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Better hoof, better horse – genetic correlations between ability to race barefoot and performance in trotting horses

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A B S T R A C T

Harness racing is popular in several parts of the world, and the ability to race barefoot is an important trait for success because of its effect on racing time. Barefoot racing is also discussed in terms of animal welfare because not all horses have hooves that tolerate racing without shoes. In Swedish Standardbred trotters (**SB**) and Swedish-Norwegian Coldblooded trotters (**CB**), the proportion of barefoot races and the probability to race barefoot in any given race (barefoot status) have low–to–moderate heritability (h^2 = 0.07–0.28). However, the genetic correlation between the ability to race barefoot and performance in harness racing has not previously been studied. Therefore, this study aimed to estimate the genetic correlations between the barefoot traits and performance traits. Three- to ten-year-old horses born from 2002 to 2018 (SB) or from 2002 to 2017 (CB) were included for the two barefoot traits. The horses were required to have raced at least ten (SB) or five times (CB). For the proportion of barefoot races, 24 928 SB with 724 232 observations and 4 050 CB with 97 682 observations were included. For barefoot status, 25 973 SB with 875 056 observations and 3 384 CB with 93 376 observations were included. Data for racing performance consisted of summarised records for 115 185 SB aged 2–5 years born 1976–2019, and 16 360 CB aged 3–6 years born 1978–2017. The performance traits included best racing time per km, summarised earnings, and placings. For SB, also earnings per start and number of starts were included. Genetic correlations and breeding values were estimated with bivariate mixed linear animal models for each breed. The absolute value of the genetic correlation between the proportion of barefoot races and performance was 0.42–0.50 in SB and 0.41–0.62 in CB. For barefoot status, the corresponding genetic correlation for SB was 0.01–0.63 and for CB 0.26–0.59. Mostly, for performance traits, a stronger genetic correlation was found with the proportion of barefoot races than with barefoot status. The annual genetic improvement was larger for the proportion of barefoot races than for barefoot status for both breeds. In conclusion, the proportion of barefoot races and barefoot status was favourably correlated with performance. These novel traits seem to add information beyond performance and could be of interest for inclusion in the genetic evaluation of SB and CB, and possibly also for other trotter populations.

Implications

Racing barefoot improves horses' speed in trotting races. Consequently, the ability to race barefoot repeatedly is of economic importance. It is also an animal welfare issue discussed in several countries, as not all trotters tolerate barefoot racing. The proportion of barefoot races, as well as barefoot status in individual races, is heritable in Standardbred and Coldblooded trotters. In most cases, favourable and moderately strong genetic correlations were found between the barefoot traits and performance. Inclusion of a barefoot trait in the genetic evaluation would be possible. How barefoot racing in young horses impacts racing longevity remains to be studied.

Introduction

Trotting horses are commonly raced barefoot to improve speed (Solé et al., 2020), but not all horses can perform in sports and stay sound without being shod (Moiroud et al., 2014; Spörndly-Nees et al., 2023). Having strong and durable hind hooves seems to be a key factor for the ability to race barefoot in trotters (Spörndly-Nees et al., 2023). Hoof quality, measured as strength and chemical composition of the hoof, has been shown to differ within breeds (Spörndly-Nees et al., 2023) but also between breeds (Ott and

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Johnson, 2001), indicating that variation in hoof quality has a genetic background.

Recently, genetic variation was shown to partly explain the ability to race barefoot in Swedish Standardbred trotters (**SB**) and Swedish-Norwegian Coldblooded trotters (**CB**) (Berglund et al., 2025a). The ability to race barefoot was defined in two ways: as the proportion of races the horses raced with barefoot hind hooves, and as the barefoot status (shod or unshod hind hooves) at a race. These two traits showed low–to–moderate heritability estimates in SB and CB (h^2 = 0.17–0.28 and h^2 = 0.07–0.08, respectively), and estimated breeding values (**EBV**s) between these traits were highly correlated (Berglund et al., 2025a). No genetic studies on the ability to race barefoot have been carried out in other trotter populations, and no genetic evaluations including such a trait have been implemented yet. Information on shoeing condition is registered in Sweden as well as in several other European countries, such as France, Finland, Italy, and Norway.

The breeding goal of SB is to produce horses that are sound and healthy and that are competitive in trotting races. The horses should be well adapted to perform in the sport; they should be easy to handle, have a well-functioning conformation, a good trot, and also perform well over long distances (Svensk Travsport, 2025a). After their racing careers, the horses should function well in breeding. For CB, the breeding goal is to preserve the breed and breed type, improve performance, and keep the horses sound and durable (Svensk Travsport, 2025a). The horses should have a good temperament, and after their racing careers, function well in breeding.

Breeding programmes for trotting horses are usually focused on improving racing performance, and traits commonly included in genetic evaluations are related to speed, earnings, and placings (Árnason et al., 1989; Klemetsdal, 1989; Röhe et al., 2001; Langlois and Vrijenhoek, 2004; Gómez et al., 2011b; Suontama et al., 2013). The current genetic evaluation of SB includes summarised performance from 3– to 5-year-old horses (including also 2-year-old performance if available but not until the horse is at least 3 years of age) from the following traits with their heritability in parentheses (updated values originally developed by Árnason et al. (1989) and Árnason (1999; 2001)): best racing time per kilometre (0.38), summarised earnings (0.39), earnings per start (0.44), percentage of first to third placings (0.35), number of starts (0.18), and start status (0.40) (whether the horse has started in a race or not). In CB, summarised performance from 3- to 6-year-old horses is included and the traits that contribute with information in the genetic evaluation are as follows: best racing time per kilometre (0.35), summarised earnings (0.30), percentage of first to second placings (0.25), and start status (0.20) (Árnason et al., 1989; Klemetsdal, 1989). The genetic correlations between the different performance traits are strong in both SB and CB. Árnason (1999) estimated the genetic correlation between best racing time, earnings, earnings per start, and placings in the absolute range of 0.75 to 0.97 for SB. Also, in CB, the genetic correlation between some of the performance traits is close to one (Árnason et al., 1989; Klemetsdal, 1994).

