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Benefits and risks of barefoot harness racing in Standardbred trotters

Marina Solé[1] | Gabriella Lindgren[1,2] | Erik Bongcam-Rudloff[1] | Anna Jansson[3]

[1]Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences, Uppsala, Sweden
[2]Department of Biosystems, Livestock Genetics Research Group, KU Leuven, Leuven, Belgium
[3]Department of Anatomy, Physiology and Biochemistry, Swedish University of Agricultural Sciences, Uppsala, Sweden

Correspondence
Marina Solé, Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences, PO Box 7023, 75007 Uppsala, Sweden.
Email: marina.sole@slu.se

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Abstract

There is a lack of research on the benefits and risks of shoeing conditions in harness racing. Thus, our objectives were to: (a) investigate whether velocity times (VT; s/km) are affected by racing unshod (*N* = 76,932 records on 5,247 horses); (b) determine the potential risks of galloping, being penalized, and disqualification when competing unshod (*N* = 111,755 records on 6,423 horses); and (c) identify additional environmental factors that affect VT and risks. VT was found to be significantly influenced by shoeing condition (e.g., unshod, shod front, shod hind, or fully shod), but also by sex, age, season, track, track condition, start method, start position, distance, and driver-horse performance level ($p < 2e\text{-}16$). The risks of galloping and disqualification were significantly influenced by shoeing condition, sex, age, season, track, start method, start position, or driver-horse performance level ($p \le .05$). Horses racing unshod had 0.7 s/km lower VT than fully shod horses and showed better performance when racing on neutral tracks during the late summer than horses with other shoeing conditions during the same period. However, racing unshod increased the relative risks of galloping and disqualification by 15%–35% in all seasons. Horses shod only on the hind hooves showed better performance than fully shod horses, without higher risks associated with competing unshod.

KEYWORDS
environmental factors, horse, performance, shoeing, velocity

1 | INTRODUCTION

Racing barefoot (unshod) is becoming an important topic in the harness racing industry, because of claims of health implications and improved performance (enhanced velocity) compared with fully shod horses (Bertuglia, Bullone, Rossotto, & Gasparini, 2014; Gabel, 2004). Despite the likelihood that being shod affects velocity (Bertuglia et al., 2014), current knowledge of the effect of racing barefoot on performance is limited. Potential benefits and risks of racing unshod or shod, namely increased velocity, unwanted behaviors (e.g., pacing), or failure (disqualification), have yet to be clearly defined.

Previous studies have evaluated the effects of shoeing conditions and characteristics on locomotion traits. One such study has shown that in unshod horses at a slow trot, the range of vertical displacement of the scapular spine, representing movement of the trunk, is 10% lower than in shod horses (Willemen, Savelberg, & Barne-veld, 1999). Another study has found that unshod horses at slow trot (~3.3 m/s) show 7.9% less range of motion of the forelimb compared with shod horses, with the effect being more pronounced on a soft geotextile surface (Stutz, Vidondo, Ramseyer, Maninchedda, & Cruz, 2018). The relevance of these findings for high-speed trotting remains to be investigated, but if the 8%–10%

reduction in body vertical displacement persists at high speed, there could be a positive impact on racing performance. Overall, these locomotion studies, and the fact that shoes increase the weight carried, indicate that performance (namely velocity) could be improved without shoes.

Racing without shoes seems not to increase the risk of injuries (Bertuglia et al., 2014). However, the conformation and “quality” of the hoof, such as tissue volume, composition, and structure, may not always be optimal for competing unshod, which could result in high wear and tear and most likely also high sole and frog pressure. In such cases, there may be induced pain and competing may compromise horse welfare and have a negative impact on performance. It is known that hoof conformation can have a general effect on the performance of Standardbred horses and that narrow hooves seem to impair performance, at least in shod conditions (Magnusson & Thavelin, 1990). In addition, it has been suggested that hooves with more upright quarters are stiffer and possibly provide less impact absorption (Thomason, 1998). Differences in external hoof shape may also cause local variations in stress magnitude around the laminar junction (Thomason, McClinchey, Faramarzi, & Jofriet, 2005). Thus there may be a concrete link between mechanical performance and laminar morphology, which could increase the risk of failures during the race (Thomason et al., 2005).

Against the background of lack of research specifically focusing on benefits and risks of shoeing condition (unshod, shod in the front hooves or hind hooves, or fully shod) in harness racing, the aim of this study was to use observational Swedish harness racing records on Standardbred trotters to: (a) investigate whether velocity times are affected by competing unshod; (b) determine whether the risks of galloping, being penalized, or disqualified are affected by competing unshod; and (c) identify factors (e.g., season, track condition) that affect velocity and risks. Our starting hypothesis was that unshod horses have higher risks of failure (e.g., more gallop, penalties, or disqualification), but better racing performance if they avoid failure.

2 | MATERIAL AND METHODS

2.1 | Description of harness racing

Harness racing is a form of horse racing where horses race at trot or pace, sometimes ridden but most often while pulling a sulky occupied by a driver. Most races are performed on oval 800–1600 m gravel tracks. In Sweden, two methods of starting races are normally practiced, auto-start and volt-start. During auto-start, horses line up behind a car with two wings in a pre-set order (position) and then the car accelerates faster than the horses at the starting line. During volt-start, horses circle synchronized in slow trot in pre-set positions in front of the starting line, and on the judge teams’ command, the drivers allow the horses to accelerate toward the starting line. In all starting methods, it is not allowed to be out of position, and in auto-start not to be too late and in volt-start not be too early at the starting line. This will render penalties. Keeping horses at trot (and not gallop or pace) is essential. Volt-start is generally considered more challenging than auto-start for the horses with respect to keeping the proper gait. Drivers are not allowed to take advantage of gallop or pace, and in case of gallop/pace, they are obliged to slow down or pull out the horse from the race. Horses that gallop/pace more than a pre-set distance or over the finish line are disqualified. The comparatively complex task of harness racing requires horses that are well prepared for the task both from a physiological and behavioral perspective, that is horses need to be fit and cooperative and responsive to the driver's commands to be successful.

2.2 | Performance data

A longitudinal retrospective cohort observational study was conducted using performance data on all Swedish races for Standardbred horses (trotters) from November 2013 to December 2015 obtained from the Swedish Trotting Association (STA). This comprised a total of 215,874 records, referring to 18,137 individual horses. During the data collection period, STA allowed horses to compete shod or unshod all year round. We designed a Microsoft Access™ database for data handling, including individual race records with each record corresponding to a given horse's specific performance in the race. The database was cleaned by removing non-competitive premiere and qualification races, riding races, and line start method races. Only those horses that had records for both unshod and partly or fully shod conditions were retained.

