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# The genetic parameters of racing success and longevity in the New Zealand Thoroughbred racing industry

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**ABSTRACT**
Within the Thoroughbred industry, individual success can be measured with races and prize money won. At an industry level, there is a requirement for horses to be able to race from a young age and have a sustained injury-free career. Therefore, the variance components of such traits were investigated within ASReml for 26,920 New Zealand Thoroughbred racehorses. Age at first competitive high-speed event (trial or race start) had high heritability ($h^2 = 0.52 \pm 0.02$), and an inverse genetic correlation with career earnings ($-0.40 \pm 0.05$) and number of wins ($-0.35 \pm 0.06$). Career earnings ($h^2 = 0.24 \pm 0.02$) had positive genetic and phenotypic correlations ($0.59 \pm 0.004$) with career length, implying that racing success could be a useful selection proxy for career length. Horses that started earlier had longer career length ($-0.21 \pm 0.07$, $-0.18 \pm 0.01$). The low heritability of career length ($0.11 \pm 0.01$) reflects considerable environmental influence on this trait, reinforcing the importance of early training and exercise in increasing career length. Therefore, the optimal strategy is a selection programme focusing on racing success, which improves commercial appeal and is genetically correlated with longevity. A training and racing programme that encourage an early competitive high-speed event would optimise the phenotypic development of the musculoskeletal system and reduce injury risk.

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## Introduction

Success in Thoroughbred racing and breeding is defined as the production or training of a horse capable of winning the most important races, the 'group races'. Group races are commonly referred to as 'black type' races, as horses that win or are placed in these races have their names in the sales catalogue in bold font (NZTR 2024a, 2024b). At an individual level, racing success is the primary driver for breeding decisions. In New Zealand where approximately 37% of the Thoroughbred foal crop are exported as yearlings or young racehorses, astute breeding decisions that optimise performance and longevity

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ensure ongoing commercial viability for the breeder (Legg et al. 2023). At an industry level, traits such as age at first race, number of races and career length are also important to optimise the betting revenue generated, which underpins the financial viability of the racing industry (Legg et al. 2021, 2023).

The financial viability of the racing industry is heavily dependent on the revenue from betting turnover. Optimisation of betting turnover is dependent on the number of races offered, the quality of races and the number of participants in each race. However, across the major racing jurisdictions, there has been a steady and consistent contraction of the foal crop and a subsequent decline in the number of racehorses competing (International Federation of Horseracing Authorities 2019). Therefore, to maintain a sufficient number of horses in races, the current racehorse population is likely to have an increase in the number of starts and potentially longer racing careers (Legg et al. 2021). This shift in the pattern of racing places greater emphasis on breeding not only for individual success but also career duration at a population level.

For comparison of performance (or success) between racehorses, most analyses have focused on the (log) transformation of annual or lifetime (prize money) earnings (Bailey et al. 2022). The variance component estimates for earnings across racing jurisdictions are similar, in part due to the consistent relative distribution of prize money within a single race (according to placing) and the unequal distribution of prize money from the most important races (with a greater prize money pool) down to industry qualifying races (with lower prize money pools). The heritability estimates for earnings reported in the literature are generally moderate ($h^2 = 0.10–0.32$) (Park et al. 2011; Tozaki et al. 2012; Velie et al. 2015; Bailey et al. 2022; Sharman and Wilson 2023).

Increasing the number of races within a horse's racing preparation or career may increase injury risk, as an accumulation of cyclic loads appears to be the primary driver of many race day musculoskeletal injuries, particularly fractures (Rogers et al. 2020). Within the literature, there are estimates for the heritability of race day fracture, categorised either broadly as distal limb fracture (any fracture from the carpus distal) which were moderate ($h^2 = 0.21–0.37$), or at anatomically specific locations such as first phalanx, third metacarpal and carpal bone with low to moderate values ($h^2 = 0.09$, 0.17 and 0.40, respectively) (Welsh et al. 2014; Tozaki et al. 2019). Although heritability values for fracture were moderate, the relatively low incidence of race day fracture in New Zealand (~0.4/ 1,000 starters) (Gibson et al. 2022) make it impractical as selection criteria. Therefore, it may be more strategic to focus on traits associated with career longevity and durability rather than race day fracture directly.