The heritability of race speed in trotters of warmblood type in other countries has been estimated in the range 0.17–0.34 (Bugislaus et al., 2002; Bugislaus et al., 2005; Suontama et al., 2012; Ricard, 2015), for summarised earnings, the range is 0.08–0.27 (Gómez et al., 2011a; Suontama et al., 2012), for earnings per race 0.01–0.31 (Bugislaus et al., 2005; Suontama et al., 2012; Ricard, 2015), and for placings, the range of heritability estimates is 0.05–0.22 (Pösö and Ojala, 1997; Bugislaus et al., 2005; Suontama et al., 2012). However, it should be noted that the exact definition of the traits and their transformations differs between countries. For the Finnhorse, a trotter of coldblooded type that occasionally competes against CB, the heritability for performance traits has been estimated in the range of 0.28–0.34, 0.01–0.19, and 0.10 for best racing time, earnings, and placings, respectively (Suontama et al., 2012).

There is a phenotypic association between barefoot races and performance in trotters. Solé et al. (2020) showed that racing fully barefoot reduces time by ~0.7 s/km in SB, but increases galloping/disqualification risk by 15–35%. Dabbene et al. (2018) found that racing with barefoot hind hooves increased injuries on the front limbs caused by interference (when the hind hoof touches the front leg) in Standardbred trotters. However, Bertuglia et al. (2014) could not see any effect of barefoot racing on the risk of musculoskeletal injuries in Standardbred trotters followed over a period of 4 years. Many studies on hooves are linked to conformation, and hoof conformation is known to impact performance in trotting races as well as the trotters' soundness (Magnusson and Thafvelin, 1990; Dolvik and Klemetsdal, 1994).

Regulations regarding barefoot racing differ between European countries, and more or less detailed regulations per member country are published online by the European Trotting Union (The European Trotting Union, 2025a). In France, horses 4 years and older are allowed to race a maximum of 15 barefoot races (excluding races on grass) in 12 consecutive months as a result of new regulations implemented in 2024 (Le Trot, 2024). In Sweden, barefoot racing is only allowed for horses 3 years or older and in the period from March 1 to November 30 (Svensk Travsport, 2024). In Finland, where barefoot racing is allowed in the period from March 16 to November 14, regulations differ between SB and CB, where the former are allowed to race barefoot from age 3, and the latter from age 4 (The European Trotting Union, 2025b). In Italy, horses are allowed to race barefoot from age 3 (The European Trotting Union, 2025d), whereas in Germany, horses can race barefoot from age 4 (The European Trotting Union, 2025c).

There are no published studies on the genetic correlation between the ability to race barefoot and performance in trotters. The objective of this study was, therefore, to estimate the genetic correlations of two novel traits reflecting the ability to race barefoot, the proportion of barefoot races, and barefoot status, with performance traits in SB and CB. This information is needed to determine the suitability of any of the traits representing the ability to race barefoot for inclusion in the genetic evaluation of trotters, to ascertain that the new trait includes genetic variation not already explained by the currently used performance traits.

Material and methods

Data material and trait definitions

Barefoot data

Two definitions of the ability to race barefoot, proportion of barefoot races, and barefoot status, previously described by Berglund et al. (2025a), were used in the study. The proportion of barefoot races was a summarised trait reflecting the relative frequency of barefoot races in a set time period, whereas barefoot status indicated if the horse raced barefoot or not for each race (repeated measurements). For both traits, racing barefoot was defined as racing with barefoot hind hooves. In most cases, when the horses raced barefoot hind, they were also racing with barefoot front hooves (fully barefoot) (74% of the races in SB and 59% in CB). The data used were provided by the Swedish Trotting Association and consisted of repeated observations of shoeing information from Swedish trotting races from the years 2005 to 2022 in SB and from the years 2005 to 2021 in CB. Observations from 3- to 10-year-old horses at the time of the race and born in 2002–2018 (SB) and in 2002–2017 (CB), with at least 10 races for SB and five races for CB were included.

Following the trait definitions by Berglund et al. (2025a), observations from ridden (monté) races were removed (46 119 for SB and 4 597 for CB). The CB horses were born in Sweden or Norway. SB horses born outside of Sweden were excluded from the dataset (139 170 observations). All horses had observations for the shoeing condition after these data edits were performed. For all traits, geldings and stallions were kept in the same group because there is no information about when the horses were gelded.

For the trait proportion of barefoot races, only factors constant across the years could be included due to this trait being a summarised measurement for each horse. Observations from December 1 to February 28 were excluded (181 669 observations for SB and 24 082 for CB) because racing barefoot during winter has not been allowed since 2014 and thereof, there were few barefoot observations. Also, observations in winter track condition were removed because there were no barefoot observations for this track condition (2 030 observations for SB and 903 for CB). The final dataset for the proportion of barefoot races included 24 928 SB with 724 232 observations, whereof 13 777 were geldings/stallions and 11 151 were mares. For CB, the final dataset included 4 050 horses with 97 682 observations, whereof 2 421 were geldings/stallions and 1 629 were mares.

