surmised that Thoroughbred horses had reached their physiological limit, and this became known as "Cunningham's Paradox" (Bailey 1998). Other handicap-based criteria used to evaluate genetic merit have been the horse's body weight divided by handicap weight carried (Buxadera and da Mota 2008), an Elo rating (Pieramati *et al.* 2007), performance in group races (Harrison and Turrion-Gomez 2006), and distance behind the winner (Bugislaus *et al.* 2004) and horses relative rank (Tavernier 1991).

Measures of Performance Used in Medical and Surgical Intervention Studies

Whilst there are many papers outlining medical and surgical interventions on racehorses and their subsequent racing performance, there is a high degree of variation in the parameters used to measure performance. Clinical interventions often have small numbers of horses rather than subpopulations and may, or may not, be matched to a set of control horses. Some studies do not separate by breed (Standardbred or Thoroughbred) causing further difficulty in measuring and comparing outcomes (Cheetham *et al.* 2010).

Racing status is a common measure of performance related to clinical interventions and as horses must race to gain a performance measure this is a sensible first step in measuring outcomes. Secondly, the nature of interventions means that a horse returning to racing post-intervention is in itself a measure of performance. Charman and Vasey (2008) used return to racing as their only measure of performance, whilst Ulhorn *et al*. (2000) used qualifying status, racing status and number of starts as outcome measures. Number of race starts is a measure of career longevity and is often used in conjunction with racing status to provide a stepwise quantification of performance. Comparison of performance in a number of races before and after an intervention is commonplace, although there is some conjecture as to the optimum number of races. Three races pre- and post-intervention appear usual (Barakzai and Dixon 2005; Carpenter *et al.* 2009; Dykgraaf *et al.* 2008b; Fjordbakk *et al.* 2008; Getman *et al.* 2006; Parente *et al.* 2008; Reardon *et al.* 2008; Smith and Embertson 2005; Strand *et al.* 2000; Taylor *et al.* 2006; Woodie *et al.* 2005), although O'Meara *et al*. (2010) proposed that a completion of 5 races post-intervention provided a more useful outcome measure than the more commonly used 3 race starts.

Whilst earnings are a commonly used measure of performance the method of use has been varied, including median earnings (Barakzai *et al.* 2004; Colon *et al.* 2000; Jalim *et al.* 2010; Neil *et al.* 2010; Parente *et al.* 2008; Reardon *et al*. 2008; Sanchez *et al.* 2008; Santschi *et al.* 2000; Tull *et al.* 2009; Witte *et al.* 2009), total earnings (Barakzai and Dixon 2005; Busschers *et al.* 2008; Fulton *et al.* 2003;

Kane *et al.* 2003; Schnabel *et al.* 2006; Woodie *et al.* 2005), total earnings as a continuous variable (Barakzai *et al.* 2009b), total earnings changed to a binary variable (Barakzai *et al.* 2009a), earnings per start (Barnes *et al.* 2004; Busschers *et al.* 2008; Carpenter *et al.* 2009; Colon *et al.* 2000; Dykgraaf *et al.* 2008b; Fulton *et al.* 2003; Getman *et al.* 2006; Jalim *et al.* 2010; Kane *et al.* 2003; Kraus *et al.* 2005; Martin 2000; Schnabel *et al.* 2006; Smith and Embertson 2005; Smith *et al.* 2009), log of earnings (Cheetham *et al.* 2008; Hinchcliff *et al.* 2005; Ortved *et al.* 2010; Schaaf *et al.* 2009) and average or annual earnings per start (Kamm *et al.* 2011; Parente *et al.* 2008; Waselau *et al.* 2008). Median values are often reported due to a non-normalised distribution but log transformation or earnings adjusting for starts would be a more sensitive measure.

The Performance Index (Hawkins *et al.* 1997), and variations around this have been popular with a number of authors (Boyle *et al.* 2006; Carpenter *et al.* 2009; Davenport *et al.* 2001; Davidson *et al.* 2005; Dykgraaf *et al.* 2008b; Fulton *et al.* 2003; Getman *et al.* 2006; Jalim *et al.* 2010; Kikuta *et al.* 2006; Reardon *et al.* 2008; Strand *et al.* 2000; Taylor *et al.* 2006; Woodie *et al.* 2005). However, the PI has generally been used with other performance measures such as earnings, possibly because the PI lacks sensitivity as it requires that horses must run first, second or third to gain a measure, therefore excluding data of horses that do not place in a race (Reardon *et al.* 2008).

Clinicians have rarely used race time as a measure of performance, and if doing so have often included it with other measures such as the PI (Strand *et al.* 2000), earnings per start (Martin 2000) and race placings (Morley and Hinchcliff 2004). Other measures that have been reported either on their own or in conjunction with previously described measures are Racing Post Rating (O'Meara *et al.* 2010;

Reardon *et al.* 2008; Rutherford *et al.* 2007), Standard Starts Index (Barnes *et al.* 2004; Sanchez *et al.* 2008), Timeform rating (Young *et al.* 2008), qualifying status (Courouce-Malblanc *et al.* 2006; Uhlhorn *et al.* 2000), Beyer Speed Figure (Carpenter *et al.* 2009), ITR rating (French Trotter studbook rating) (Courouce-Malblanc *et al.* 2006), distance behind winner (Hinchcliff *et al.* 2005), stakes wins and places (Seder *et al.* 2003), Starts Percentile Rate ranking (Ainsworth *et al.* 2000), points system to predict finish position (Griffiths *et al.* 2000), earnings percentage (earnings/60% of purse value) (Martin 2000), and years raced (Santschi *et al.* 2000).

