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Evolutionary biology

Racehorses are getting faster

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Previous studies have concluded that thoroughbred racehorse speed is improving very slowly, if at all, despite heritable variation for performance and putatively intensive selective breeding. This has led to the suggestion that racehorses have reached a selection limit. However, previous studies have been limited, focusing only on the winning times of a few elite races run over middle and long distances, and failing to account for potentially confounding factors. Using a much larger dataset covering the full range of race distances and accounting for variation in factors such as ground softness, we show that improvement is, in fact, ongoing for the population as a whole, but driven largely by increasing speed in sprint races. In contrast, speed over middle and long distances, at least at the elite level, appears to be reaching an asymptote. Whether this reflects a selection limit to speed over middle and long distances or a shift in breeding practices to target sprint performances remains to be determined.

1. Introduction

Winning times of some thoroughbred horse races in Great Britain (GB) are on record from the mid-1800s. Nowadays, winning times are recorded for all races run, and times of beaten horses can be inferred. Notably, the few studies to analyse temporal changes in performance have reported little recent improvement in winning times of elite races in GB [1,2]. Similarly, a study of the three most prestigious races in America reported no increase in winning speed since the early-1970s [3], and concluded that racehorses will reach maximal speed imminently. This conclusion was also reached in a study of the best performances worldwide [4]. The lack of improvement is striking given putatively intensive selective breeding [5] and high heritability estimates for performance traits [4–6], prompting the suggestion that thoroughbreds have reached a selection limit [3,4,7–9]. However, previous studies have been limited. First, they analysed only winning time (or speed) of a small number of middle- and long-distance elite races. Second, no account has been taken for temporal variation in potentially confounding factors such as ground softness [1–4]. Here, we address these limitations to test for and characterize improvement, both at the elite level and in the racehorse population as a whole.

2. Methods

Data were sourced from *Ruff's Guide to the Turf* (1850–1951 annual editions), the *Raceform Flat Annual* (1949–1994) and Raceform Interactive (1996–2012; www.raceform.co.uk). We included only GB flat races run on the turf. For an average of 48 (range 11–106) elite races (termed 'Group' races since 1971) per year in 47 years between 1850 and 1996 (2243 races in total), we recorded: winning time, timing method (hand-timed or automatic), race distance, racecourse, official going (ground softness), number of runners (no.runners) and name, age and sex of the winner. 'Going' was converted from its official (categorical) description to a numerical scale using conversion tables provided at www.britishhorseracing.com/wp-content/uploads/2014/03/Going-Stick-Average-Readings.pdf. We collected similar data for a larger set of races (>50 000; elite and otherwise) held every year between 1997 and 2012. For these races, times of beaten horses were estimated based on distance beaten and conversion

Table 1. Linear rates of speed improvement estimated from datasets from model 1. Parameter estimates are from REML models with year fitted as continuous covariate. Inference is by likelihood comparison of full and reduced models fitted by ML (see text for details).

dataset	years	classes	finishers	distance (furlongs)	temporal trend ± s.e. (yards s^{-1} year^{-1})	χ^2_1	p
1.1	1850–2012	elite	winners	5–7	$0.014 \pm 5 \times 10^{-4}$	659	<0.001
1.2	1850–2012	elite	winners	8–12	$0.013 \pm 4 \times 10^{-4}$	677	<0.001
1.3	1850–2012	elite	winners	14–20	0.011 ± 0.001	106	<0.001
1.4	1997–2012	elite	winners	5–7	0.020 ± 0.002	64.3	<0.001
1.5	1997–2012	elite	winners	8–12	0.006 ± 0.002	5.8077	0.016
1.6	1997–2012	elite	winners	14–20	0.007 ± 0.005	2.71	0.100
1.7	1997–2012	elite	all	5–7	0.023 ± 0.001	409	<0.001
1.8	1997–2012	elite	all	8–12	0.006 ± 0.001	26.0	<0.001
1.9	1997–2012	elite	all	14–20	0.008 ± 0.002	12.3	<0.001
1.10	1997–2012	all	winners	5–7	$0.014 \pm 6 \times 10^{-4}$	466	<0.001
1.11	1997–2012	all	winners	8–12	$0.006 \pm 7 \times 10^{-4}$	70.6	<0.001
1.12	1997–2012	all	winners	14–20	0.005 ± 0.002	11.2	<0.001
1.13	1997–2012	all	all	5–7	$0.018 \pm 4 \times 10^{-4}$	2212	<0.001
1.14	1997–2012	all	all	8–12	$0.010 \pm 4 \times 10^{-4}$	634	<0.001
1.15	1997–2012	all	all	14–20	$0.009 \pm 8 \times 10^{-4}$	114	<0.001

scales published at www.britishhorseracing.com/wp-content/uploads/2014/04/Lengths-Per-Second-Scale-Tables.pdf. The full dataset comprises 616 084 race times run by 70 388 horses.