Age at first race, or at first trial, has been reported to be associated with longer and more successful racing careers (Tanner et al. 2013; Velie et al. 2013; Flash et al. 2022). Based on data from intervention trials, it has been proposed that this may be due to the priming of the musculoskeletal system when the tissues are most receptive (Rogers et al. 2008, 2020). This alteration in the developmental pathway of the musculoskeletal tissue represents a positive change in phenotype. The selective breeding of a favourable genotype may provide a mechanism to amplify the positive phenotypic response of early exercise in the horse.

In light of the reduction in the number of horses entering the racing population, it is important to identify strategies on how the industry can best meet the need for successful and durable horses. The ability to positively alter phenotype by early exercise is well described. There is currently limited data on the relative genetic contribution to racing longevity. Therefore, the aim of this study was to estimate the heritability of traits associated with racing success and longevity in the New Zealand Thoroughbred population.

## Methods

### Data collection

Race records of all New Zealand Thoroughbred races (flat and jumps racing) for 17 racing seasons (2005/06–2022/23) were provided as an electronic extract by New Zealand Thoroughbred Racing (NZTR), the governing body for Thoroughbred racing in New Zealand. The extract provided race and horse-level data. Race data included the date of race or trial, race type (flat/steeplechase/hurdle) and earnings won for each race start. Horse data included horse name, sex (female; recorded as filly or mare, or male; recorded as stallion, gelding, colt or rig), date of birth, sire and dam. Pedigree information (sire, dam and dam sire) were provided as an extract from the NZTR official stud book records. The race and pedigree datasets were then combined using horse ID as the unique identifier. Horse eligibility was restricted to horses born between the 2003/04–2017/18 breeding seasons. This inclusion criteria ensured capture of race and trial data at the youngest age possible (horses can start in trials and races on 1st August of their 2nd year, when they officially become 2-year-olds) and sufficient number of seasons racing to ensure the final foal crop (the 2017/18 born foals) had completed their racing career, which typically is completed when the horse is 6 years old (Legg et al. 2021). The completion of racing career was further confirmed using the criteria of a period of greater than 365 days since the last recorded race start.

### Traits derived

To describe racing success and career longevity the following traits were calculated: age at first competitive high-speed event (number of days from birth until either first trial or race start, whichever occurred first), age at first race start (number of days from birth), total career starts, total career length (days from first to last recorded race start) and number of races per season (horses with only 1 race start had a career length of 1 d) and total career earnings. Career earnings were heavily skewed and were log-transformed for analysis.

### Data analysis

Genetic parameters were estimated for all traits derived using ASReml version 4.2 software package (Butler et al. 2023). A single-trait animal model was used to estimate variance components to calculate heritability. A bivariate animal model was also used to estimate the genetic and phenotypic correlations between two traits. Horse sex, race type (flat, hurdle and steeple), and year of birth were included as fixed effects and animal was included as a random effect in the single-trait and bivariate animal models for all traits. Trainer was attempted to be fitted as a random effect within the models but failed to permit models to converge.

In matrix notation, the bivariate model can be represented as Equation (1):

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} + \begin{bmatrix} Z_1 & 0 \\ 0 & Z_2 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} \tag{1}$$

where $\mathbf{y_1}$ and $\mathbf{y_2}$ are the vectors of phenotypic measures for two traits under study, $\mathbf{X_1}$ and $\mathbf{X_2}$ and $\mathbf{Z_1}$ and $\mathbf{Z_2}$ are design matrices relating the fixed and additive genetic effects to the phenotypes respectively, $\mathbf{b_1}$ and $\mathbf{b_2}$ are the solution vectors of fixed effects of sex, race type, year of birth and racing status (active/retired), $\mathbf{u_1}$ and $\mathbf{u_2}$ are the vectors of random genetic effects of animal for each trait and $\mathbf{e_1}$ and $\mathbf{e_2}$ are vectors of residual errors not accounted for by the fixed and random effects. The distributional properties of the elements in the model with $E$ and $V$ indicating the expectation and variance were as follows in Equation (2) and Equation (3):

$$\mathrm{E}\begin{bmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \end{bmatrix} = \begin{bmatrix} \mathrm{X}_1 & 0 \\ 0 & \mathrm{X}_2 \end{bmatrix} \begin{bmatrix} \mathrm{b}_1 \\ \mathrm{b}_2 \end{bmatrix} \tag{2}$$