Studies with matched controls as a comparison used siblings; maternal (Sanchez *et al.* 2008; Santschi *et al.* 2000; Schaaf *et al.* 2009; Schnabel *et al.* 2007; Smith *et al.* 2004; Tull *et al.* 2009) and paternal (Rutherford *et al.* 2007), race matched (Barakzai *et al.* 2009a; Barakzai *et al.* 2009b; Cheetham *et al.* 2008; Waselau *et al.* 2008), matched by training yard (Barakzai and Dixon 2005; Barakzai *et al.* 2004; O'Meara *et al.* 2010; Reardon *et al.* 2008), non-diseased controls (Ortved *et al.* 2010), and yearling sales classification (Smith *et al.* 2004).

Conclusion

It is clear that there is wide variability in the measures used to quantify performance in both genetic evaluation and clinical intervention, which agrees with findings of van Vleck (1990) and Cheetham (2010). The availability of data may govern the performance measures used, and indeed the variation of systems within racing jurisdictions and countries contribute to the variability of performance measures. Therefore, there will always be difficulty comparing across countries and between breeds of horse with the use of outcome measures.

Horses must race or compete in order to get a performance measure, but due to industry wastage up to 50% of horses do not succeed in entering competition (Jeffcott *et al.* 1982; Wilsher *et al.* 2006). Furthermore, most performance data is of a highly skewed nature, as many horses that compete do not earn prize money, creating a large cluster of horses with zero earnings. The latter appears to be one of the main difficulties faced by researchers when quantifying performance. The common solution to date has been to exclude horses with zero earnings, which means the true population is not being represented. Some authors allocate a nominal dollar value to horses with no earnings or allocate one dollar to all horses' earnings. As non-normally distributed data are common in most measures of performance, they must be transformed.

Earnings are of economic importance to owners, trainers and breeders of racehorses; probably more so than wins, placings, race time or black-type. Thus, earnings are the most effective measure of racing success. The number of race starts a horse has is an effective measure of career length and becomes an adjustment factor for earnings in statistical modelling. Wastage studies have identified that many horses in a population fail to enter training or racing.

This study will investigate the achievement of key industry milestones; entering training, competing in a trial, and starting in a race and the relationship of these milestones with racing performance. The accepted outcome measure of racing performance as directed by the literature is log transformation of earnings and total race starts. The review of the industry situation suggests evidence that early exercise may be beneficial and the identification of robust and appropriate outcome measures, to be applied in large cohorts of horses whose race performance was measured over many years, has led to an integrated biologically sensible hypothesis.

HYPOTHESIS

It is hypothesised that Thoroughbred and Standardbred horses that achieve training milestones at 2 years of age will have significantly longer and more successful careers than horses that achieve those milestones as 3-year-olds or older.

AIMS

The aims of this research thesis were to:

a. Test the hypothesis above in an experiment, which used the complete datasets that were available from Harness Racing New Zealand (HRNZ) and New Zealand Thoroughbred Racing (NZTR), respectively, of the Standardbred and the Thoroughbred cohorts of foals that were born in the 2001/2002 season.
b. Analyse the data , using appropriate statistical methods so that the subsequent interpretation will be as rigorous as possible both for comparison with other studies but also for application
c. Make recommendations as to how the data can best be of use to the relevant racing and breeding authorities so that the knowledge gained from the study assists in advancing the industry and its stakeholders, and also advances the health and welfare of New Zealand racehorses.

PRELUDE TO CHAPTER 2

Chapter 2 reports the retrospective following of a cohort of Standardbred foals born in 2001/2002 until the end of their 7-year-old season. The study utilises survival analysis, logistic regression and linear regression to examine the association of attaining training milestones at two years of age with outcomes measuring career length and racing success.

Supplementary statistical information on model diagnostics is appended to the end of this Chapter.

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CHAPTER 2
THE RELATIONSHIP OF 2-YEAR-OLD TRAINING MILESTONES WITH RACING SUCCESS IN A POPULATION OF STANDARDBRED HORSES IN NEW ZEALAND

ABSTRACT

AIM: To investigate the association of attainment of training milestones by 2-year-old horses with racing outcomes in a population of Standardbred racehorses in New Zealand.

METHODS: Retrospective records of the 2001/2002-born Standardbred foals were obtained. The three training milestones used were: registered with a trainer, entered in a trial, and competed in a race. The racing outcomes were length of career in years raced and number of race starts, and total earnings. Cox regression analysis was used to assess the association between age at attainment of the three milestones and the number of race starts and years raced. Logistic regression models were used to determine the association between age at attainment of the milestones and the outcomes won and placed in a race. Linear regression was used to model the association between age at attainment of the milestones and annual earnings and total earnings (transformed using Ln (earnings +NZ$100)).

RESULTS: Of 3,032 horses in the population, 2,075 (68.4%) registered with a trainer, 1,810 (59.7%) trialled, and 1,457 (48.1%) raced and had 29,572 race starts. Horses that first raced as 2-year-olds had a longer racing career and more race starts than those that did not race as 2-year-olds ($p<0.001$); this was also true when starts in the 2-year-old year were omitted from analyses. Horses that were registered with a trainer, trialled or raced as 2-year-olds were more likely to have won or placed in a race than those that did not achieve the milestones as 2-year-olds ($p<0.001$). Linear regression showed horses that trialled and raced as 2-year-olds had greater total earnings than those that did not trial and race as 2-year-olds, and male horses had higher total earnings than female horses.