Additional information without missing values considered for each horse record included horse ID, sex (three classes: stallion, gelding, mare), age (11 classes: 2 to 12 years old), season (four classes: winter (21 December-19 March), spring-midsummer (20 March-20 June), late summer (21 June-21 September), autumn (22 September-20 December)), track (32 classes), track condition (four classes: winter, heavy, slightly heavy, neutral), start method (two classes: volt-start (circle start), auto-start), start position (two classes: less favorable for starting positions ≥ 4 in volt-start and ≥ 7 for auto-start, favorable for starting positions 1–3 in volt-start and 1–6 in auto-start; according to Swedish regulations (https://www.travsport.se/artikel/ovrig_statistik)), distance (three classes: short ≤ 1,720 m, medium 2140–2720 m, long ≥ 3,140 m), driver category combined with the horse performance level (four classes; EG: elite drivers combined with “good” horses for those drivers winning more than 5 million Swedish Krona (SEK) per year in the study period and for those horses with a minimum of 600 racing points from the last five races (data from STA, the more earnings and placings 1 to 3, the more points, 600 corresponds to a minimum of two victories) by the end of the study, NC: non-elite drivers combined with control horses for those drivers winning less than 5 million SEK per year in the study period and for those horses with less than 600 racing points by the end of the study period, EC: elite drivers combined with control horses, and NG: non-elite drivers combined with good horses), shoeing condition (four classes: unshod, shod front, shod hind, fully shod), gallop status (Yes/No), penalties for the driver (Yes/No), disqualification (Yes/No), disqualification for behavioral reasons (Yes/No), and velocity time (s/km).

2.3 | Outcome variables

The performance traits of interest were:

- Velocity time (s/km) as a continuous trait. Velocity was recorded as mean seconds per km. The dataset analyzed (*N* = 76,932 records referring to 5,247 individual horses) considered races where horses did not show gallop, penalties, or disqualification.
- Risk of galloping, driver penalties (wrong starting position, too early at the starting line, disturbed other participants, or poor conduction on volt-start), disqualification, and behavioral disqualification related to unwanted specific behaviors (pacing or driving outside the track) as binary traits. The dataset analyzed considered all relevant races (*N* = 111,755 records referring to 6,423 individuals).

2.4 | Predictive variables

Predictive variables investigated in this study were: sex, age, season, track, track condition, start method, start position, distance, driver-horse performance level, and shoeing condition.

2.5 | Statistical analyses

All statistical analyses on velocity time data were performed using R (Development Core Team, 2011). The two cleaned datasets for the analysis were imported and managed using the R packages "lme4," "car," "lsmeans," "lmerTest," and "multicomp." First, identification of possible outliers and normality distribution for velocity time [s/km] were verified based on descriptive statistics, Kolmogorov–Smirnov test, and visualization in a histogram plot. The continuous trait studied was normally distributed and no outliers were detected (Figure 1). Velocity time was modeled using a multivariable linear-mixed effect model with repeated measures analysis of variance (ANOVA) to determine which predictive variables were associated with the outcome. Each horse record was considered a subject random variable, with sex, age, season, track, track condition, start method, start position, distance, driver-horse performance level, and shoeing condition as within fixed factors. In order to test for two- and three-way interaction effects on velocity time between shoeing condition and season and/or track condition, additional independent tests were conducted using repeated measures ANOVA models. In cases where the interaction effect was significant ($p \le .05$), pairwise mean differences were tested using Tukey's HSD as a post hoc test for those combinations with available data. Winter tracks only had fully shod condition records. Spring-midsummer and midsummer only had slightly heavy or neutral track conditions.

The binary outcome variables were analyzed using the PROC GLIMMIX procedure in SAS (version 9.4; SAS Institute Inc., 2013). The variables were modeled using a multivariable generalized linear mixed (GLM) model considering a binomial error distribution, the "logit" function, and the same factors as for the velocity model. The significance was determined using the Wald test. Each predictive variable effect was analyzed by comparisons of the odds ratio (OR) and confidence interval (95% CI). Level of significance was always set at $p \le .05$ for each association test. Additional GLM models considering a two-way interaction effect between shoeing condition and

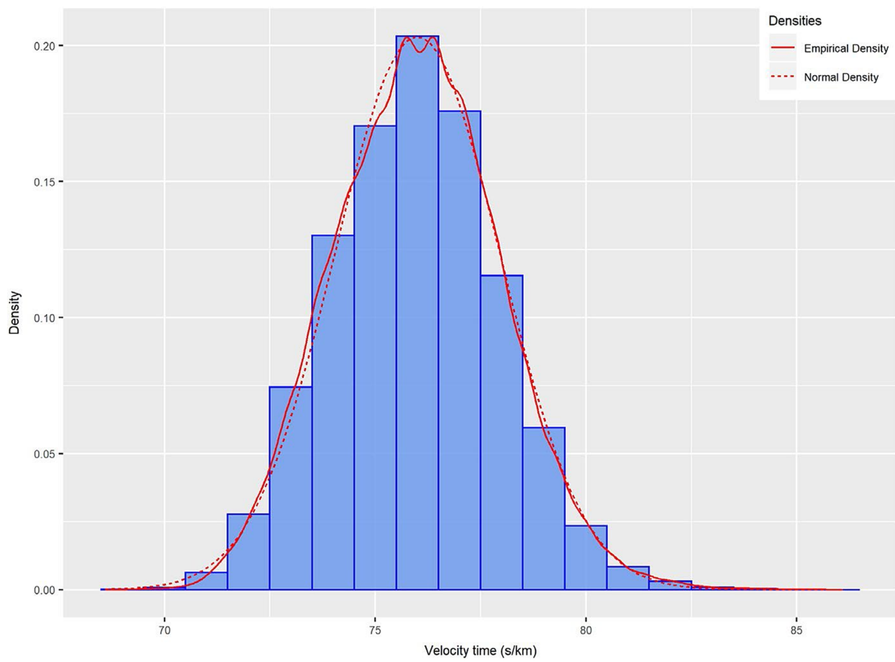

FIGURE 1 Histogram of velocity time (s/km) distribution for 5,247 Swedish Standardbred trotter (harness) horses racing between November 2013 and December 2016 (*N* = 76,932 records). Descriptive statistics: Average velocity time was 76.0 s/km (min. 68.6 s/km, max. 86.1 s/km). Normality Kolmogorov–Smirnov test *p*-value = 0.2894