We modelled speed using linear-mixed effect models fitted to datasets differing with respect to: races since 1850 versus 1997; inclusion of winners versus all finishers; data from all races versus elite races; and data from sprint (5–7 furlongs), middle (8–12 furlongs) and long distance (14–20 furlongs) races (table 1). For each dataset, we first fitted model 1 as

$$\begin{aligned}\text{horse speed} &\sim \mu + \text{year} + \text{distance} + \text{distance}^2 + \text{no.runners}\\ &+ \text{no.runners}^2 + \text{going} + \text{going}^2 + \text{age} + \text{sex} + \text{timing method}\\ &+ \text{course} + \text{distance:going} + \text{distance:no.runners} + \text{horse}\end{aligned}$$

where year, distance (yards), no.runners and going were fitted as continuous covariates and age (years), sex, timing method and course were included as fixed factors. We mean-centred *going* and no.runners and where going was unknown, assumed a value of zero. Horse identity was included as a random effect because individuals contribute multiple records. Significance of the trend was first determined by comparing log-likelihoods of models with and without year (fitted by maximum-likelihood using the R package LME4), before obtaining final parameter estimates using restricted maximum-likelihood in ASReml.

Model 1 tests for a simple (linear) improvement in speed averaged over the distance variation within each dataset. To determine patterns of temporal change without assuming a linear (or other parametric) relationship, and to explicitly characterize improvement rates as a function of race distance, we fitted a modified model (model 2) with year effect as a multi-level factor and inclusion of year (continuous) by distance and year by distance^2 interactions. Nonlinear improvement has been previously reported (2,3,4) and consistent with this, refitting model 1 treating year as a factor improved model fits (e.g. ΔAIC = 132.9 analysing 1850–2012 elite winners; full results not presented). Model 2 was fitted to datasets differing with respect to: races since 1850 versus 1997; inclusion of winners versus all finishers; data from all races versus elite races (table 2), and used to predict average speed by year at 6, 10 and 17 furlongs (representing sprint, middle and long distances). Significance of the horse effect was assessed by likelihood ratio test and among-horse variance was divided by phenotypic variance (conditional on fixed effects) to estimate the (among-horse) repeatability of speed.

3. Results

Average racehorse speed has improved historically (since 1850) and continues to increase (since 1997; table 1). Under model 1, year effects were positive in all 15 datasets examined and significant in all but one (winners of elite, long-distance races, 1997–2012). However, a more nuanced picture is revealed by model 2. First, historical improvement has not been linear (figure 1). Rapid improvement occurred from the late-1800s to 1910, followed by comparative stasis to 1975, then relatively greater rates since. Second, significant interactions between year (continuous) and distance/distance^2 ($|Z| > 1.96$, $p < 0.05$; electronic supplementary material, table S1) mean that, between 1850 and 2012, elite race winners improved more rapidly at shorter distances (figure 1) both in absolute and percentage terms. For instance, predicted speed increases at 6, 10 and 17 furlongs, respectively, were of 2.11, 1.69 and 1.49 yards s^{-1}, representing increases of 12.9%, 10.6% and 9.7% relative to speed in 1850 (or average yearly gains of approximately 0.080%, 0.065% and 0.060%; table 2).

Examining model predictions for the 1997–2012 data in more detail shows that while winners of elite races continue to improve, this is almost wholly driven by sprint races with winning speed increasing by an average 0.110% per year since 1997 (table 2). Corresponding average changes in elite winning speed over middle and long distances were estimated at 0.020% and −0.009% per year, respectively (table 2 and figure 2*a*). Qualitative patterns are broadly similar using data from all finishers in elite races (figure 2*b*), winners of all races (figure 2*c*) and all finishers in all races (figure 2*d*). In all cases, improvement is most rapid for sprints. For instance, winning speed of all races has increased by an estimated average of 0.062%, 0.037% and 0.022% per year (of 1997