$$V\begin{bmatrix} u_1 \\ u_2 \\ e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} A\sigma^2_{a1} & A\sigma_{a12} & 0 & 0 \\ A\sigma_{a12} & A\sigma^2_{a2} & 0 & 0 \\ 0 & 0 & I\sigma^2_{e1} & I\sigma_{e12} \\ 0 & 0 & I\sigma_{e12} & I\sigma^2_{e2} \end{bmatrix} \tag{3}$$

where $\mathbf{A}$ is the numerator relationship matrix of size 33,286, the total number of animals in the pedigree file; $\boldsymbol{\sigma}^2_{a1}$, $\boldsymbol{\sigma}^2_{a2}$, and $\boldsymbol{\sigma}_{\mathbf{a12}}$ are the additive animal (co)variance components for the traits under consideration, $\mathbf{I}$ is an identity matrix of size 21,691, the number of phenotypic records; $\boldsymbol{\sigma}^2_{\mathbf{e1}}$, $\boldsymbol{\sigma}^2_{\mathbf{e2}}$, $\boldsymbol{\sigma}_{\mathbf{e12}}$ are the residual error (co)variance components for the traits. Estimates of (co)variance components were obtained using the Restricted Maximal Likelihood procedure in ASReml package (Butler et al., 2023).

Heritability ($h^2$) of a trait was calculated as displayed in Equation (4):

$$h^2 = \frac{\sigma^2_a}{(\sigma^2_a + \sigma^2_e)} \tag{4}$$

where $\sigma^2_a$ = additive animal variance and $\sigma^2_e$ = residual error variance

Genetic correlations ($r_g$) were calculated as displayed in Equation (5):

$$r_g = \frac{\sigma_{g12}}{\sigma_{g1} \times \sigma_{g2}} \tag{5}$$

where $\sigma_{g12}$ = genetic covariance between trait 1 and trait 2, equivalent to $\sigma_{a12}$, $\sigma_{g1}$ = genetic additive standard deviation for trait 1, equivalent to $\sqrt{\sigma^2_{a1}}$, .. = genetic additive standard deviation for trait 2, equivalent to $\sqrt{\sigma^2_{a2}}$, and phenotypic correlations ($r_p$) were calculated as displayed in Equation (6):

$$r_p = \frac{\sigma_{p12}}{\sigma_{p1} \times \sigma_{p2}} \tag{6}$$

where $\sigma_{p12}$ = phenotypic covariance between trait 1 and trait 2, equivalent to $\sigma_{a12} + \sigma_{e12}$, $\sigma_{p1}$ = phenotypic standard deviation for trait 1, equivalent to

$\sqrt{\sigma_{a1}^2 + \sigma_{e1}^2}$, and $\sigma_{p2} =$ phenotypic standard deviation for trait 2, equivalent to $\sqrt{\sigma_{a2}^2 + \sigma_{e2}^2}$.

## Results

There were 61,358 horses born during the 2003/04–2017/18 breeding seasons and these were the progeny of 18,523 mares and 803 sires. The merged dataset of race and pedigree records resulted in records for 26,920 horses, 13,419 males and 14,852 females (40% of the foal crop) which were the progeny of 12,854 mares and 633 sires. The majority of the horses in the data set (80%) were the progeny of 20% of the sires recorded. Eighty percent (21,645/26,920) of the horses were registered to 20% (316/1371) of trainers in the dataset (Figure 1). There was also an unequal distribution of sires within these trainer groups, with 57% ($n = 788/1371$) of trainers having trained horses representing 5 or fewer different sires (Figure 2).