The second trait, barefoot status, was a binary trait with repeated observations defined as racing with barefoot hind hooves in a race (2) or not (1). For this trait, observations from the winter season were kept but corrected for in the statistical model. However, observations from the winter track condition were removed because there were no barefoot observations for this track condition. Also, observations from the non-standard start method line start (1 270 observations for SB and 86 for CB), and observations from tracks with very few starts were removed (297 observations for SB and 62 for CB). There is a strong incentive to race barefoot in trotting races because of the favourable effect it has on race speed. Therefore, trainers who had never raced any of their horses barefoot were assumed to have decided against the practice, regardless of whether the individual horses could tolerate barefoot racing or not. Following this reasoning, observations from horses with trainers who had never started a race with a barefoot horse were removed. This resulted in the removal of 3 and 18% of the observations for SB and CB, respectively. The final dataset for barefoot status included 25 973 SB with 875 056 observations, whereof 14 260 were geldings/stallions and 11 713 were mares. There were 3 384 CB, with a total of 93 376 observations whereof 2 081 were geldings/stallions and 1 303 were mares.

Racing distances were grouped according to the standard race lengths in Sweden: short-distance races measure 1 640 m, medium-distance 2 140 m, and long-distance races 2 640 m (Svensk Travsport, 2025d). For SB, there were also observations from races longer than 2 640 m, and these were grouped in a fourth group named marathon. The level of the race was defined as the winner's earnings in each race and grouped into 14 levels for SB, with the median for each level in the range of 3.75 k SEK to 1 600 k SEK and for CB into nine levels from 4 k SEK to 150 k SEK. Trainers were grouped as either being professional trainers (trainer level A) or amateur trainers (trainer level B) based on official information included with all race observations. In Sweden, the A and B licences come with different requirements in experience, education and number of allowed horses in training etc. (Svensk Travsport, 2025c).

Performance data

Performance data used for the study were obtained by the Swedish Trotting Association and included yearly summaries of the number of starts in races, placings, earnings, and best racing time per km for SB and CB. Data editing, trait definitions and transformations applied were the same as in the routine genetic evaluation of SB. These traits and their transformations have been described by Árnason (1994; 1999; 2001). However, since then, the transformations for earning and best racing time have been updated to better fit the data but have not been published in a scientific paper. For CB, traits and trait transformations were developed by Árnason et al. (1989) and Klemetsdal (1989).

In SB, performance data from horses born in 1976–2019 were included and edited following the same routines as for the current genetic evaluation. The horses were 2– to 5-year-old Swedish-born SB or SB registered abroad with at least six races in Sweden. Racing results from years without a best racing time per km were removed from the dataset. Two seconds were added to all observations from races with start method auto-start (start behind a car) to equal out the difference to the start method volt-start (start from a circle) following the approach described by Árnason (2001). Racing time per km was in the format of, e.g., 1156, interpreted as 1 min, 15 s and 6 tenths of a second. The final dataset with racing performance included 115 185 SB (61 554 males and 53 631 females) and the number of horses born per year ranged from 1 480 to 3 473. For SB, the performance traits included in the study were best racing time per kilometre, earnings, earnings per start, percentage of placings (1–3) and number of starts. Trait transformations and descriptions are shown in Table 1. Descriptive statistics for the barefoot traits and performance traits before and after transformations are given in Supplementary Tables S1 and S2, respectively. The distribution of the performance traits before and after transformation for SB is shown in Supplementary Figure S1. For the distribution of proportion of barefoot races before and after transformation in SB, see Berglund et al. (2025a).

For CB, horses with performance data from 3-6 years of age, born in 1978–2018, were included. As for SB, 2 s were added to the racing time for observations with the start method auto-start and observations with missing racing time were removed. In total, performance data from 16 360 CB (9 629 males and 6 773 females) were included for further analysis. There were 11 122 horses registered in Sweden and 5 238 in Norway and the number of horses per birth year ranged from 198 to 554. The performance traits included in this study were best racing time, earnings (standardised within country of registration and birth year), and placings. Trait transformations and descriptions are shown in Table 1. Descriptive statistics for the barefoot traits and performance traits before and after transformations are given in Supplementary Tables S1 and S2, respectively. In Supplementary Figure S2, the distribution of the performance traits is shown before and after the transformation was applied to the data. For the proportion of barefoot races, the distribution of the trait before and after transformation is published in Berglund et al. (2025a).

Not all horses with performance data had observations for the barefoot traits, and *vice versa*. This was mainly because there was no barefoot information before 2005 but also because of different editing rules, for e.g. age span for the different traits. Most SB (98.5%) with an observation of the proportion of barefoot races also had available performance data, and 21.3% of SB with performance data had an observation of the proportion of barefoot races. For CB, the corresponding numbers were 96.7 and 23.9%, respectively. For barefoot status, 98.5% of SB with an observation also had performance data, and 22.2% of the horses with performance data had an observation for barefoot status. For CB, the corresponding numbers were 97.4 and 20.1%, respectively.

Statistical analysis

Variance components and genetic correlations

Variance components and genetic correlations between barefoot traits and performance traits were estimated using bivariate mixed linear models in the DMU software (Madsen and Jensen,

2013) for SB and CB separately, with the convergence criteria set to 1×10^{-7}. The pedigree files obtained from The Swedish Trotting Association included 305 035 animals for SB and 118 239 for CB. The average pedigree completeness index calculated according to MacCluer et al. (1983) for 5 ancestral generations was above 0.99 for horses born from year 2000 in both breeds.

Barefoot traits

The statistical models applied for the proportion of barefoot races and barefoot status were previously described in Berglund et al. (2025a). However, in contrast to the use of a threshold model for barefoot status in that study, linear models were used for both traits in the bivariate analyses in the present study. For the proportion of barefoot races, the following mixed linear animal model was applied for both SB and CB:

$$y = Xb + Za + e, \tag{1}$$

where y is the proportion of races barefoot hind, X and Z are incidence matrices, b is the vector of the fixed effects: sex (gelding/stallion or mare) and year of birth (2002–2018 for SB and 2002–2017 for CB), a is the vector of the random additive genetic effect with 24 928 levels for SB and 4 050 levels for CB ~N(0, A σ_a^2), where σ_a^2 is the additive genetic variance, A is the numerator relationship matrix, and e is a vector of residuals ~N(0, I σ_e^2), where I is an identity matrix and σ_e^2 is the residual variance.