TABLE 1 Results of linear-mixed model analysis of velocity time, with horse as random factor and shoeing condition, sex, age, season, track condition, start method, start position, distance, and driver-horse performance level as fixed factors

	No. of horses (No. of observations)	Estimate (s/km)	Std. Error	*df*	t value	*p*-value
Shoeing condition						
Unshod	5,244 (24,957)	Ref				
Shod front	1,205 (3,640)	+0.3	0.02	73,870	15.09	<2e−16*
Shod hind	3,109 (13,536)	+0.3	0.01	73,370	21.61	<2e−16*
Fully shod	4,816 (34,799)	+0.7	0.01	73,510	70.75	<2e−16*
Sex						
Stallion	380 (5,398)	Ref				
Gelding	2,706 (39,651)	+1.0	0.06	4,746	14.92	<2e−16*
Mare	2,161 (31,883)	+1.1	0.07	4,760	16.37	<2e−16*
Age (years)						
12	73 (411)	Ref				
2	144 (338)	+3.7	0.11	57,380	33.63	<2e−16*
3	1,424 (7,285)	+1.5	0.09	43,560	15.85	<2e−16*
4	2,257 (15,150)	+0.6	0.09	43,530	6.79	1.11e−11*
5	2,424 (17,102)	+0.2	0.09	44,250	2.64	0.008390**
6	2037 (14,721)	−0.0	0.09	45,420	−0.06	0.951249
7	1,403 (9,902)	−0.1	0.09	47,490	−1.68	0.093587
8	889 (5,948)	−0.2	0.09	51,070	−2.55	0.010858*
9	534 (3,368)	−0.3	0.09	57,140	−2.95	0.003227**
10	289 (1843)	−0.2	0.08	66,090	−2.61	0.008993**
11	132 (864)	−0.2	0.08	76,280	−2.25	0.024312*
Season						
Winter	4,034 (14,998)	Ref				
Spring-midsummer	4,614 (19,276)	−0.7	0.01	72,210	−58.34	<2e−16*
Late summer	4,502 (19,963)	−1.0	0.01	72,440	−80.10	<2e−16*
Autumn	4,785 (22,695)	−0.6	0.01	73,330	−53.31	<2e−16*
Track condition						
Winter	332 (861)	Ref				
Heavy	190 (204)	+2.8	0.08	71,870	36.59	<2e−16*
Slightly heavy	2,762 (4,662)	+0.5	0.04	72,250	12.40	<2e−16*
Neutral	5,247 (71,205)	−0.6	0.04	72,320	−16.03	<2e−16*
Start method						
Volt-start	4,741 (28,271)	Ref				
Auto-start	5,101 (48,661)	−0.6	0.01	72,930	−73.06	<2e−16*
Start position						
Less favorable	5,148 (37,983)	Ref				
Favorable	5,176 (38,949)	−0.1	0.01	71,850	−12.11	<2e−16*
Distance						
Short	4,049 (16,630)	Ref				
Medium	5,220 (58,580)	+1.5	0.01	72,410	159.79	<2e−16*
Long	781 (1722)	+2.3	0.03	72,720	84.13	<2e−16*

(Continues)

TABLE 1 (Continued)

	No. of horses (No. of observations)	Estimate (s/km)	Std. Error	*df*	t value	*p*-value
Driver-Horse						
Non-Elite & Control	4,828 (55,380)	Ref				
Elite & Control	3,161 (18,509)	−0.3	0.01	75,680	−29.48	<2e−16*
Non-Elite & Good	149 (1503)	−1.6	0.09	5,445	−17.76	<2e−16*
Elite & Good	151 (1,540)	−1.8	0.09	5,308	−20.20	<2e−16*

*Level of significance was set to $p \le .05$ (Likelihood Ratio test).

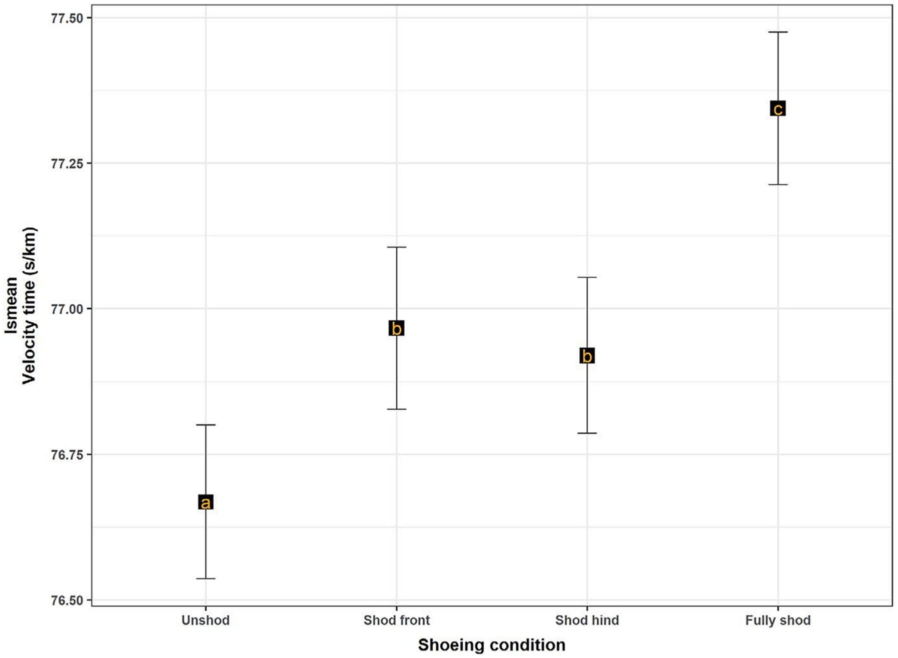

FIGURE 2 Boxplot showing the effect of shoeing condition on velocity time (s/km) in harness racing of Standardbred trotters. Boxes indicate least squares mean (LSM). Error bars indicate the 95% confidence interval of LSM. Means with different letters are significantly different (Tukey-adjusted comparisons). Level of significance was set to $p \le .05$

season were conducted. In cases where the interaction effect was significant ($p \le .05$), pairwise mean differences were tested using the Student's *t*-test as a post hoc test.