The horses had 385,635 race and 94,213 trial starts. Most horses recorded their first competitive high-speed event as a 2-year-old (43 ± 11%) or 3-year-old (39 ± 4%). Most (87 ± 7%) horses had a trial start prior to their first race start. Fewer horses (17 ± 4%) had their first race start as a 2-year-old compared to horses that had their first start as a 3-year-old (50 ± 8%). The descriptive statistics for the career, longevity and

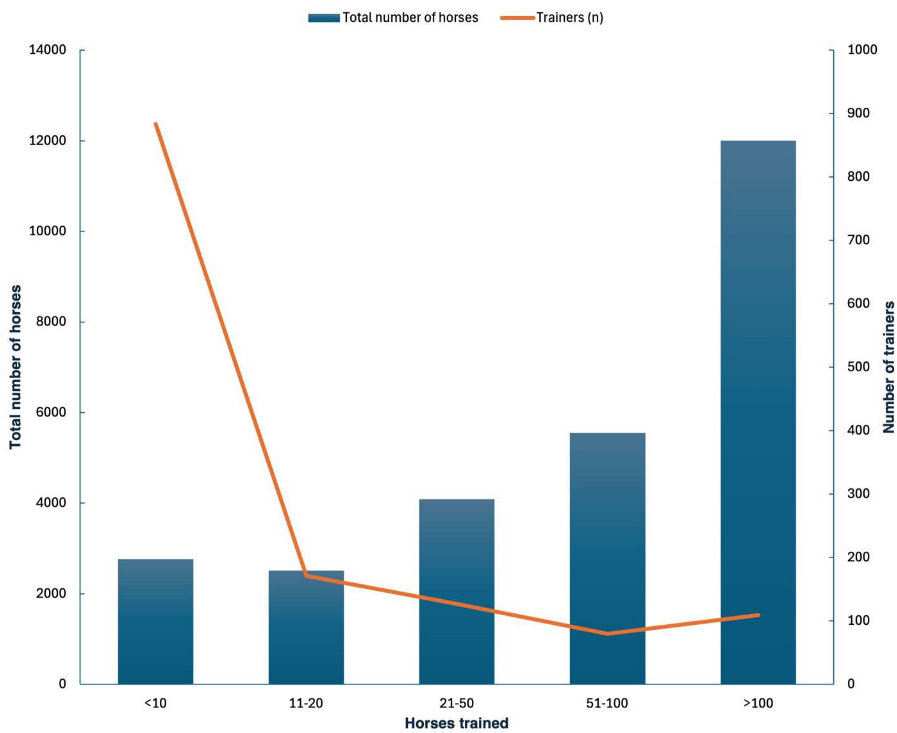


**Figure 1.** The total number of trainers (line, right axis) and the distribution of total number of horses trained (bar, left axis) by categories of horses trained per trainer (<10, 11–20, 21–50, <100) over seventeen Thoroughbred racing seasons in New Zealand (2005/06 – 2022/23).

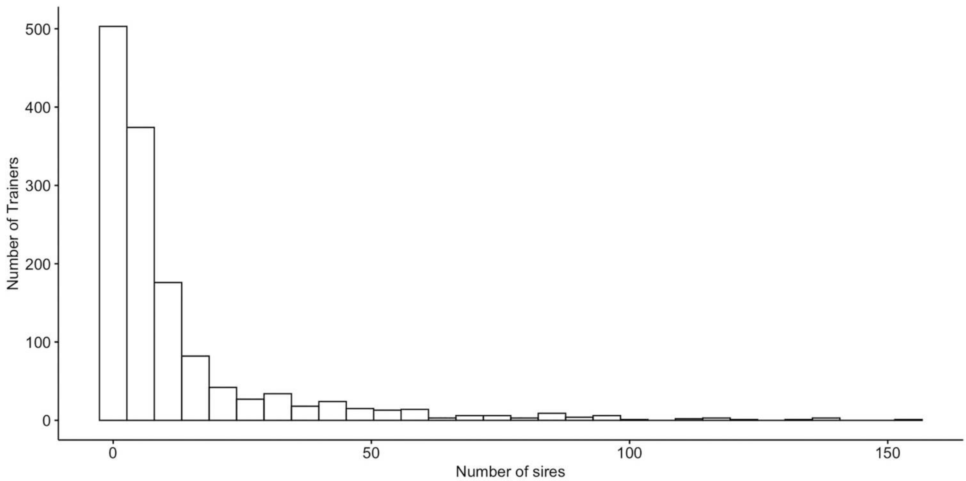


**Figure 2.** Relative distribution of number of sires clustered within trainer over seventeen Thoroughbred racing seasons in New Zealand (2005/06 – 2022/23).

performance of New Zealand racehorses included in the analyses are presented in Table 1. The median career length was 462 (134–884) days and the median age at last race was 5 (4–6) years old. There was a large range in the number of races during a career (1–160). There was no significant between-year difference in age at last race or career length indicating limited or no right censoring of the career data. Few horses within this dataset had only one career race start (7.2%), and 1.1% had one career race start with no trial. Fifty-one per cent of horses had won at least one race and 28% of horses won ≥2 races during their career.