For barefoot status, a binary trait with repeated observations, the following mixed linear animal model was used:

$$y = Xb + Z_{ys}ys + Z_t t + Z_a a + Z_{pe}pe + e, \tag{2}$$

where y is barefoot status, which is 2 if the horse raced with barefoot hind hooves and 1 if not, X and Zs are incidence matrices, b is the vector of the fixed effects: sex (gelding/stallion or mare) and racing year (2005–2022 for SB and 2005–2021 for CB), age (3–10 for both SB and CB), track (33 levels for SB and 24 levels for CB), start method (volt or auto start) track condition (3 levels for SB and 2 levels for CB), season (winter, spring, early summer, late summer and autumn for SB, and winter-spring, early summer, late summer and autumn–winter for CB), race level (14 levels for SB and 9 levels for CB), distance (short-, medium-, long-, marathon-distance for SB and short-, medium-, long-distance for CB), trainer level (amateur or professional), ys is the vector of the random effects of year and season ~N(0,I σ_{ys}^2), t is the vector of the random effect of the trainer ~N(0,I σ_t^2), a is the vector of the random additive genetic effect with 25 973 levels for SB and 3384 levels for CB ~N(0, A σ_a^2), pe is the permanent environment effect ~N(0, I σ_{pe}^2), where σ_{pe}^2 is the permanent environmental variance, and e is a vector of residuals ~N(0,I σ_e^2).

Performance traits

The mixed linear animal model used for performance traits in SB and CB was as follows:

$$y = Xb + Za + e, \tag{3}$$

where y is the transformed performance trait, X and Z are incidence matrices, b is the vector of the fixed effect sex (gelding/stallion or mare) and year of birth (1976–2019) combined (88 levels) for SB, and sex (gelding/stallion or mare), year of birth (1978–2018) and country of registration (Sweden or Norway) combined (164 levels) for CB, a is the vector of the random additive genetic effect with 115 185 levels for SB and 16 360 levels for CB ~N(0, A σ_a^2), and e is a vector of residuals ~N(0, I σ_e^2).

Covariance structure and heritability estimates

Covariance structure between the barefoot trait (bf) (the proportion of barefoot races or barefoot status) and performance (perf) traits was defined as:

$$Var\begin{bmatrix} a_{bf} \\ a_{perf} \end{bmatrix} = \begin{bmatrix} \sigma^2_{abf} & \sigma_{abf,aperf} \\ \sigma_{abf,aperf} & \sigma^2_{aperf} \end{bmatrix} \otimes A_a$$

$$Var\begin{bmatrix} e_{bf} \\ e_{perf} \end{bmatrix} = \begin{bmatrix} \sigma^2_{ebf} & \sigma_{ebf,eperf} \\ \sigma_{ebf,eperf} & \sigma^2_{eperf} \end{bmatrix} \otimes I_e$$

where $\otimes$ is the Kronecker product that combines the genetic (co)-variance matrix with the relationship matrix, and the residual co(-variance) matrix with the identity matrix, by multiplication of each element in the first matrix with the entire second matrix. However, the residual covariances between the summarised performance traits and the repeatedly observed barefoot status were not estimated, because of the differing time points for the observations. The genetic correlation (r_g) between trait bf (proportion of barefoot races or barefoot status) and perf (performance trait) was estimated as:

Table 1
Description of traits and their transformations in Swedish Standardbred trotters[a] and Swedish-Norwegian Coldblooded trotters[b].

Breed	Trait	Transformation	Description
SB	Proportion of barefoot races	None	Proportion of barefoot races (in hind) in non-winter season
	Barefoot status	None	Barefoot (in hind) in a race or not
	Best racing time	Ln (best racing time per km – 68.2)	Best racing time per km (in the format of e.g. 1 122 is 1 min, 12 s and 2 tenths of a second) minus 1 082 (68.2 s = 1 min and 8.2 s)
	Earnings	Ln (earnings + 1 000)	Summarised earnings in SEK
	Earnings per start	Ln ((earnings + 1 000) / number of starts)	Summarised earnings in SEK per start
	Placings	$((\text{Placings} \times 100) / \text{number of starts})^{0.8}$	Percentage of 1st to 3rd placings
	Number of starts	$(\text{Number of starts in races})^{0.2}$	
CB	Proportion of barefoot races	None	Proportion of barefoot races (in hind) in non-winter season
	Barefoot status	None	Barefoot (in hind) in a race or not
	Best racing time	$(\text{Best racing time per km})^{0.5}$	Best racing time per km (in the format of e.g. 1 202 is 1 min, 20 s and 2 tenths of a second) minus 1 000.
	Earnings	$\text{Earnings}^{0.25}$	Summarised earnings standardised within country of registration and birth year
	Placings	$((\text{Number of placings} \times 100) / \text{number of starts})^{0.5}$	Percentage of 1st to 2nd placings

Abbreviations: SB = Swedish Standardbred trotter, CB = Swedish-Norwegian Coldblooded trotter, SEK = Swedish krona.