CONCLUSION: Less than half the Standardbred racehorses born in 2001/2002 subsequently raced, but the results of this study indicate that horses that begin training, trialling, or racing as 2-year-olds have longer and more successful careers than those that do not achieve the milestones as 2-year-olds. Further investigation is required to quantify the management practices of these horses to determine the factors that may be associated with a successful racing career.

INTRODUCTION

Wastage studies in the Thoroughbred industry have shown as many as 50% of foals born do not go into training and that not all horses that are trained will go on to race (Bailey *et al*. 1997; Perkins *et al*. 2004ab; Wilsher *et al*. 2006), further reducing the pool of available horses. There are few data available on population-based research within the Standardbred industry, except population demographics of the Canadian Standardbred (Physick-Sheard 1986a, 1986b; Physick-Sheard and Russell 1986), a report commissioned by the New Zealand Racing Board on wastage from conception to racing (McCarthy 2009), and the description of a crop of Standardbred foals in New Zealand (Tanner *et al*. 2010).

The ability to start a career at an early age and perform well is desirable in Standardbred racehorses (Saastamoinen and Nylander 1996), and horses that start their career early are often better performers and have longer careers than those that begin at a later age (Physick-Sheard 1986b; Saastamoinen and Ojala 1994). In Thoroughbreds, career longevity is the length of productive racing life of an individual (Burns *et al*. 2006) and can be measured as years raced or number of race starts. Longer career length is associated with horses starting at an earlier age, gender, and performance during first year of racing (More 1999). Career longevity is important from an industry perspective in terms of maximising the available racing product as well as a benefit to owners and trainers.

Early exercise has a positive effect on the growth and development of young horses as it adapts the musculoskeletal system when it is most receptive. Cancellous and cortical bone mineral density of Thoroughbred horses that had undertaken early 2-year-old training was higher than in pastured horses (Firth and Rogers 2005). Preconditioning has also been shown to have a positive effect on skeletal muscle (Rietbroek *et al*. 2007), and articular cartilage (Rogers *et al*. 2008; van Weeren *et al*. 2008). Therefore, horses that enter training at a young age may have a physiological advantage over those that do not enter training until a later age.

In contrast to other racing countries, the regulation and control of both breeding and racing in New Zealand is under one governing body for each code, namely, Harness Racing New Zealand (Inc) and New Zealand Thoroughbred Racing (Inc). Thus the racing industry in New Zealand is relatively homogeneous and compact, facilitating collection of annual racing and breeding data which are suitable for large scale epidemiological analysis. The aim of this study was to investigate the association of attainment of training milestones by 2-year-old horses with racing outcomes, in a population of Standardbred racehorses in New Zealand. The first training milestone was registering with a trainer, which is when a trainer officially notifies the governing body (HRNZ) that a horse has entered training in their stable. The second milestone was being entered in an official trial and the third milestone was competing in a race. The outcomes investigated were length of career in years raced and number of race starts, and career success measured as total earnings. The hypothesis was that in this population of Standardbred horses, the attainment of any of the three training milestones at 2-years-old was associated with longer and more successful careers.

MATERIALS AND METHODS

Data

Annual racing data of the 2001/2002-born Standardbred foals in New Zealand were provided as an electronic extract by Harness Racing New Zealand (HRNZ). The data included gender, sire, dam, trainer, and the year first registered with a trainer. Racing and trialling records were provided as annual totals of number of trials, number of races, and total and annual stakes earnings. All data were current up to 31 July 2009 which was the end of the horses' 7-year-old racing season.

Statistical analysis

Horses were categorised as male or female, as no castration records were available; gait predilection (trotter or pacer) was not distinguished. Trainer was the trainer of the horse at the time of the electronic extract, and may not have been the trainer for that horse's entire career, and thus was not included in the statistical analysis. Horses were excluded from the dataset if unregistered, exported at ≤1 year of age, or imported for breeding purposes only. Data were structured for analysis in Excel and imported into Stata 11 (StataCorp LP, College Station TX, USA) for analysis. Integrity of the data was checked with histograms and cross tabulation and any outliers were cross referenced with the HRNZ database. For the three training milestones binary variables were created as follows; first registered with a trainer as a 2-year-old (yes/no), first trialled as a 2-year-old (yes/no), first raced as a 2-year-old (yes/no).

Length of career

Time to cessation of racing was measured as either number of years raced, or as used by Rutherford *et al*. (2007), number of race starts and number of race starts with the 2-year-old year omitted. Kaplan-Meier curves were used for exploratory analysis. Cox regression analysis, using the Breslow method of handling ties, was performed to assess the association between age at attainment of the three training milestones, and gender and the outcomes of years raced and race starts. Start time was considered to be the year in which the horse first raced for number of years raced, or the horse's first race start for number of race starts. Variables showing univariable relationships ($p < 0.2$) with the outcome were evaluated in a multivariable model with each variable removed sequentially from the full model in a backward stepwise fashion. The goodness-of-fit of the models were evaluated using the Nelson-Aalen cumulative hazard function versus Cox-Snell residuals (Dohoo *et al*. 2003a).

Racing success

Simple logistic regression analysis was used to determine the association between age at attainment of the three training milestones and the outcomes of whether the horse won a race, or was placed (first-to-third) in a race. Variables showing univariable association ($p<0.2$) with each outcome were evaluated in a multivariable logistic regression model with each variable removed sequentially from the full model in a backward stepwise fashion. Variables with a Wald-test $p \leq 0.05$ or that improved model fit (likelihood ratio statistic (LRS) $p \leq 0.05$) were retained in the model. The goodness-of-fit of the models were assessed using the Hosmer-Lemeshow test statistic (Dohoo *et al*. 2003b).