## Heritability estimates

Heritability estimates and standard errors for career, longevity and performance traits are presented in Table 2. Age at the first competitive high-speed event (days) ($h^2 = 0.52 \pm 0.02$) and age at the first race start ($h^2 = 0.37 \pm 0.02$) had the highest heritability estimates, followed by career earnings ($h^2 = 0.24 \pm 0.02$) while all other traits examined ranged between 0.08 and 0.12 ± 0.01.

## Phenotypic and Genetic correlations between traits

There were moderate to strong positive phenotypic correlations between career earnings, number of flat races won, total number of races, races per racing season and career length (0.56 ± 0.01–0.78 ± 0.003) (Table 3). The genetic associations for the measures of racing performance were high, reflecting strong co-linearity in the different measures of racing performance. Near unity values were observed between career earnings and number of flat wins (0.96 ± 0.01) and between career length and career total number of starts (0.96 ± 0.01). However, more moderate phenotypic and genetic associations were observed for career earnings with the total number of career races or career length (0.55–0.66).

**Table 1.** Median (IQR), and range of career, longevity and performance traits for a population of New Zealand Thoroughbred racehorses that raced between the 2005/06 and 2022/23 racing seasons.

| Year cohort | Number of horses | Age at first competitive high-speed event (days) | Age at first race start (days) | Age last race (days) | Career length (days) | Career total number of races | Average number of races per racing season | Career number of flat race wins | Career earnings (NZ$) |
|---|---|---|---|---|---|---|---|---|---|
| 2003/4 | 1958 | 1066 (877, 1230) | 1214 (1077, 1409) | 1787 (1463, 2196) | 501 (147, 934) | 10 (4, 22) | 5 (3, 7) | 1 (0, 2) | 5550 (162, 19,450) |
| 2004/5 | 1971 | 1041 (881, 1244) | 1230 (1080, 1432) | 1807 (1506, 2239) | 532 (168, 968) | 11 (4, 22) | 5 (3, 7) | 1 (0, 2) | 5675 (187, 21,735) |
| 2005/6 | 2068 | 1047 (883, 1200) | 1191 (1081, 1396) | 1736 (1417, 2147) | 446 (137, 881) | 10 (4, 20) | 4 (3, 7) | 0 (0, 2) | 4618 (150, 16,014) |
| 2006/7 | 1939 | 1049 (882, 1235) | 1198 (1068, 1414) | 1731 (1443, 2156) | 458 (113, 918) | 10 (4, 20) | 4 (3, 7) | 0 (0, 2) | 4550 (150, 16,600) |
| 2007/8 | 2043 | 1043 (884, 1220) | 1193 (1066, 1404) | 1747 (1436, 2206) | 455 (140, 946) | 10 (4, 21) | 5 (3, 7) | 1 (0, 2) | 4950 (175, 19,775) |
| 2008/9 | 2051 | 1069 (907, 1275) | 1239 (1084, 1437) | 1788 (1441, 2216) | 451 (121, 885) | 9 (4, 21) | 4 (3, 6) | 0 (0, 2) | 4925 (175, 20,175) |
| 2009/10 | 1904 | 1081 (897, 1286) | 1214 (1078, 1427) | 1800 (1436, 2230) | 499 (128, 934) | 10 (4, 21) | 4 (2, 6) | 1 (0, 2) | 5738 (175, 21,863) |
| 2010/11 | 1770 | 1057 (897, 1252) | 1207 (1071, 1397) | 1764 (1426, 2194) | 481 (138, 917) | 10 (4, 20) | 4 (3, 6) | 1 (0, 2) | 5850 (300, 22,275) |
| 2011/12 | 1801 | 1039 (888, 1227) | 1200 (1064, 1374) | 1746 (1447, 2191) | 494 (167, 919) | 10 (4, 21) | 4 (2, 6) | 1 (0, 2) | 6425 (350, 25,185) |
| 2012/13 | 1793 | 1055 (880, 1247) | 1194 (1069, 1406) | 1777 (1466, 2226) | 511 (188, 962) | 10 (4, 21) | 4 (3, 6) | 1 (0, 2) | 7075 (250, 29,600) |
| 2013/14 | 1570 | 1041 (892, 1231) | 1210 (1073, 1418) | 1766 (1450, 2192) | 484 (148, 967) | 9 (4, 20) | 4 (2, 6) | 0 (0, 2) | 6825 (250, 28,174) |
| 2014/15 | 1679 | 1074 (903, 1268) | 1245 (1101, 1448) | 1789 (1475, 2252) | 473 (130, 947) | 10 (4, 19) | 4 (3, 6) | 1 (0, 2) | 7475 (500, 28,260) |
| 2015/16 | 1495 | 1043 (899, 1224) | 1213 (1085, 1401) | 1824 (1451, 2247) | 478 (131, 885) | 9 (4, 18) | 4 (2, 6) | 1 (0, 2) | 7904 (600, 28,875) |
| 2016/17 | 1379 | 1034 (877, 1236) | 1197 (1064, 1473) | 1779 (1508, 2172) | 435 (129, 715) | 9 (4, 16) | 4 (3, 6) | 1 (0, 2) | 9920 (1140, 32,450) |
| 2017/18 | 1499 | 1056 (910, 1204) | 1222 (1101, 1381) | 1744 (1450, 2025) | 464 (166, 759) | 10 (4, 18) | 4 (2, 6) | 1 (0, 2) | 10,060 (1280, 32,674) |
| All cohorts | 26,920 | 1053 (890–1240) | 1211 (1077–1415) | 1772 (1453, 2175) | 462 (134–884) | 9 (4–19) | 4 (3–6) | 1 (0–2) | 6125 (325–23,363) |