3 | RESULTS

3.1 | Descriptive information on shoeing condition

The studied population for velocity times represented 36, 8, 22, and 34% of individual horses which had raced unshod, shod front, shod hind, and fully shod, respectively (Table 1). A total of 76,932 observations (race records) were available for these horses and the most frequent shoeing condition was fully shod (45%), followed by unshod (32%), shod hind (18%), and shod front (5%) (Table 1).

3.2 | Effects on velocity time

The ANOVA test showed that all predictive variables considered in the multivariable linear-mixed effect model were associated with velocity time (p < 2e-16). Horses racing unshod showed faster velocity times (p < 2e-16) than horses racing in any of the other shoeing conditions (shod front, shod hind, fully shod) (Table 1). Racing in late summer gave the best velocity times (−1.0 s/km; p < 2e-16) of all seasons, and neutral tracks gave the best velocity times of all track conditions (−0.6 s/km; p < 2e-16) (Table 1). Moreover, when season and track conditions were both included in the model, the best velocity times were observed in late summer on neutral tracks (Table S1). Velocity times also differed between tracks, start method, start position, distance, or driver-horse performance level (p < 2e-16). For instance, horses racing on the fastest tracks showed velocity times that were between 0.78 and 0.97 s/km lower than those racing on the reference track (data

TABLE 2 Results of multivariable generalized linear mixed model analysis of risk factors for gallop, with horse as random factor and shoeing condition, sex, age, season, track condition, start method, start position, distance, and driver-horse performance level as fixed factors

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Shoeing condition					
Unshod	3,889 (7,093)	5,410 (26,070)	Ref		
Shod front	753 (1,154)	1,479 (4,695)	0.80	0.74–0.86	<0.0001*
Shod hind	1998 (3,685)	3,542 (15,568)	0.85	0.82–0.89	<0.0001*
Fully shod	3,621 (10,080)	5,823 (43,410)	0.74	0.71–0.76	<0.0001*
Sex					
Stallion	353 (1,143)	449 (6,166)	Ref		
Gelding	2,759 (11,624)	3,293 (46,256)	1.30	1.22–1.39	<0.0001*
Mare	2,254 (9,245)	2,639 (37,321)	1.16	1.08–1.24	<0.0001*
Age (years)					
12	36 (67)	79 (468)	Ref		
2	108 (161)	178 (417)	3.52	2.55–4.85	<0.0001*
3	1,267 (2,936)	1,790 (8,921)	3.03	2.33–3.95	<0.0001*
4	1982 (5,320)	2,746 (18,003)	2.60	2.00–3.38	<0.0001*
5	1988 (5,077)	2,876 (19,992)	2.18	1.68–2.83	<0.0001*
6	1613 (3,862)	2,425 (17,179)	1.88	1.44–2.43	<0.0001*
7	960 (2,216)	1634 (11,293)	1.59	1.22–2.06	0.0006*
8	572 (1,281)	1,016 (6,697)	1.52	1.17–1.99	0.0019*
9	314 (628)	600 (3,768)	1.33	1.01–1.74	0.0415*
10	163 (335)	327 (2059)	1.26	0.95–1.67	0.1141
11	72 (129)	149 (946)	1.01	0.73–1.38	0.9772
Season					
Winter	2,360 (3,901)	4,791 (17,490)	Ref		
Spring-midsummer	3,403 (6,235)	5,477 (22,460)	1.10	1.05–1.15	0.0002*
Late summer	3,162 (5,790)	5,325 (23,358)	0.92	0.87–0.96	0.0006*
Autumn	3,257 (6,086)	5,685 (26,435)	0.90	0.86–0.94	<0.0001*
Track condition					
Winter	156 (239)	399 (1,041)	Ref		
Heavy	69 (70)	241 (257)	1.20	0.88–1.64	0.2486
Slightly heavy	1,083 (1,304)	3,288 (5,564)	1.03	0.87–1.23	0.7246
Neutral	5,286 (20,399)	6,367 (82,881)	1.06	0.90–1.25	0.5025
Start method					
Volt-start	4,110 (11,079)	5,764 (34,393)	Ref		
Auto-start	4,298 (10,933)	6,075 (55,350)	0.61	0.59–0.63	<0.0001*
Start position					
Less favorable	4,339 (10,997)	6,188 (44,443)	Ref		
Favorable	4,412 (11,015)	6,214 (45,300)	1.05	1.02–1.08	0.0032*
Distance					
Short	2,630 (4,227)	4,656 (18,541)	Ref		
Medium	4,926 (17,385)	6,328 (69,213)	0.92	0.88–0.96	<0.0001*
Long	303 (400)	907 (1989)	0.66	0.59–0.75	<0.0001*

(Continues)

TABLE 2 (continued)

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Driver-Horse					
Non-Elite & Control	5,862 (65,388)	4,651 (16,612)	Ref		
Elite & Control	3,736 (20,947)	2,130 (4,767)	0.89	0.86–0.92	<0.0001*
Non-Elite & Good	165 (1705)	112 (352)	0.80	0.71–0.90	0.0002*
Elite & Good	167 (1703)	108 (281)	0.71	0.62–0.81	<0.0001*

*Level of significance was set to $p \le .05$ (Wald test).

not shown). Racing with the auto-start method and with a favorable start position showed the lowest velocity times, as did short-distance races (Table 1). Moreover, stallions showed lower velocity times than geldings and mares (by at least −1.1 s/km; $p <$ 2e-16) (Table 1). Young horses, aged from 2 to 5 years, had higher velocity times than horses older than 7 years (by between +0.2 and +3.7 s/km; $p <$ 2e-16). Race time was also improved (velocity time 1.8 s/km lower) by racing with an elite driver combined with a good horse compared with non-elite driver combined with a control horse (Table 1; $p <$ 2e-16).

The post hoc comparisons revealed mean differences ($p \le .05$) for shoeing condition and the interaction between shoeing condition x season x track condition (Figure 2 and Table S1). The interactions between shoeing condition x season and between shoeing condition x track condition were not statistically significant ($p = .0880$ and $p = .1741$, respectively). These results indicate that unshod horses performed better than other shod types (e.g., least squares mean (LSM) difference of −0.7 s/km between unshod and fully shod) (Figure 2), but there was no difference in performance between horses shod hind and shod front (Figure 2). Moreover, there was a difference of 5.1 s/km in the horses' velocity time between the best conditions (unshod, late summer, neutral track) and the worst conditions (fully shod, winter, heavy track) (Table S1).