[a] Performance and barefoot data from Standardbred trotters aged 2–5 and 3–10 years old, respectively. For performance, data from 2-year-olds were only included from

$$r_g = \frac{\sigma_{abf,aperf}}{\sqrt{\sigma^2_{abf} \times \sigma^2_{aperf}}}$$

Heritability for proportion of barefoot races and performance traits was estimated as:

$$\widehat{h^2} = \frac{\widehat{\sigma^2_a}}{\widehat{\sigma^2_a} + \widehat{\sigma^2_e}}$$

Heritability for barefoot status was estimated as:

$$\widehat{h^2} = \frac{\widehat{\sigma^2_a}}{\widehat{\sigma^2_a} + \widehat{\sigma^2_{pe}} + \widehat{\sigma^2_e}}$$

SE of heritability estimates for the bivariate models including barefoot status and performance was not given by the program and was therefore estimated following McKinnon Edwards (2017) as:

$$se\left(h^2\right) = \sqrt{\begin{bmatrix} \left(\frac{\partial h^2}{\partial \sigma^2_a}\right)^2 (se_a)^2 + \left(\frac{\partial h^2}{\partial \sigma^2_{pe}}\right)^2 (se_{pe})^2 + \left(\frac{\partial h^2}{\partial \sigma^2_e}\right)^2 (se_e)^2 + \\ 2\left(\frac{\partial h^2}{\partial \sigma^2_a}\right)\left(\frac{\partial h^2}{\partial \sigma^2_e}\right)\rho_{a,e} se_a se_e + 2\left(\frac{\partial h^2}{\partial \sigma^2_a}\right)\left(\frac{\partial h^2}{\partial \sigma^2_{pe}}\right)\rho_{a,pe} se_a se_{pe} + 2\left(\frac{\partial h^2}{\partial \sigma^2_{pe}}\right)\left(\frac{\partial h^2}{\partial \sigma^2_e}\right)\rho_{pe,e} se_{pe} se_e \end{bmatrix}}$$

where h^2 is the estimated heritability, σ^2_a is the additive genetic variance, σ^2_{pe} is the permanent environmental variance, and σ^2_e is the residual variance.

In all analyses presented, the method used for setting up the inverse of A did not take inbreeding into account. However, the analyses were redone, including inbreeding to test the impact on the estimates.

Genetic trends

Genetic trends for the proportion of barefoot races and barefoot status were calculated as mean EBVs per year for SB born 2002–2018 and CB born 2002–2017. The genetic trend, expressed as a change in genetic SDs per year, was calculated from the regression coefficient of annual mean EBVs on birth year, divided by the genetic SD for each trait and breed. The change in genetic SDs per generation was calculated with a generation interval of 11 years for SB (estimated with Pedig (Boichard, 2002), from all available pedigree data from animals born in 1980–2018) and 11.5 years for CB (Olsen and Klemetsdal, 2020).

Results

Variance components and heritability

Variance components and heritability estimates from the bivariate analysis, including performance traits and the proportion of barefoot races or barefoot status for SB and CB, are shown in Table 2. The estimated heritability for proportion of barefoot races was moderate for SB (range 0.24 to 0.28 with a mean of 0.26) and slightly lower for CB (range 0.15–0.17 with a mean of 0.16). For barefoot status, the heritability was low but similar across breeds (range 0.03– 0.05 and 0.02–0.03), with a mean of 0.04 and 0.03 in SB and CB, respectively.

The variance components and estimated heritability for performance traits in the bivariate analyses with either the proportion of barefoot races or barefoot status were very similar; therefore, averages of the two analyses are presented in Table 2. For SB, the heritability ranged from 0.19 (number of starts) to 0.43 (earnings per start). For CB, the estimated heritability for performance traits ranged from 0.29 (earnings) to 0.34 (best racing time). When repeating the analyses with a relationship matrix including inbreeding, the estimates of both heritabilities and genetic correlations were unchanged.

Correlations between the ability to race barefoot and performance

For both SB and CB, genetic correlations between the proportion of barefoot races and performance were generally favourable, indicating that a higher proportion of barefoot races is associated with better performance (Table 3). In both breeds, the strongest genetic correlation with proportion of barefoot races was seen for best racing time km (–0.50 for SB and –0.62 in CB), whereas the weakest genetic correlation was found for earnings per start in SB (0.42) and placings in CB (0.41). For the trait barefoot status, the strongest correlation was seen between barefoot status and number of starts (0.63) whereas no correlation was seen between barefoot status and placings (–0.01) for SB. For CB, the strongest genetic correlation was between barefoot status and best racing time (–0.59) and weakest between barefoot status and placings (0.26). The residual correlations had the same sign as the genetic correlations, but were always weaker (Table 3).

Genetic trends

Genetic trends for the proportion of barefoot races and barefoot status in SB and CB are shown in Fig. 1. For both traits, the EBVs are

Table 2
Estimates of heritability, additive genetic variance, trainer variance, year and season variance, permanent environmental variance, and residual variance for proportion of barefoot races, barefoot status and performance traits[a] in Swedish Standardbred trotters and Swedish-Norwegian Coldblooded trotters. SE are presented as subscripts[b].

Breed	Trait	h^2	σ^2_a	σ^2_t	σ^2_{ys}	σ^2_{pe}	σ^2_e
SB	Proportion of barefoot races	$0.26_{0.019}$	$0.02_{0.001}$				$0.05_{0.001}$
	Barefoot status	$0.04_{0.004}$	$0.01_{0.001}$	$0.02_{0.001}$	$0.002_{0.0004}$	$0.03_{0.001}$	$0.13_{0.001}$
	Best racing time	$0.36_{0.008}$	$0.02_{0.001}$				$0.03_{0.001}$
	Placings	$0.35_{0.008}$	$23.11_{0.606}$				$43.35_{0.412}$
	Earnings	$0.35_{0.008}$	$0.84_{0.021}$				$1.52_{0.014}$
	Earnings per start	$0.43_{0.007}$	$0.39_{0.008}$				$0.52_{0.005}$
	Number of starts	$0.19_{0.007}$	$0.02_{0.001}$				$0.07_{0.001}$
CB	Proportion of barefoot races	$0.16_{0.036}$	$0.01_{0.001}$				$0.02_{0.001}$
	Barefoot status	$0.03_{0.009}$	$0.003_{0.001}$	$0.01_{0.001}$	$0.0001_{0.00004}$	$0.02_{0.001}$	$0.07_{0.001}$
	Best racing time	$0.34_{0.021}$	$0.54_{0.038}$				$1.05_{0.027}$
	Placings	$0.30_{0.021}$	$1.72_{0.134}$				$3.94_{0.097}$
	Earnings	$0.29_{0.019}$	$0.31_{0.022}$				$0.77_{0.017}$

Abbreviations: h^2= heritability, σ^2_a= additive genetic variance, σ^2_t= trainer variance, σ^2_{ys}= year and season variance, σ^2_{pe}= permanent environmental variance, σ^2_e= residual variance, SB = Swedish Standardbred trotter, CB = Swedish-Norwegian Coldblooded trotter.