Linear regression was used to model the association between age at attainment of the three training milestones, and gender and annual earnings and total earnings. To normalise the distribution of both these measures, they were transformed as Ln (earnings + NZ$100), but will be referred to as annual and total earnings, respectively. A multivariable linear regression model was built with each variable removed sequentially from the full model in a backward stepwise fashion. Variables with a two-tailed $p \leq 0.05$ or that improved model fit (likelihood ratio statistic (LRS) $p \leq 0.05$) were retained in the model. The continuous variable total race starts was included as a quadratic term in the final model to improve model fit; the original variable was centred by subtracting the mean value from the observed value prior to squaring to prevent collinearity (Dohoo *et al*. 2003c). Studentised residuals were plotted for kernel density and standardized normal probability (P–P) plot, and heteroscedasticity and multicollinearity were tested.

RESULTS

Descriptive results

The foal crop contained 3,401 horses, of which 88 died prior to branding, 221 unregistered foals and 46 horses exported as foals or yearlings were removed from the dataset, and 14 horses imported as breeding stock. Thus 3,032 horses

(1,521 males and 1,511 females) was the study population, of which 1,457 horses raced and had 29,572 race starts by the end of their 7-year-old season. Male horses accounted for 55% of the horses that raced ($p<0.001$). The age at which training milestones were first attained are shown in Table 1. A total of 957/3,032 (31.6%) horses in the study population were never registered with a trainer, 1,222/3032 (40.3%) never trialled, and 1,575/3032 (51.9%) never raced in New Zealand.

Table 1. The number (and percentage) of a population of Standardbred horses in New Zealand born in 2001/2002 within each age group when they attained the training milestones of registered with a trainer, trialled, and raced.

Age (years)	Registered	Trialled	Raced
2	1,018 (49.0%)	609 (33.7%)	272 (18.6%)
3	774 (37.3%)	825 (45.6%)	644 (44.2)
4	215 (10.4%)	294 (16.2%)	390 (26.8%)
5	49 (2.4%)	57 (3.1%)	112 (7.7%)
≥6	19 (0.9%)	25 (1.4%)	39 (2.7%)
Total	**2,075 (100%)**	**1,810 (100%)**	**1,457 (100%)**

Length of career

Univariable analysis showed that there were significant associations between first registered with a trainer as a 2-year-old, first trialled as a 2-year-old and first raced as a 2-year-old and the number of race starts ($p<0.001$), but there was no association with gender. In the final models first trialled as a 2-year-old became non-significant in all models. First registered with a trainer as a 2-year-oldwas also non-significant for all outcomes but was included in all models to improve model fit (Table 2). Those horses that first raced as 2-year-olds had less risk of ceasing racing (i.e. were more likely to continue racing), and had more race starts, than those that started racing at a later age ($p<0.001$). This was also true when the

2-year-old year of racing was omitted from the number of race starts to reduce potential bias. The goodness-of-fit of the models using the Nelson-Aalen cumulative hazard function versus Cox-Snell residuals indicated the final model fitted the data very well for both the number of race starts and number of race starts with the 2-year-old year omitted outcomes, but less well for the number of years raced outcome.

Table 2: Results of multivariable Cox regression models of the association between the 2-year-old training milestones and the three measures of career length outcomes; number of race starts, number of race starts (2-year-old (2yo) year omitted) and number of years raced in the 2001/02 Standardbred foal crop

Outcome	Coefficient	SE	P-value	Hazard Ratio	95% CI
Race starts					
$RegTr_2$	-0.110	0.059	0.06	0.896	0.800-1.001
$Race_2$	-0.322	0.076	<0.001	0.725	0.624-0.840
Race starts (2yo year omitted)					
$RegTr_2$	-0.109	0.059	0.07	0.897	0.799-1.001
$Race_2$	-0.180	0.076	0.02	0.835	0.720-0.969
Years raced					
$RegTr_2$	-0.087	0.059	not sig	0.917	0.816-1.030
$Race_2$	-0.421	0.078	<0.001	0.656	0.564-0.764

Racing success

The final multivariable logistic regression models for the outcomes won a race and placed in a race are summarised in Table 3. Attainment of all training milestones as 2-year-olds and gender were significant for both outcomes modelled ($p<0.001$). The Hosmer-Lemeshow statistic for the won a race model was 0.24 ($p=0.99$), and for the placed in a race model was 1.25 ($p=0.87$), both indicating good model fit.

Table 3: Multivariable logistic regression models of the 2-year-old training milestones associated with the racing success outcomes; won a race, placed (first-to-third) in a race in the 2001/02 Standardbred foal crop

		Outcome: Won			Outcome: Placed		
		OR (95%CI)	Wald test	LRS[a] P-value	OR (95%CI)	Wald test	LRS[a] P-value
RegTr$_2$	No	Reference					
	Yes	2.20 (1.75-2.77)	<0.001		2.24 (1.79-2.79)	<0.001	
Trial$_2$	No	Reference					
	Yes	1.81 (1.35-2.43)	<0.001	<0.001	2.14 (1.60-2.87)	<0.001	<0.001
Race$_2$	No	Reference					
	Yes	2.24 (1.60-3.13)	<0.001		4.34 (2.87-6.58)	<0.001	
Sex	Female	Reference					
	Male	1.56 (1.32-1.84)	<0.001		1.60 (1.35-1.88)	<0.001	