3.3 | Risk performance traits

The multivariable GLM test for the risk of gallop model showed that all predictive variables except the track condition were associated ($p \le .05$). Horses racing in any shoeing condition (front, hind, or fully) had a lower OR value (0.74–0.85) for risk of galloping than unshod horses (Table 2). Among the seasons, racing during spring-midsummer had the highest OR for risk of galloping. Some tracks showed increased OR (2.46; data not shown) in comparison with the reference. Horses racing with the auto-start method had a lower OR for risk of galloping than those with volt-start, but starting in a favorable position increased the OR to 1.05 (Table 2). Racing over medium and long distances gave a lower OR (0.92 and 0.66, respectively) for risk of galloping than racing over short distances, while racing with an elite driver combined with a good horse reduced the OR (0.71) in comparison with a non-elite driver combined with a control horse (Table 2). Geldings and mares had increased the OR for risk of galloping in comparison with stallions, and horses from 2 years up to 9 years had increased OR in comparison with 12-year-old horses (OR = 1.33–3.52) (Table 2).

Regarding the risk factors for driver penalties, the multivariable GLM test showed that age, track condition, and shoeing condition were not associated ($p > .05$). Only mares showed reduced OR for risk of penalties in comparison with stallions (Table 3). Racing during late summer had a higher OR for risk of driver penalties in relation to winter season. Some tracks showed reduced OR (e.g., 0.54; data not shown) in comparison with the reference. Similarly to the risk of galloping, horses racing with the auto-start method had reduced OR for risk of driver penalties in comparison with volt-start, but starting in a favorable position increased the OR for risk of driver penalties to 1.38 (Table 3). Long distances had reduced the OR for risk of driver penalties (0.61) in comparison with short distances, and the OR for an elite driver combined with a good horse (0.59) in comparison with a non-elite driver combined with a control horse (Table 3).

The multivariable GLM test for the risk of disqualification model showed that all predictive variables except the track condition and distance were associated ($p \le .05$). Horses racing in any shoeing condition (front, hind, or fully) had reduced OR (0.75–0.86) for risk of disqualification in comparison with unshod horses (Table 4). Racing during spring-midsummer had increased the OR for risk of disqualification in relation to winter season. Five tracks showed reduced OR (0.69–0.83; data not shown) in comparison with the reference. Horses racing with the auto-start method had also reduced OR for risk of disqualification in comparison with volt-start, but starting in a favorable position increased the OR to 1.14 (Table 4). Racing with an elite driver combined with a good horse had a reduced OR (0.75) in comparison with a non-elite driver combined with a control horse. Geldings and mares had a higher OR for risk of disqualification in comparison with stallions, and young horses aged from 3 to 5 years had a higher OR for risk of disqualification in comparison with 12-year-old horses (OR = 1.45–1.70) (Table 4).

The multivariable GLM tests for the risk of behavioral disqualification related to unwanted specific behaviors showed that season and track condition were not associated ($p > .05$). Horses racing in any of the shoeing condition (front, hind, or fully) had reduced OR (0.76–0.86) for risk of behavioral disqualification in comparison with unshod horses (Table 5). Horses racing in spring-midsummer also showed increased OR compared with horses racing in winter. Nine tracks showed reduced OR (0.67–0.74; data not shown) in comparison with the reference. Horses racing with the auto-start method also had reduced OR for risk of behavioral disqualification in comparison

TABLE 3 Results of multivariable generalized linear mixed model analysis of risk factors for driver penalties, with horse as random factor and shoeing condition, sex, age, season, track condition, start method, start position, distance, and driver-horse performance level as fixed factors

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Shoeing condition					
Unshod	543 (584)	6,390 (32,579)	Ref		
Shod front	102 (106)	1706 (5,743)	0.97	0.79–1.20	0.7709
Shod hind	308 (339)	3,910 (18,914)	0.98	0.85–1.12	0.7526
Fully shod	858 (1,012)	5,964 (52,478)	0.94	0.84–1.04	0.2240
Sex					
Stallion	106 (131)	452 (7,178)	Ref		
Gelding	880 (1,127)	3,316 (56,753)	0.89	0.74–1.07	0.2030
Mare	636 (783)	2,655 (45,783)	0.76	0.63–0.92	0.0050*
Age (years)					
12	14 (16)	82 (519)	Ref		
2	10 (11)	205 (567)	0.72	0.32–1.60	0.4204
3	173 (186)	1910 (11,671)	0.62	0.36–1.05	0.0759
4	343 (379)	2,882 (22,944)	0.68	0.40–1.14	0.1398
5	409 (461)	2,972 (24,608)	0.76	0.45–1.27	0.2914
6	367 (414)	2,495 (20,627)	0.80	0.48–1.35	0.4069
7	228 (264)	1677 (13,245)	0.78	0.47–1.32	0.3564
8	131 (149)	1,052 (7,829)	0.74	0.44–1.26	0.2677
9	79 (86)	611 (4,310)	0.77	0.44–1.33	0.3416
10	46 (53)	333 (2,341)	0.82	0.46–1.45	0.4958
11	20 (22)	153 (1,053)	0.71	0.37–1.38	0.3136
Season					
Winter	339 (352)	5,067 (21,039)	Ref		
Spring-midsummer	504 (539)	5,753 (28,156)	1.10	0.95–1.27	0.2038
Late summer	555 (609)	5,573 (28,539)	1.20	1.04–1.39	0.0134*
Autumn	504 (541)	5,900 (31,980)	1.01	0.88–1.17	0.8566
Track condition					
Winter	20 (20)	439 (1,260)	Ref		
Heavy	8 (8)	296 (319)	1.20	0.51–2.82	0.6814
Slightly heavy	124 (126)	3,687 (6,742)	1.20	0.71–2.03	0.5066
Neutral	1526 (1887)	6,418 (101,393)	1.21	0.73–2.01	0.4571
Start method					
Volt-start	1,107 (1,314)	5,962 (44,158)	Ref		
Auto-start	662 (727)	6,253 (65,556)	0.36	0.33–0.40	<0.0001*
Start position					
Less favorable	804 (907)	6,322 (54,533)	Ref		
Favorable	1,001 (1,134)	6,343 (55,181)	1.38	1.26–1.51	<0.0001*
Distance					
Short	310 (326)	5,106 (22,442)	Ref		
Medium	1,375 (1672)	6,392 (84,926)	1.04	0.91–1.18	0.6030
Long	42 (43)	1,008 (2,346)	0.61	0.44–0.85	0.0036*