[a] Variances and heritability are presented as averages from the bivariate analyses.

[b] For SE, the highest estimates from the bivariate analyses are presented.

Table 3
Genetic and residual correlations between proportion of barefoot races (Proportion), barefoot status (Status) and performance in Swedish Standardbred trotters and Swedish-Norwegian Coldblooded trotters. SE are shown as subscripts.

		r_g		r_e
Breed	Performance trait	Proportion	Status	Proportion
SB	Best racing time	$-0.50_{0.032}$	$-0.38_{0.028}$	$-0.28_{0.011}$
	Earnings	$0.49_{0.032}$	$0.37_{0.031}$	$0.34_{0.011}$
	Earnings per start	$0.42_{0.035}$	$0.11_{0.030}$	$0.28_{0.012}$
	Placings	$0.47_{0.035}$	$-0.01_{0.034}$	$0.19_{0.012}$
	Number of starts	$0.43_{0.042}$	$0.63_{0.031}$	$0.20_{0.012}$
CB	Best racing time	$-0.62_{0.089}$	$-0.59_{0.093}$	$-0.18_{0.028}$
	Earnings	$0.52_{0.098}$	$0.50_{0.097}$	$0.15_{0.026}$
	Placings	$0.41_{0.105}$	$0.26_{0.120}$	$0.03_{0.029}$

Abbreviations: r_g = genetic correlation, r_e = residual correlation, SB = Swedish Standardbred trotter, CB = Swedish-Norwegian Coldblooded trotter.

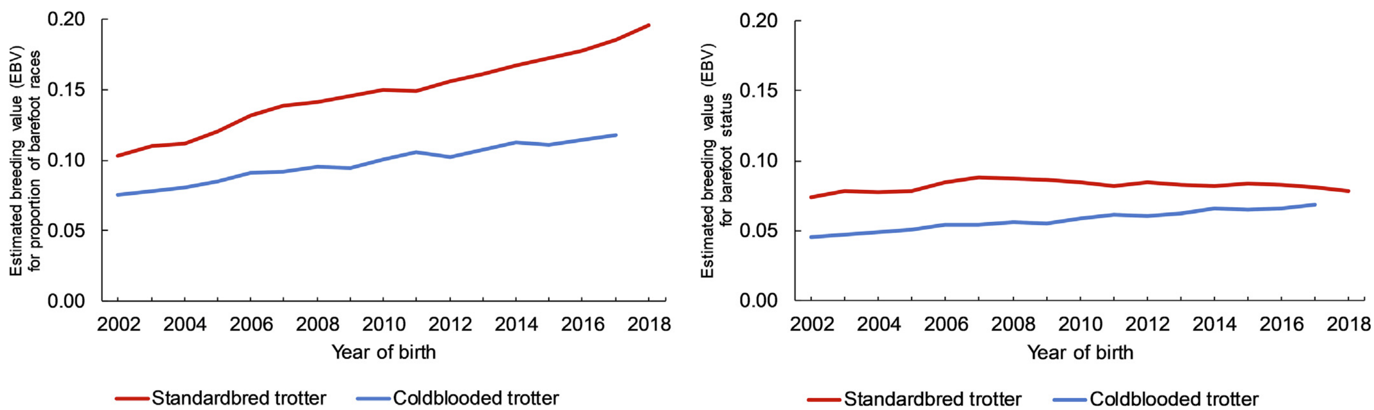

Fig. 1. Mean estimated breeding values per year of birth for the proportion of barefoot races (left) and barefoot status (right) in Standardbred trotters and Swedish-Norwegian Coldblooded trotters.

from the bivariate analysis with the best racing time, and the additive genetic variance is the mean value from estimates in Table 3. For the proportion of barefoot races, there was a favourable genetic trend for animals born from 2002 to 2018 in SB and from 2002 to 2017 in CB. In SB, this corresponds to a change of 0.04 genetic SDs per year and 0.41 genetic SDs per generation. In CB, the proportion of barefoot races improved with 0.04 and 0.46 genetic SDs per year and generation, respectively. In Supplementary Tables S3 and S4, mean EBVs together with minimum, maximum, SD and number of horses born each year are shown for SB and CB, respectively. For barefoot status, the genetic improvement seen for SB for horses born between 2002 and 2018 was very low (0.002 genetic SDs per year and 0.02 per generation). In CB, the genetic improvement for horses born between 2002 and 2017 was larger, 0.03 and 0.32 genetic SDs per year and generation, respectively. Supplementary Tables S5 and S6 show the mean EBVs per birth year together with descriptive statistics for SB and CB, respectively.

Discussion

Trait definitions

The ability to race barefoot is a trait of economic importance in trotters in several European countries because of its link to improved racing performance (Solé et al., 2020). This is the first study to analyse the genetic correlations between two previously defined traits, reflecting the ability to race barefoot in Swedish trotters and racing performance. The two barefoot traits in this study were formed as measures of the ability to race barefoot, which may indirectly comprise aspects of hoof quality, and, especially for CB, also balance in trot at high speed (Berglund et al., 2025a). However, one initial concern regarding the barefoot traits in this study was whether the trait definitions allowed for capturing such other aspects from what is measured in the currently used performance traits. Racing barefoot has previously been shown to be phenotypically favourably correlated to performance in terms of improved racing time in SB (Solé et al., 2020), and a clear effect of the level of prize money in the race on the probability of racing barefoot was found by Berglund et al. (2025a). Especially, the trait proportion of barefoot races could not be corrected for the level of the race in the model, which could possibly increase its relationship with performance.