(Outcome: Won LRS chi-square = 375.54, 4 degrees of freedom; Outcome: Placed LRS chi-square = 557.81, 4 degrees of freedom)

Footnote: [a]LRS = Likelihood Ratio Test Statistic

For both annual earnings and total earnings, there were univariable associations with age at first registration, age first trialled, age first raced and total race starts. During the analysis, both annual earnings and total earnings showed similar patterns of association, therefore total earnings were used as the outcome in the final linear regression model (Table 4). Horses that first trialled as 2-year-olds had greater total earnings than those that first trialled at a later age, and horses that first raced as 2-year-olds had greater total earnings compared with horses that first raced at a later age. Male horses had higher total earnings than female horses. Fitting total races as a centred quadratic term improved model fit and R^2. The adjusted R^2 indicated that 64% of amount of variance was explained by the variables in the model. A residual-versus-fitted plot indicated the residuals were relatively randomly scattered around zero. Mean variance inflation factor for the model was 2.67 indicating that collinearity was relatively mild.

Table 4: Multivariable linear regression model analysis with the variables significantly associated with racing success measured as natural logarithm of total earnings won +$100 in the 2001/02 Standardbred foal crop

	Coefficient	95%CI	P-value
Total race starts[*]	0.142	0.135-0.149	<0.0001
Total race starts^{2*}	-0.001	-0.002--0.001	<0.0001
$Race_2$	0.307	0.105-0.510	0.003
$Trial_2$	0.170	0.008-0.333	0.04
Sex (male)	0.333	0.211-0.455	<0.0001

(Adjusted R^2 = 0.64, RMS Error = 1.18[a], p<0.0001, n = 1,454)

Footnote [*]centred by subtracting the mean value from total race starts prior to squaring, [a] Root Mean Square Error

DISCUSSION

The aim of this study was to investigate the association of attainment of training milestones by 2-year-old horses with career length and racing success. This study captured the career of an entire crop of foals until the end of their 7-year-old year, making it valuable and powerful for analysis. The data examined may not be representative of the Standardbred industry in New Zealand as it was based on only one foal crop and could be influenced by economic or environmental factors. However, the McCarthy (2009) report demonstrated that the Standardbred industry is relatively consistent across years in terms of the proportion of each foal crop to achieve the training milestones, suggesting that our findings may apply to crops of Standardbred foals born in other years. Previous studies have commented on the effect of age at first start, in particular that 2-year-olds appear to have longer careers than horses that start at a later age. These studies include a population-based descriptive analysis of racing performance of Canadian Standardbreds (Physick-Sheard (1986a), number of years racing and early career in a cohort of Finnish Standardbreds (Saastamoinen and Ojala 1994), performance during the first years of racing in Queensland Thoroughbreds (More 1999), age at first race and career duration in Thoroughbreds offered at the 1991 Australian Easter Sale (Bailey *et al*. 1999), and horses that raced at three racing tracks in Poland (Sobczynska 2007). In contrast to the current study, these cohort studies chose their study cohorts from horses that had raced within their given sample populations rather than an entire population. To the authors' knowledge, the current study is the first to show the association of attaining training milestones with career length and racing outcomes, and in particular the effect of racing as a 2-year-old.

Of the population of 2001/2002-born foals, 32% never reached the first milestone of being registered with a trainer, which is in close agreement with a previous industry-commissioned supply chain wastage report (McCarthy 2009). The failure of this proportion of the population to reach this first career milestone is not unique to the Standardbred racing industry, or New Zealand, with 32.7% (1,531/4,683) of Thoroughbred foals in New Zealand failing to register (JC Tanner, unpubl. obs.). In the United Kingdom, 38% (2886/7640) of the original named foal crop failed to enter flat race training in the UK and 49% (3773/7640) of horses did not race (Jeffcott *et al* 1982). In the 2001/2002-born Standardbred population, 40% of the horses did not trial, representing a 9% loss of horses from the first to second milestone, and only 48% raced (in New Zealand). The relatively low percentage loss of horses after the initial decision to register a horse with a trainer implies that considerable thought was given to registering a horse with a trainer. In other words, by achieving the first milestone there was a real intention by owners and trainers to get that horse to the races. The difference in race programming in Canada may explain the higher number of horses not starting in a race in New Zealand compared with only 34% of the Standardbred population in Canada (Physick-Sheard 1986a). In Canada and the United States of America, claiming races are programmed to cater for all classes of horse, allowing greater opportunities for lower class horses to race competitively. Claiming races enable owners and trainers to place a horse in a race with a set price which allows another person to purchase (claim) the horse following the running of that race. In essence these races ensure that horses of similar value race against each other, thus creating better racing opportunities for these horses. The lack of claiming races combined with relatively lower production costs in New Zealand until a horse enters training may mean that breeders or owners will not register a horse with a trainer unless they believe the horse would be competitive. From a racing industry perspective there are untapped potential racehorses within this ‘unraced’ population which should be the focus of future work examining the structure of the race grading system and opportunities for the less competitive / athletic horses.