**Table 2.** Estimates of heritability ($h^2$) and standard errors (S.E.) for the career, longevity and performance traits in Thoroughbred racehorses in New Zealand that raced between the 2005/06 and 2022/23 racing seasons.

| Trait | $\sigma_a^2$ | $\sigma_e^2$ | $\sigma_{total}^2$ | $h^2 \pm S.E.$ |
|---|---|---|---|---|
| Age at first competitive high-speed event (days) | 34703 | 32109 | 66812 | 0.52 ± 0.02 |
| Age at first race (days) | 22437 | 38701 | 61138 | 0.37 ± 0.02 |
| Career earnings (log) | 3.75 | 11.58 | 15.33 | 0.24 ± 0.02 |
| Career number of flat race wins | 0.47 | 3.42 | 3.89 | 0.12 ± 0.01 |
| Career total number of races | 24.30 | 174.63 | 198.93 | 0.12 ± 0.01 |
| Career length (days) | 32,168 | 256,535 | 288,703 | 0.11 ± 0.01 |
| Average races per racing season | 0.60 | 6.79 | 7.39 | 0.08 ± 0.01 |

Notes $\sigma_a^2$ = animal additive variance, $\sigma_e^2$ = residual error variance, $\sigma_{total}^2$ = sum of all variances.

Age at first competitive high-speed event and age at first race had close to unity genetic correlation (0.99 ± 0.01) and strong phenotypic correlation (0.91 ± 0.001), reflecting that these are essentially identical traits. Phenotypically, horses that trialed or raced as 2-year-olds had greater earnings, more races per season and during their career and had longer careers. This pattern was also reflected in the genetic associations of age at first start. The exception to this trend was the low negative genetic association between age at first race and number of career races.

## Discussion

The demographics of the current dataset reflect earlier reports of the New Zealand Thoroughbred racing industry (Tanner et al. 2013; Legg et al. 2021, 2023). The low percentage of the foal crop with a New Zealand race record (~40%) is a consequence of the strong export focus of the New Zealand industry with approximately 37% of the foal crop exported annually, most of which are exported as youngstock (predominantly as yearlings) or as 2-year-olds in early work and prior to their first start (Rogers et al. 2017; Legg et al. 2023). Historically only 57% of the (non-exported) foal crop were recorded as having a trial start (Tanner et al. 2013). This data indicates that in recent years, the percentage of the non-exported foal crop that recorded a trial start has increased slightly, to approximately 66% in New Zealand.