(Continues)

TABLE 3 (Continued)

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Driver-Horse					
Non-Elite & Control	5,987 (80,229)	1,406 (1771)	Ref		
Elite & Control	3,964 (25,495)	205 (219)	0.43	0.37–0.50	<0.0001*
Non-Elite & Good	171 (2027)	26 (30)	0.77	0.54–1.12	0.1674
Elite & Good	168 (1963)	18 (21)	0.59	0.38–0.91	0.0179*

*Level of significance was set to $p \le .05$ (Wald test).

with volt-start, but starting in a favorable position increased the OR to 1.18 (Table 5). Racing over medium and long distances increased the OR to 1.21 and 1.38, respectively, in comparison with short distances. Racing with an elite driver combined with a good horse had a reduced OR (0.65) in comparison with a non-elite driver combined with a control horse. As with the other risk factors studied, geldings and mares showed higher OR (1.34 and 1.41, respectively) for risk of behavioral disqualification (Table 5). However, young horses aged 2 years had a lower OR compared with adult horses aged 12 years.

The two-way test for interactions between season and shoeing condition showed an association ($p \le .05$) for the risk of gallop and disqualification (Table S2 and S3). Thus, fully shod horses racing in any seasons showed decreased OR (0.65–0.82) for risk of galloping compared with unshod horses (Table S2). Shod hind horses showed decreased OR (0.81–0.88) for risk of galloping in all seasons compared with unshod horses (Table S2). Shod front horses showed decreased OR (0.74–0.77) for risk of galloping in spring-midsummer, late summer, and winter compared with unshod horses (Table S2). Similarly, fully shod horses racing in any season showed decreased OR (0.66–0.85) for risk of being disqualified compared with unshod horses (Table S3). Shod hind horses showed decreased OR (0.83–0.91) for risk of being disqualified in autumn, spring-midsummer, and winter compared with unshod horses (Table S3). Shod front horses showed decreased OR (0.75–0.77) for risk of being disqualified in spring-midsummer and late summer compared with unshod horses (Table S3).

Overall, compared with the unshod condition, shoeing either the front or hind hooves lowered the risk of galloping in all seasons except for autumn, when shoeing front did not affect the risk (Table S2). Compared with the unshod condition, shoeing hind also lowered the risk of disqualification in all seasons except in late summer, whereas shoeing front lowered the risk during spring-midsummer and late summer (Table S3).

4 | DISCUSSION

4.1 | Effects related to shoeing condition

This longitudinal retrospective cohort study, conducted over a 2-year observation period, is the first study to examine the benefits and risks of racing barefoot (unshod) in harness Standardbred races. It provides statistical evidence that racing barefoot improves velocity time if the horse does not gallop, is not penalized, or is not disqualified from the race, but also that racing unshod involves higher risks of failure (galloping and disqualification). The differences observed in velocity times can have marked effects on earnings performance, since prizes are awarded on a logarithmic scale and, in a race with evenly matched competitors, tenths of a second have marked effects on earnings.

The descriptive analysis showed that trainers definitely have a strategy regarding which hooves should be left unshod. The most common condition was to race unshod on all hooves, while the least common condition was to race shod front but without shoes on hind hooves. The racing unshod strategy is based on a perceived general improvement in performance, which was supported by the findings in the present study. For horses that preferably should be raced unshod (according to the trainer) but where the current condition of the hooves or the track poses a perceived risk, the general practice is to race with shoes on hind hooves. The hind hooves are generally considered “limiting” with respect to wear and tear. The use of this strategy was in some way confirmed by the present study, since shod hind was the most common strategy after unshod and fully shod. There were comparatively few observations (5%) for horses racing shod front, which means that trainers perceive that very few horses benefit from racing in this condition. However, there were no differences in performance between shod front and shod hind horses. This indicates that trainers are skilled in judging how individual horses should be shod.

Competing shod on all hooves decreased the relative risk of galloping and of being disqualified by 26% compared with racing unshod, whereas having shoes on front or hind hooves decreased the relative risk by 20 and 15%, respectively. The slightly lower risk observed when horses were shod front could, according to general trainer experiences, be because some horses find it easier to maintain a symmetrical trot with some weight on the front hooves. Similar results were observed for racing season, with the greatest difference during winter, when the relative risks of galloping and of being disqualified were 34%–35% higher for unshod horses in comparison with shod horses.

TABLE 4 Results of multivariable generalized linear mixed model analysis of risk factors for disqualification, with horse as random factor and shoeing condition, sex, age, season, track condition, start method, start position, distance, and driver-horse performance level as fixed factors

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Shoeing condition					
Unshod	2,739 (4,125)	5,809 (29,038)	Ref		
Shod front	485 (640)	1,580 (5,209)	0.80	0.73–0.87	<0.0001*
Shod hind	1,437 (2,126)	3,690 (17,127)	0.86	0.82–0.91	<0.0001*
Fully shod	2,754 (5,529)	5,883 (47,961)	0.75	0.72–0.79	<0.0001*
Sex					
Stallion	273 (634)	450 (6,675)	Ref		
Gelding	2,352 (6,642)	3,307 (51,238)	1.37	1.26–1.50	<0.0001*
Mare	1893 (5,144)	2,649 (41,422)	1.23	1.12–1.34	<0.0001*
Age (years)					
12	29 (52)	79 (483)	Ref		
2	33 (40)	201 (538)	0.88	0.56–1.36	0.5588
3	910 (1531)	1853 (10,326)	1.70	1.26–2.30	0.0006*
4	1551 (3,071)	2,818 (20,252)	1.67	1.24–2.25	0.0007*
5	1523 (2,946)	2,916 (22,123)	1.45	1.08–1.94	0.0134*
6	1,200 (2,150)	2,454 (18,891)	1.21	0.90–1.62	0.2019
7	722 (1,271)	1645 (12,238)	1.08	0.80–1.45	0.6167
8	415 (705)	1,028 (7,273)	0.99	0.74–1.34	0.9644
9	232 (373)	609 (4,023)	0.95	0.70–1.29	0.7337
10	132 (214)	332 (2,180)	0.98	0.72–1.36	0.9238
11	47 (67)	150 (1,008)	0.64	0.44–0.94	0.0212*
Season					
Winter	1,580 (2,171)	4,902 (19,220)	Ref		
Spring-midsummer	2,345 (3,493)	5,620 (25,202)	1.12	1.06–1.19	0.0002*
Late summer	2,238 (3,262)	5,451 (25,886)	0.97	0.91–1.04	0.4007
Autumn	2,289 (3,494)	5,793 (29,027)	0.97	0.92–1.03	0.3786
Track condition					
Winter	94 (118)	420 (1,162)	Ref		
Heavy	33 (33)	272 (294)	1.01	0.67–1.54	0.9545
Slightly heavy	650 (721)	3,493 (6,147)	1.07	0.85–1.34	0.5618
Neutral	4,408 (11,548)	6,400 (91,732)	1.10	0.88–1.36	0.4113
Start method					
Volt-start	2,993 (5,869)	5,879 (39,603)	Ref		
Auto-start	3,356 (6,551)	6,166 (59,732)	0.72	0.69–0.75	<0.0001*
Start position					
Less favorable	3,204 (5,907)	6,268 (49,533)	Ref		
Favorable	3,432 (6,513)	6,242 (49,802)	1.14	1.10–1.18	<0.0001*
Distance					
Short	1715 (2,356)	4,883 (20,412)	Ref		
Medium	4,033 (9,793)	6,363 (76,805)	0.97	0.92–1.02	0.1946
Long	232 (271)	938 (2,118)	0.88	0.77–1.01	0.0760