How to handle trainer differences in attitude towards racing barefoot was previously discussed by Berglund et al. (2025a), where the main concern of trainers never letting any of their horses race barefoot as a practice was dealt with by removing observations from these trainers. For trainers who only race with one horse, it might be misleading to generalise and say that they would never race a horse barefoot, but these contribute little to the total number of observations; for SB, this strict data editing only removed 3% of the observations. For CB, the strict data editing removed 20% of the observations, but the estimated heritability was similar to that for SB (0.03 and 0.04, respectively).

Genetic correlations

One potential a priori risk with the new barefoot traits was that they would be so highly genetically correlated with performance that there would be no room for also explaining differences in the ability to race barefoot, and potentially, hoof quality.

However, the results in this study showed low–to–moderate genetic correlations between performance and the two barefoot traits; the range in absolute values per breed was 0.01–0.63 and 0.26–0.62 in SB and CB, respectively. Averaged per trait, the genetic correlation was 0.41–0.62 and 0.01–0.63 for proportion of barefoot races and barefoot status, respectively. In SB, a stronger genetic correlation was found between best racing time and proportion of barefoot races (0.50) than with barefoot status (0.38). In CB, the difference in genetic correlation between best racing time and the two barefoot traits was less obvious (0.62 for the proportion of barefoot races and 0.59 for barefoot status), but was, on the other hand, the strongest correlations estimated for this breed.

For the trait number of starts, the genetic correlation with barefoot status in SB was the strongest of all trait combinations studied (0.63). Number of starts is not included as a correlated trait in the genetic evaluation of SB (but an EBV for this trait is estimated). The genetic correlation between the number of starts and performance in SB was previously estimated to be low (range in absolute values 0.03–0.38) in a study by Árnason et al. (1989). Breeding values for the number of starts are not estimated in the genetic evaluation for CB, and its correlation with the barefoot traits was therefore not estimated in the current study.

In SB, the genetic correlation that differed most between barefoot trait definitions in the current study was that between placings and barefoot status, which was zero compared with 0.47 between the same trait and proportion of barefoot races. This may be influenced by the considerably higher frequency of barefoot racing with SB than with CB. If, in an extreme example, all horses in a specific race are barefoot, the correlation with being placed as 1st to 3rd in the race will be zero. Also in CB, the correlation between barefoot status and placings was lower than for the proportion trait, but not zero.

The proportion of barefoot races is a summarised trait that reflects the relative frequency of barefoot races over a long period of time, in contrast to barefoot status, which measures whether the horse raced barefoot or not in a single race event. For barefoot status, environmental and event-specific factors could be corrected for, such as trainer, level of the race, track condition, etc. Therefore, the barefoot status trait might be better at capturing genetic variation unrelated to performance.

It has been argued that the ability to keep the balance in trot at high speed without shoeing is more limiting in CB than in SB (Svensk Travsport, 2023), which may explain the somewhat stronger correlation between, especially, the barefoot status trait and the performance traits in CB compared with SB. The genetic correlation estimated in the current study indicates that the barefoot traits measure something other than pure performance, which could make them a valuable addition to the genetic evaluation.

Genetic gain

In both SB and CB, the genetic correlation with performance traits was stronger for the proportion of barefoot races than for barefoot status (with the exception of number of starts in SB). Thus, intense selection for performance traits may indirectly have driven the faster genetic gain seen for the proportion of barefoot races than for barefoot status for both breeds. One might also hypothesise that the low heritability for barefoot status may have contributed to a slower improvement of that trait. However, it is unlikely that the ability to race barefoot has been directly selected for.

The genetic trend for barefoot status may seem more reasonable compared to the proportion of barefoot races which is likely more influenced by its correlation to performance. The genetic trend was stronger for CB than for SB, especially for barefoot status, which could be an indicator that this trait captured also aspects that were less separated from performance in CB, such as balance which, as previously mentioned, seems to be more limiting for this breed (Svensk Travsport, 2023). The ability to balance trot at high speed and not break over to gallop has in SB been shown to be associated with the *DMRT3* gene, which is involved in locomotor patterns, where a mutation from C to A was associated with improved performance (Andersson et al., 2012). The A allele is almost fixed in SB, whereas the frequency of the A allele has been estimated to be about 45% in CB (Promerová et al., 2014). This may add to the differences between the breeds, although the genetics behind gaits is more complex than the influence of a single gene (Sigurðardóttir et al., 2025).

Variance components and heritability

Barefoot traits

For the proportion of barefoot races, the average heritability from the bivariate analyses was estimated at 0.26 in SB and 0.16 in CB. For both breeds, these estimates were similar to those estimated from a single trait model (0.28 and 0.17, respectively). For barefoot status, the average heritability was estimated at 0.04 in SB and 0.03 in CB in the current study. However, with a single-trait threshold model, the mean heritability on the underlying scale for barefoot status has previously been estimated at 0.08 in SB and 0.07 in CB (Berglund et al., 2025a). The estimated heritability from binary traits (with two possible values) on the underlying scale is generally higher than that estimated on the observed scale (Kadarmideen et al., 2000; Carlén et al., 2006). However, correlations between EBVs have previously been shown to be very high between linear and threshold models (≥0.98), also the genetic gain has been shown to be the same, despite the difference in heritability estimates on the two scales (Boettcher et al., 1999; Carlén et al., 2006).