The majority of horses had their first high-speed event as 2-year-old and their first race start as a 3-year-old. This pattern reflects the observation that in New Zealand, the primary reason for training horses as a two-year-old is education and to obtain an early gauge on the precociousness and talent of the young racehorse (Bolwell et al. 2010; Rogers et al. 2020). Age at first start and age at first race had high genetic correlations and this implies that, within the current dataset, these could be considered the same trait. This is useful from a population analysis perspective as only ~20% of the horses have a race start as a 2-year-old.

Epidemiological studies in both New Zealand (Tanner et al. 2013) and Australia (Flash et al. 2022) have shown that horses that had an early start in their racing career (either a trial or race start as a 2-year-old) had longer and more successful careers. The positive genetic and phenotypic association of young age at first competitive start and measures of racing success (career earnings and race wins) observed here is consistent with these findings. The uniformity of the early two-year-old production process in New Zealand

**Table 3.** Estimates of genetic (below diagonal) and phenotypic correlations (above diagonal) and standard errors for the career, longevity and performance traits in New Zealand Thoroughbred racehorses that raced between the 2005/06and 2022/23 racing seasons.

| | Age to first competitive high-speed event (days) | Age to first race (days) | Career earnings (log NZ$) | Career number of flat wins | Career total number of races | Career length (days) | Average number of races per season |
|---|---|---|---|---|---|---|---|
| Age to first competitive high-speed event (days) | | 0.91 ± 0.001 | −0.20 ± 0.01 | −0.14 ± 0.01 | −0.15 ± 0.01 | −0.18 ± 0.01 | −0.18 ± 0.01 |
| Age to first race (days) | 0.99 ± 0.01 | | −0.20 ± 0.01 | −0.15 ± 0.01 | −0.16 ± 0.01 | −0.19 ± 0.01 | −0.15 ± 0.01 |
| Career earnings (log NZ$) | −0.40 ± 0.05 | −0.40 ± 0.05 | | 0.60 ± 0.004 | 0.62 ± 0.004 | 0.59 ± 0.004 | 0.65 ± 0.004 |
| Career number of flat wins | −0.35 ± 0.06 | −0.39 ± 0.06 | 0.96 ± 0.01 | | 0.72 ± 0.003 | 0.64 ± 0.004 | 0.56 ± 0.01 |
| Career total number of races | −0.05 ± 0.07 | −0.05 ± 0.07 | 0.55 ± 0.04 | 0.66 ± 0.04 | | 0.88 ± 0.002 | 0.78 ± 0.003 |
| Career length (days) | −0.28 ± 0.07 | −0.21 ± 0.07 | 0.59 ± 0.06 | 0.69 ± 0.05 | 0.96 ± 0.01 | | 0.58 ± 0.004 |
| Average number of races per racing season | −0.36 ± 0.07 | −0.45 ± 0.06 | 0.78 ± 0.04 | 0.83 ± 0.04 | 0.89 ± 0.03 | 0.75 ± 0.06 | |

(Bolwell et al. 2010) may explain the greater heritability estimate for age at first competitive high-speed event ($h^2 = 0.52 \pm 0.02$) compared to age at first race ($h^2 = 0.37 \pm 0.02$). The heritability values estimated for age at first competitive high-speed event and age at first race reflect the industry perception that precociousness and racing success are highly heritable in the Thoroughbred.

The heritability estimates for career earnings of the New Zealand population in the current study were similar to those reported in other jurisdictions such as Australia, Hong Kong and the non-linear estimates from Japan, which ranged from $h^2 = 0.19$–0.34 (Tozaki et al. 2012; Velie et al. 2015). The similarity in heritability suggests that irrespective of the total stakes on offer in each country, the relative distribution of prize money within a race and between the different grades of races is consistent between racing jurisdictions (NZTR 2024c). It is generally recognised that the heritability estimates for this trait (career earnings) may contain some positive bias due to preferential treatment or opportunities and assortative mating. Horses by well-performing, and thus expensive sires are more likely to have greater racing opportunities (i.e. placed with higher ranking trainers and greater financial support) compared to those by lower performing or less commercial sires. The less commercial sires are also more likely to be mated to a greater proportion of lesser performing mares, and their progeny in turn may have fewer opportunities to race (Rogers and Gee 2011).