(Continues)

TABLE 4 (Continued)

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Driver-Horse					
Non-Elite & Control	5,925 (72,822)	3,769 (9,178)	Ref		
Elite & Control	3,824 (22,840)	1619 (2,874)	0.96	0.91–1.00	0.0745
Non-Elite & Good	170 (1856)	84 (201)	0.84	0.72–0.97	0.0190*
Elite & Good	168 (1817)	88 (167)	0.75	0.64–0.88	0.0006*

*Level of significance was set to $p \le .05$ (Wald test).

During the data collection period, it was permitted to race horses without shoes during the winter, but this has since been banned due to perceived animal welfare issues. Assuming that welfare problems related to racing unshod during the winter season would be manifested in a particularly high risk of galloping, disqualification, or penalties, our data provide some support for this hypothesis. Racing shod on hind hooves versus unshod in the winter showed similar odds ratios for gallop and disqualification as during the other seasons but for fully shod versus unshod horses, the lowest odds ratios for gallop and disqualification were observed during the winter (0.65 and 0.66, respectively, Table S2). For this comparison, however, odds ratios of the same magnitude were observed also in the spring-summer (0.70 for gallop and 0.69 for disqualification).

Having shoes on hind hooves during all seasons (winter, spring-midsummer, late summer, autumn) decreased the relative risk of galloping and being disqualified (except in late summer; $p = .07$, Table S3) by between 12% and 19% compared with the unshod condition, indicating a consistent trend regardless of season. This clear trend was not observed for shod front horses, which indicates that the hind hooves are a weak spot and that racing with shoes on hind hooves is a safe strategy. This confirms the common belief among trainers that hind hooves are most sensitive to unshod racing.

It is important to highlight that there were no associations between having horses shod or not and penalties (wrong starting position, too early at the starting line, disturb other participants, or poor execution of volt-start). Thus the data did not support our hypothesis that the risk of penalties is linked to shoeing condition, either because of more offensive (optimistic) driving of unshod horses or because horses may be less easy to control if they experience discomfort from unshod hooves. However, horses competing unshod had an increased risk of behavioral disqualification (gallop, pacing, or driving outside the track). Driving outside the track might be a sign of lack of control, but may sometimes be done intentionally by the driver. The increased risk of gallop and pace might reflect greater difficulties in maintaining rhythm in a high-speed trot without shoes, but might also indicate some discomfort in unshod hooves.

4.2 | General effects

The influence of sex on harness racing times has been examined in previous studies (Ojala & Hellman, 1987; Štrbac & Trivunović, 2013; Štrbac, Trivunović, & Baban, 2015). These report that, in the majority of cases, stallions achieve lower velocity times than females (on average by −0.15 to −2.29 s/km) (Ojala & Hellman, 1987; Štrbac & Trivunović, 2013). In this study, we provide statistical evidence supporting these findings and indicating that stallions also show lower risks of galloping and disqualification. It is well known that, on average, stallions have greater physiological and metabolic capacity than mares (Persson & Ullberg, 1974), but there may also be psychological differences between the sexes. Our findings also indicate that, over time, athletic exercise may improve harness racing performance in adult horses, resulting in faster times and fewer disqualifications than in young horses (3–5 years), which may be attributable to improved co-ordination (Leleu, Cotrel, & Barrey, 2004).

We identified other factors affecting velocity time, such as start method, start position, distance, or driver-horse performance level. Auto-start races were generally faster, as reported in other studies (Čačić & Šimundža, 2012). The analysis also confirmed the general belief that the auto-start method reduces the risks of galloping, penalties, and disqualification. This is most likely attributable to the challenges associated with volt-start races, that is mental and technical challenges in starting a race at slow speed. As expected, the horses racing in a favorable position (according to statistics from STA) showed better velocity times, regardless of the start method. However, racing in a favorable position can lead to higher pressure on the horse and the driver, manifested as an increased risk of galloping, penalties, or disqualification. Reduced velocity times in long-distance races have also been observed in other studies (Štrbac & Trivunović, 2013). In this study, we observed less risk of galloping and penalties for horses racing over long distances, but there was an increased risk of disqualification for unwanted behaviors (e.g., more unwanted and asymmetric gaits). Another general belief is that some drivers are better than others and our study confirmed this. Good performance horses racing with elite drivers not only gained in terms of velocity, but also showed lower risks of galloping, penalties, and disqualification.