Most Standardbred horses that entered training did so as 2-year-olds but 2-year-old horses that raced represented the smallest proportion of the 2001/2002 born foals. Of the horses that raced within this population, horses that first raced as 2-

year-olds had significantly more race starts and years racing than those that first started at a later age, even when the contribution of the 2-year-old year were removed from the analysis. In the univariable analysis, first registered with a trainer as a 2-year-old, first trialled as a 2-year-old and first raced as a 2-year-old were associated with career length, although only first raced as a 2-year-old was significant in the multivariable models. This is the first time that early training and not just racing has been shown to have a positive effect on career length. A possible hypothesis for this could be the 'healthy horse' effect, observed in a study examining French show jumping records (Ricard and Fournet-Hanocq 1997). The hypothesis proposed was that riders and trainers may identify that healthy athletic horses are preferentially put into training ahead of those deemed to be less athletic, or less tractable. The pre-selection of horses by owners or trainers is understandable and could be a contributing factor to the number of horses that reached the first training milestone in this population of 2001/2002-born Standardbred foals. Therefore, it is possible that a combination of the perceived healthy horse that receives exercise when in training as a 2-year-old may have a positive association with career length. However, there may be missing training data for those horses first registered with a trainer as ≥ 3-year-old if these horses had received some training load during the period after breaking-in until being registered with a trainer.

Within the literature various measures have been proposed to quantify the complex trait of 'racing success'. The most common measures used within the industry and for genetic evaluation are earnings or a transformation of earnings. As a summary measure for annual, or lifetime success, the log of earnings was the best descriptor for the Standardbred population in New Zealand. In this country, Standardbred horses must run in a qualifying trial before they can race and so there may be some underestimation of the true effect of 2-year-old racing, as age at first trial was a significant variable in the final linear regression model. In agreement with previous cohort studies, males were more likely to earn prize money and earned approximately one-third more than females. The variables available to be included in the model were limited to the industry parameters in the data provided and accounted for 64% of the variance within the linear regression model. However, other authors have found variables that may have affected our measure of racing success. For instance, Standardbred gait (trotter or pacer) was found to have a significant association with race earnings in US Standardbreds (Cheetham *et al*. 2010). In both the US and New Zealand most (~80%) are pacers and hence there are significantly more races for pacers and an opportunity for them to earn prize money. The quantity of high speed or canter exercise during training was shown to have a significant effect on racing success in Thoroughbreds (Verheyen *et al*. 2009). However, the use of total/lifetime earnings in our study should negate the effect of exercise variation between horses. ‘Trainer’ was also significantly associated with racing performance (Ely *et al*. 2010). Within the New Zealand Standardbred dataset there were approximately 700 trainers of the 2075 horses that were registered with a trainer, providing a relatively heterogeneous dataset. Unfortunately, trainer was unable to be analysed within our dataset as the most recent trainer may not have trained the horse for its career. However, the distribution of horses with trainers was heavily skewed and reflects the owner –trainer bias to the New Zealand industry rather than a trend for owners to send horses to public trainers for race preparation.

The data presented demonstrate a strong association between attainment of training milestones at 2 years-old with positive career outcomes. Early exercise had a beneficial effect on the musculoskeletal system (Firth and Rogers 2005; Rietbroek *et al*. 2007; van Weeren *et al*. 2008) and training, trialling or racing as a 2-year-old may be stimulating the tissues for the future racing workload when they are still receptive. Further investigation is required to quantify the early management and exercise practices of those horses that were started as 2-year-olds, to determine whether they received a rearing environment that has stimulated their development and the optimal age to stimulate the musculoskeletal tissue, so they are better suited and adapted to a racing career.

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APPENDIX A

Cox Regression Model Testing

As reported by Dohoo et al (2010) Modelling survival data *Veterinary Epidemiologic Research (2nd Ed)* p499

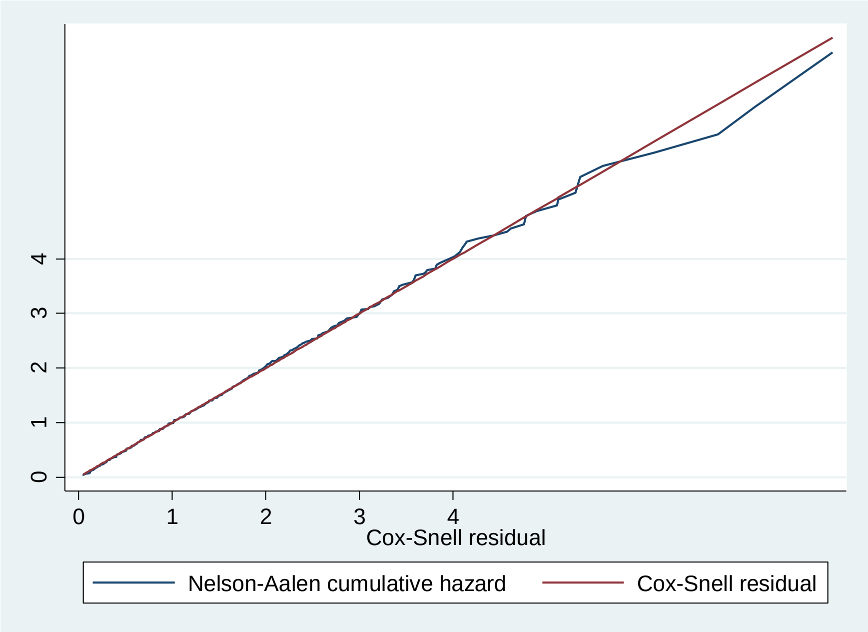

Figure A1: Cox-Snell residuals were computed and plotted for the Cox regression model for the outcome; number of race starts. It appears there is good agreement between the plotted values and the expected 45° line.