The proportion of barefoot races was intended to reflect the ability to race barefoot repeatedly and could be seen as a measure of durability of racing without shoes. Spörndly-Nees et al. (2023) suggested that the chemical composition of the hoof could have an impact on hoof durability and found significantly lower copper concentrations in hooves from SB reported to sustain racing barefoot repeatedly compared to those reported not to, implying individual differences in hoof quality. Hoof quality is also known to differ between breeds (Ott and Johnson, 2001), although the genetic background of hoof quality remains relatively unexplored. Genes linked to the function of the lamellar tissue (which connects the hoof wall to the coffin bone) were suggested as candidate genes for hoof quality in a study of a Mongolian horse breed known for durable hooves (Han et al., 2023). Also, in the same 18 SB horses that Spörndly-Nees et al. (2023) studied, differences in gene expression in hind hooves from barefoot racers and non-barefoot racers were seen for genes related to keratinisation, immune response, and increased blood flow (Alameddine, 2023).

Most previous studies incorporating heritability estimation of hoof-related traits focused on conformation rather than the ability to perform barefoot. For example, the heritability of hoof conformation in Finnish Standardbred trotters and Finnhorse trotters has been estimated at 0.09 and 0.16, respectively (Suontama et al., 2013). In Norwegian Coldblooded trotters, Dolvik and Klemetsdal (1999) estimated the heritability for traits related to hoof conformation to be in a range from 0.02 to 0.52.

Performance traits

Árnason (1999) estimated the heritability of performance traits in SB in the range of 0.16–0.36. Since then, the heritability for performance has slightly increased (ranging from 0.18 to 0.44 in the current genetic evaluation (Svensk Travsport, 2025b). The average estimated heritability in the current study for performance traits from the bivariate analyses with the proportion of barefoot races and barefoot status aligned very well with those currently used and were also similar to those estimated for SB in a study by Berglund et al. (2025b). These values are also in line with other Standardbred trotter populations, where heritability of performance has been estimated as ranging from 0.01 to 0.56, depending on the definition of the traits and the models used (Röhe et al., 2001; Gómez et al., 2011a; Suontama et al., 2012; Ricard, 2015).

For CB, variance components for performance traits used in the current genetic evaluation were estimated already in 1994 with a heritability ranging from 0.20 to 0.35 (not published). The level of estimated heritability for performance traits in the current study (range 0.29–0.34) was similar to those obtained in 1994, in spite of the differences in birth years of included horses and that the majority of the data were from Swedish races in the present study (as opposed to having all racing records from both Sweden and Norway).

Implications of the results

The ability to race barefoot, a trait that indirectly could cover aspects such as hoof quality (Solé et al., 2020; Alameddine, 2023; Spörndly-Nees et al., 2023) and balance (Spörndly-Nees et al., 2023), is also a trait of economic importance in harness racing. Our results suggest a potential for including a trait reflecting the ability to race barefoot also in other countries such as France, Finland and Italy, that routinely register shoeing conditions in all races and have well–defined regulations (The European Trotting Union, 2024, 2025b and 2025d). The above–mentioned countries also include similar performance traits as for SB in their genetic evaluations (e.g., best racing time, earnings and placings (Langlois and Vrijenhoek, 2004; Pieramati et al., 2007; Suontama et al., 2012).

In Sweden, where the genetic evaluation of SB and CB is based on summarised performance, the proportion trait would probably be the easiest to implement as this is also summarised across years. For the trait barefoot status, a more complex model could be used, which seemed to better separate the barefoot trait from performance, but the barefoot traits were strongly correlated to each other (Berglund et al., 2025a).

In the routine genetic evaluation of CB, which combines Swedish and Norwegian results, decisions on including new traits must be agreed upon between the breeding organisations in the two countries. Norway started to register shoeing information on all trotting races in 2021 and their regulations differ from those in Sweden. In Norway, the staff at each race track decides whether barefoot racing should be allowed in the race or not, and there is no ban on barefoot racing in winter *per se* (Det Norske Travselskap, 2021). However, the CB populations in Sweden and Norway are closely related (Olsen and Klemetsdal, 2020), and therefore, the results obtained in this study are also relevant for CB in Norway.

With an increased awareness of sport horse welfare and a strive for maintaining a so–called social licence to operate, inclusion of new traits in the genetic evaluation of trotters such as the ability to race barefoot as an indirect measurement of durable hooves and balance could be a step in the right direction. Although there are individual differences in the ability to tolerate barefoot racing (Spörndly-Nees et al., 2023) that could be utilised in the genetic evaluation of Swedish trotters, attention must be given to concerns regarding possible impact on the durability of the horses from racing barefoot as young. Barefoot racing has been pointed out as an animal welfare concern in the sport, leading to additional regulations (Le Trot, 2024), and risk associated with barefoot racing of young trotters is a field that requires more research for trotting associations around the world to base regulations on.

Conclusions

In this study, we estimated low–to–moderate favourable genetic correlations between performance and proportion of barefoot races or barefoot status, reflecting the ability to race barefoot in SB and CB. For most trait combinations, stronger correlations were found between the proportion of barefoot races and performance. A genetic improvement over birth years could be seen in both breeds for the proportion of barefoot races, whereas, for barefoot status, no genetic change was seen for SB. The ability to repeatedly race barefoot shows potential for inclusion in the genetic evaluation of Swedish trotters. Further studies on the impact of barefoot racing on racing longevity are needed before implementing such a trait in the breeding goal.

Supplementary material

Supplementary Material for this article (https://doi.org/10.1016/j.animal.2025.101664) can be found at the foot of the online page, in the Appendix section.

Ethics approval

Not applicable.

Data and model availability statement

The data and the model used for this study were not deposited in an official repository. The data used for this study were provided by the Swedish Trotting Association, which holds the rights to decide who can access it.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

Susanne Eriksson and Sreten Andonov have commitments to the Swedish Trotting Association for work related to developing the genetic evaluation for Swedish trotters. The authors declare no other known conflicts of interest.

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