TABLE 5 Results of multivariable generalized linear mixed model analysis of risk factors for behavioral disqualification, with horse as random factor and shoeing condition, sex, age, season, track condition, start method, start position, distance, and driver-horse performance level as fixed factors

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Shoeing condition					
Unshod	1592 (2049)	6,140 (31,114)	Ref		
Shod front	286 (335)	1642 (5,514)	0.86	0.76–0.97	0.0116*
Shod hind	838 (1,056)	3,816 (18,197)	0.86	0.79–0.93	0.0001*
Fully shod	1827 (2,818)	5,922 (50,672)	0.76	0.72–0.81	<0.0001*
Sex					
Stallion	181 (293)	451 (7,016)	Ref		
Gelding	1,690 (3,170)	3,311 (54,710)	1.34	1.19–1.52	<0.0001*
Mare	1,426 (2,795)	2,652 (43,771)	1.41	1.24–1.60	<0.0001*
Age (years)					
12	21 (33)	81 (502)	Ref		
2	14 (15)	205 (563)	0.48	0.26–0.91	0.0239*
3	549 (746)	1885 (11,111)	1.06	0.74–1.53	0.7459
4	1,037 (1532)	2,852 (21,791)	1.12	0.78–1.60	0.5535
5	994 (1513)	2,950 (23,556)	1.03	0.72–1.47	0.8845
6	762 (1,094)	2,480 (19,947)	0.87	0.61–1.25	0.4601
7	457 (641)	1655 (12,868)	0.78	0.54–1.13	0.1844
8	252 (344)	1,038 (7,634)	0.70	0.49–1.02	0.0631
9	152 (191)	612 (4,205)	0.72	0.50–1.07	0.1022
10	91 (118)	333 (2,276)	0.82	0.55–1.23	0.3421
11	25 (31)	153 (1,044)	0.48	0.29–0.79	0.0039*
Season					
Winter	914 (1,065)	4,991 (20,326)	Ref		
Spring-midsummer	1,381 (1722)	5,700 (26,973)	1.11	1.02–1.20	0.0161*
Late summer	1,344 (1677)	5,528 (27,471)	1.03	0.94–1.12	0.5233
Autumn	1,401 (1794)	5,859 (30,727)	1.03	0.95–1.12	0.4301
Track condition					
Winter	57 (64)	429 (1,216)	Ref		
Heavy	20 (20)	285 (307)	1.03	0.61–1.75	0.9143
Slightly heavy	375 (400)	3,596 (6,468)	1.07	0.79–1.45	0.6439
Neutral	3,159 (5,774)	6,410 (97,506)	1.03	0.77–1.38	0.8297
Start method					
Volt-start	2,101 (3,272)	5,919 (42,200)	Ref		
Auto-start	2066 (2,986)	6,225 (63,297)	0.62	0.59–0.66	<0.0001*
Start position					
Less favorable	2042 (2,941)	6,297 (52,499)	Ref		
Favorable	2,267 (3,317)	6,321 (52,998)	1.18	1.12–1.24	<0.0001*
Distance					
Short	827 (950)	5,044 (21,818)	Ref		
Medium	2,911 (5,132)	6,375 (81,466)	1.21	1.13–1.31	<0.0001*
Long	163 (176)	960 (2,213)	1.38	1.16–1.65	0.0003*

(Continues)

TABLE 5 (Continued)

	No. of cases (No. of observations)	No. of controls (No. of observations)	Odds Ratio	95% CI	*p*-value
Driver-Horse					
Non-Elite & Control	5,925 (72,822)	3,769 (9,178)	Ref		
Elite & Control	3,824 (22,840)	1619 (2,874)	0.99	0.93–1.05	0.7285
Non-Elite & Good	170 (1856)	84 (201)	0.74	0.60–0.93	0.0083*
Elite & Good	168 (1817)	88 (167)	0.65	0.50–0.83	0.0005*

*Level of significance was set to $p \leq .05$ (Wald test).

Weather variations during the different seasons, the track and its condition are important factors for the performance of racing horses. Racing under different weather conditions affects velocity times, while there is great variation between different race tracks in terms of risk factors for durability traits (Gómez, Menéndez-Buxadera, Valera, & Molina, 2015; Solé et al., 2017; Štrbac et al., 2015). In the present study, the national arena showed faster velocity times, with no statistically associated risk factors. However, this might be due partly to a clear bias in the quality of horses competing in this arena compared with other tracks, that is more elite horses race in the arena. Interestingly, the best performances were observed during late summer (velocity times −1.0 s/km compared with winter), and horses were also less likely to gallop in late summer than in the winter. The reason for this is not clear but it can also be due to the quality of horses racing in this season and maybe also due to the climate. During this period (July-August 2014 and 2015), the mean monthly temperature was 15–20°C (Swedish Meteorological and Hydrological Institute, https://www.smhi.se). This is in accordance with observations of good performance in Spanish Standardbreds (Gómez et al., 2015). In that study, performance was negatively affected at higher temperatures (around + 0.5 s/m lower speeds at temperatures > 20°C). Moreover, when track conditions were also included in post hoc comparisons of performance, the best performances were also observed in late summer, on neutral tracks.

Racing on heavy track surfaces showed the worst velocity times (+2.8 s/km compared with winter surface), but none of the risk factors was statistically associated with this (e.g., no more gallop or disqualification), suggesting that horses may adapt to surface conditions. Alternatively, since unshod horses showed lower velocity times, trainers may strategically race their horses unshod in specific seasonal and track surface conditions, in an attempt to get a good lifetime record. In the ranking of the best performances based on shoeing condition, season, and track condition (Table S1), 15 of the top 20 results were performed on neutral tracks, indicating that the track is of great importance for velocity. No horses were raced unshod on winter tracks which is most likely due to that it is impossible because of lack of grip.

This study included the majority of factors influencing racing unshod in multivariable linear and general mixed models with repeated measures. However, there were some limitations in the dataset and analysis. For example, there were correlations between the explanatory variables that could not be accounted for in the models, due to computational limitations. Thus, the present study alone is unlikely to have identified individual horses that are associated with higher risks when racing unshod. Further research is needed, particularly to investigate the quality of the hooves in frequently raced unshod Standardbreds and to examine beneficial genetic factors for barefoot racing conditions.

In summary, this study provides evidence to support the hypothesis that Swedish harness racing performance is better in unshod horses, but that potential risk factors are also more influential (e.g., more galloping and disqualification). We found that velocity time can be affected by multiple factors such as sex, age, season, racetrack, racetrack condition, start method and position, distance, or driver-horse performance level, and that higher velocities are achieved when racing unshod under specific seasonal and track surface conditions (e.g., late summer, neutral tracks). The results of this study also indicate that shoeing the hind hooves of horses may improve racing performance, regardless of the season, without introducing associated risks.

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ORCID

Marina Solé https://orcid.org/0000-0001-7884-1051

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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