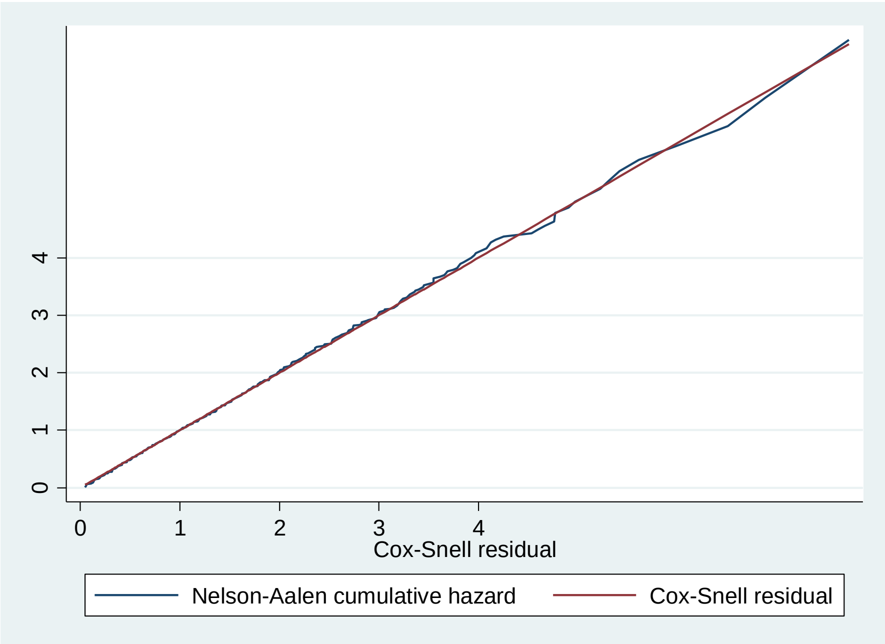

Figure A2: Cox-Snell residuals were computed and plotted for the Cox regression model for the outcome; number of race starts (2-year-old year omitted). It appears there is good agreement between the plotted values and the expected 45° line.

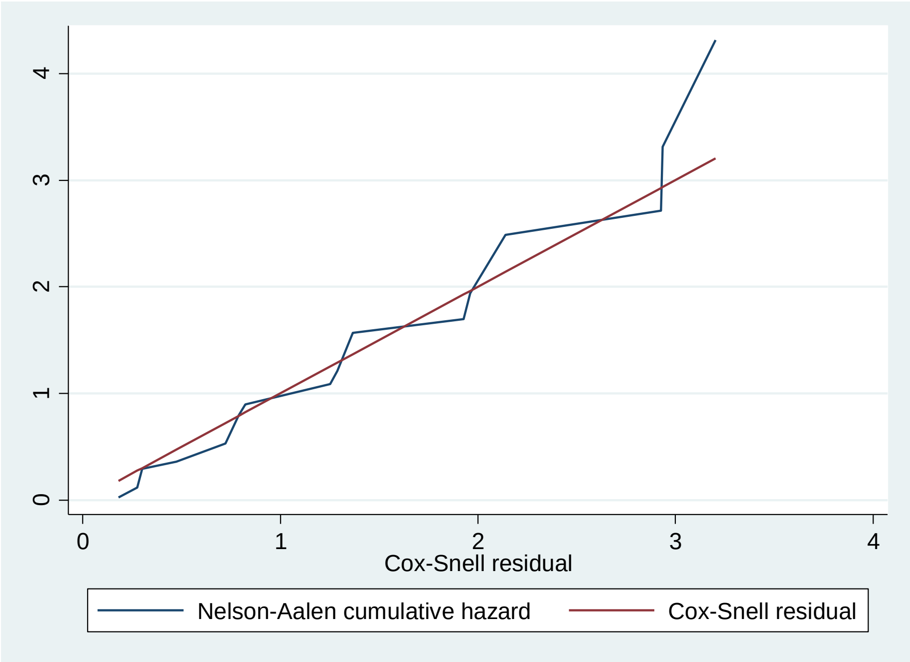

Figure A3: Cox-Snell residuals were computed and plotted for the Cox regression model for the outcome; number of years raced. It appears there is some deviation between the plotted values and the expected 45° line.

Linear Regression Model Testing

Evaluating normality of the residuals as reported by Dohoo et al (2010) Linear regression *Veterinary Epidemiologic Research* p. 352.

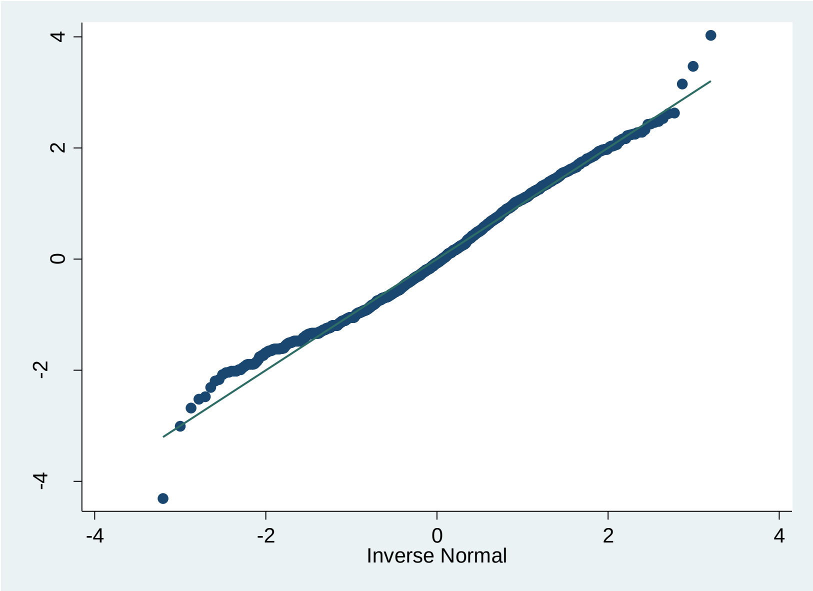

Figure A4: A Q-Q plot indicating normal distribution of the quantiles of the residuals versus the quantiles of the normal probability distribution for the outcome Total Earnings