In the current study, there was a moderate genotypic and phenotypic association of career earnings with career length. The majority (~60%) of prize money on offer within Thoroughbred racing in New Zealand is targeted towards two-and three-year-old races (Bolwell et al. 2014), and thus the economic incentive to race lower performing horses after three years of age decreases. A similar structure is observed in most racing jurisdictions and this skew in prize money offered reduces the linearity of the relationship between career length, number of races and career earnings. The linearity between success (prize-money) and longevity (i.e. career starts and length) can be further distorted with the earlier retirement to stud of elite higher performing horses (typically after their 3-year-old season). New Zealand has an active export market for 2-year-old ready-to-race, and early race career 3-year-olds and thus owners and trainers have an economic incentive to export elite high-performing horses in their 3-year-old racing year. Therefore, the career length of these horses may be artificially shortened within the dataset due to its termination of New Zealand racing records. In some jurisdictions, such as the United States of America, this is accentuated with the use of claiming races that permit an extended racing career for the lower grade horses (Legg et al., 2023). These jurisdictional differences should be considered when comparing estimates between racing jurisdictions.

The high export rate of horses restricted the size of the dataset for analysis. However, the objective of this study was to focus on the New Zealand racing conditions and pattern of racing. The inclusion of race data from the largest export markets, namely Australia and Hong Kong could have increased the sample size but may introduce some additional environmental variation and bias down the variance component estimates. Support for this view is the observation of lower heritability estimates with the linear vs non-linear categorisation of race earnings (Tozaki et al. 2012). In contrast to New Zealand and Australia, Hong Kong has strict entrance performance criteria for horses, which effectively limits entry of New Zealand horses into Hong Kong until they have demonstrated sufficient ability in a trial or race in New Zealand, generally as a 2-year-old.

At present, there are few heritability estimates for career longevity reported within the literature. Heritability estimates for career length of the New Zealand population were similar to estimates reported in one study for horses racing in Australia and Hong Kong (0.11 vs 0.10), which reflects a large environmental influence to career length rather than a genotypic effect (∼90% of variance being due to non-genetic factors) irrespective of jurisdiction (Velie et al. 2015). This heritability also indicates that this trait requires longer and a greater selection pressure to obtain selection progress. Commercially, racing success rather than longevity provides the driver for increased sale price. It is therefore unlikely that commercial breeders would divert selection pressure away from racing success to increase the emphasis on longevity. However, practically the high heritability of career earnings and its positive association with career length within the New Zealand population indicates that at a selection level, career earnings would also provide a suitable selection trait for racing longevity and indirectly durability.

Lack of talent, followed by musculoskeletal injury are the leading causes for a horse to cease training and racing (Perkins et al. 2005; Shrestha et al. 2021). Across a number of epidemiological and intervention studies, a positive effect of early exposure to exercise and training on moderating risk factors for injury has been demonstrated (Rogers et al. 2008, 2020). The physiological basis for this is believed to be due to the priming or upregulating of the tissue (cartilage and bone) within the musculoskeletal system (Rogers et al., 2020). These findings provide a possible explanation for the phenotypic association between earlier age to the first competitive high-speed event with a longer career length.

The lower heritability of career length indicates that rather than directly selecting for this trait as a proxy for durability and musculoskeletal health, the industry would achieve optimal phenotypic response by selecting for career success (career earnings, wins) and ensuring the horse had either a trial or race start as a 2-year-old. This appears to be current industry practice and reflects potentially a holistic view of racing success and horse welfare.

## Conclusion

The high heritability for career earnings was in agreement with other published reports and reflects the primary selection focus of the Thoroughbred racing industry. A younger age at the first competitive high-speed event was highly heritable and positively associated with measures of racing success, reflecting observations in other racing jurisdictions. To optimise genetic progress for racing success and reduce the risk profile for musculoskeletal injury, breeders could focus on breeding stock with high career earnings and ensure horses have a competitive high-speed event as a 2-year-old.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Data availability statement

The data that support the findings of this study were provided by New Zealand Thoroughbred Racing [third party]. These data are available upon request and permission from New Zealand Thoroughbred Racing.

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