PRELUDE TO CHAPTER 3

Similar to the previous chapter on Standardbred horses, Chapter 3 reports the retrospective following of a cohort of Thoroughbred foals born in 2001/2002 until the end of their 7-year-old season. The study utilises survival analysis, logistic regression and linear regression to examine the association of attaining training milestones at two years of age with outcomes measuring career length and racing success.

Supplementary statistical information on model diagnostics is appended to the end of this Chapter.

Chapter 3 is accepted for publication in Equine Veterinary Journal.

Tanner, J.C., Rogers, C.W. and Firth, E.C. (2011) The association of 2-year-old training milestones with career length and racing success in a sample of Thoroughbred horses in New Zealand. *Equine Veterinary Journal* **in press**.

CHAPTER 4

GENERAL DISCUSSION

SUMMARY OF FINDINGS

The primary aim of this thesis was to investigate the association of attainment of training milestones by 2-year-old horses with career length and racing success in a cohort of Standardbred and Thoroughbred horses in New Zealand. Previous studies have indicated that horses that begin their racing career during their 2-year-old year race for longer than those that start later in life (Bailey *et al.* 1999; More 1999; Physick-Sheard 1986b; Saastamoinen and Ojala 1994; Sobczynska 2007). However, these cohort studies were reporting findings from population studies rather than focussing on horses in their 2-year-old year. To the authors knowledge this is the first study to identify 2-year-old training milestones, and not just racing milestones, having a positive association with successful racing outcomes.

The results from this thesis demonstrated that horses that achieved training milestones as 2-year-olds had more race starts, were more likely to win or place in a race, and earned more money than horses that achieved those milestones later in life. This was true across both breeds of horse indicating that the training milestones were suitable predictors of future racing performance. As this study was based on data analysis only, it did not investigate the biology related to training and racing horses as 2-year-olds. However, the epidemiology of this study fits in with the biological findings of the positive effects of early exercise on musculoskeletal health by other authors (Barneveld and van Weeren 1999; Firth and Rogers 2005).

There was a high percentage of wastage within both the Thoroughbred and Standardbred racing industries in New Zealand. The number of horses failing to enter training and race in the 2001/2002 born population was in agreement with McCarthy's (2009) supply chain wastage report. Internationally the level of wastage appears similar with approximately 50% of Thoroughbred horses failing to race in the United Kingdom (Wilsher *et al.* 2006) and 33% of Standardbreds that fail to race in Canada (Physick-Sheard 1986a).

The difficulty of using one parameter to measure racing performance or success was highlighted. However, transformed earnings appeared to be the best and most reliable method of predicting racing success. The number of race starts is the most suitable predictor of career length. It is important that the number of race starts is used as an adjustment factor within the earnings model to improve model accuracy.

LIMITATIONS

This study utilised data from one year of foal crops only. However, the New Zealand Thoroughbred and Standardbred racing industries appear to be relatively homogenous across years, in particular the number of 2-year-old horses that race each year appears to remain relatively constant. The key industry production parameters in the year chosen were not appreciably different from other years and therefore the findings from the study cohort could be applied to foal crops from other years. Trainer was unable to be analysed within either dataset as the trainer at the time of data extraction may not have been the horse's trainer for its whole career. This may have been a limitation to the study as other authors have found 'Trainer' to be significantly associated with racing performance (Ely *et al.* 2010).

FUTURE APPLICATION AND FURTHER WORK

The raw data produced by the racing industry is a valuable tool for population-based research and highlights the importance of accurate database records and data collection. A good quality equine database capturing expansive and accurate records allows racing administrators to make informed decisions regarding future racing trends and policy adjustments, as well as being valuable for future epidemiological research. The methodology used in this study could become an industry tool applied across a number of Standardbred and Thoroughbred foal crops to make comparisons across years and to calculate average indices for the attainment of training milestones and racing success. It is important that Standardbred and Thoroughbred racehorses start in their 2-year-old year, as horses that begin training, trial, or race in that year have significantly longer and more successful careers than those that do not achieve the milestones until their 3-year-old year or later. From an industry perspective the correct management and training of horses during their 2-year-old year could have important implications for future horse performance. As the foal crop declines it is necessary to better utilise the pool of horses that are available to race. There is a high percentage of wastage in both the Thoroughbred and Standardbred industries, with approximately one-third of the foal crop failing to reach the first training milestone. The reasons behind this failure require further investigation as there are potentially ‘untapped’ horses that could enter training within this population.

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APPENDIX C

Table 1: Standardbred and Thoroughbred data variables supplied by Harness Racing New Zealand and New Zealand Thoroughbred Racing

Standardbred and Thoroughbred data variables
Name
Country first registered
Sex
Sire
Dam
Brand
Last registered trainer
Current registered owner
Age exported
Age registered with trainer
Number of trial starts per age
Number of trial wins per age
Number of trial places per age
Number of race starts per age
Number of race wins per age
Number of race places per age
Earnings per age
Total earnings