Table 2. Predicted rates of speed improvement at 6, 10 and 17 furlongs determined from model 2 fitted to datasets. Average yearly improvement is expressed in absolute units (yards s^{-1} $year^{-1}$) and as a percentage of speed in the first year of analysis (1850 or 1997).

dataset	years	classes	finishers	distance (furlongs)	average predicted change in speed per year (yards sec^{-1} $year^{-1}$)	average predicted change in speed per year (% of 1850 or 1997 speed)
2.1	1850–2012	elite	winners	6	0.013	0.080
				10	0.010	0.065
				17	0.009	0.060
2.2	1997–2012	elite	winners	6	0.020	0.110
				10	0.004	0.020
				17	−0.002	−0.009
2.3	1997–2012	elite	all	6	0.022	0.124
				10	0.004	0.022
				17	0.003	0.016
2.4	1997–2012	all	winners	6	0.011	0.062
				10	0.006	0.037
				17	0.004	0.022
2.5	1997–2012	all	all	6	0.015	0.090
				10	0.011	0.065
				17	0.006	0.034

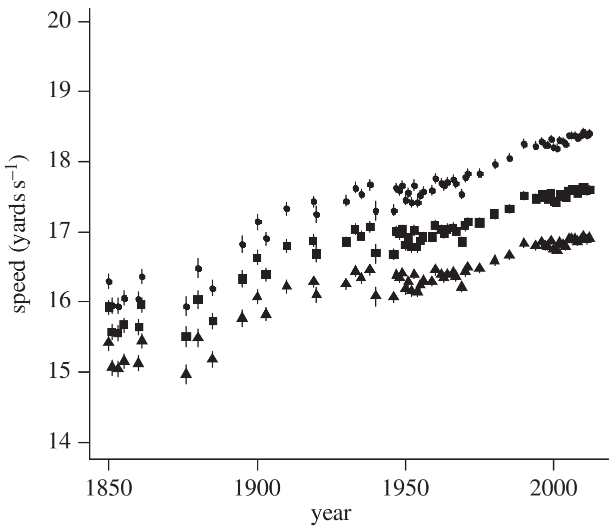

Figure 1. Patterns of temporal change in speeds of elite race winners since 1850. Circles, squares and triangles represent average speed predicted from model 2 at 6, 10 and 17 furlongs, respectively (bars indicate ±1 s.e.).

values) at 6, 10 and 17 furlongs, respectively (table 2). Estimated rates are slightly higher at 0.090%, 0.065% and 0.034% per year when considering all finishers in all races from 1997 to 2012 (table 2). See electronic supplementary material, table S1 for full (fixed) parameter estimates under model 2 and electronic supplementary material, table S2 for predicted speed by year at 6, 10 and 17 furlongs. Estimates of among-horse repeatability are provided in the electronic supplementary material, table S3.

4. Discussion

Our analyses show that elite race winning speeds have improved greatly since 1850. Furthermore, 1997–2012 data reveal that this improvement is ongoing but, importantly, rates vary across distances. Contemporary improvement is low for middle and long distances, but winning speed for elite sprint races actually exceeds estimated historical rates. A similar pattern emerges when all elite finishers are included, and if the wider population of non-elite performers is considered.

Three recent studies concluded that racehorses are at (or very close to) maximal speed [2–4], with a fourth reporting modest continued improvement (although significant change was limited to 4 of 11 races analysed [1]). Given that these studies were limited to elite races run over middle and long distances, our results are broadly consistent (in terms of improvement rates) even if our qualitative conclusion—that horses *are* still getting faster—is different. The qualitative discrepancy likely reflects our greater statistical power combined with explicit modelling of environmental factors known [10] or hypothesized to influence speed. Ongoing improvement in sprint performance, not previously analysed, is much more rapid. Between 1997 and 2012, winning speed for elite 6-furlong races have increased by an estimated 0.110% per year, corresponding to an improvement in predicted winning time from 72.92 to 71.74 s. On good ground, a difference of 1.18 s corresponds to over seven horse lengths (www.britishhorseracing.com/wp-content/uploads/2014/04/Lengths-Per-Second-Scale-tables.pdf), a distinct margin given that we calculated the average winning distance of 6 furlong elite races between 1997 and 2012 to be just 1.28 lengths.

There are several possible explanations for sprint race speeds continuing to improve rapidly relative to middle- and long-distance races. Racehorse performance over longer distances could be reaching a selection limit as has been previously suggested [3,4,7–9], but we also note that the focus of breeding in GB may also have shifted towards producing sprint horses. More generally, care should be taken not to

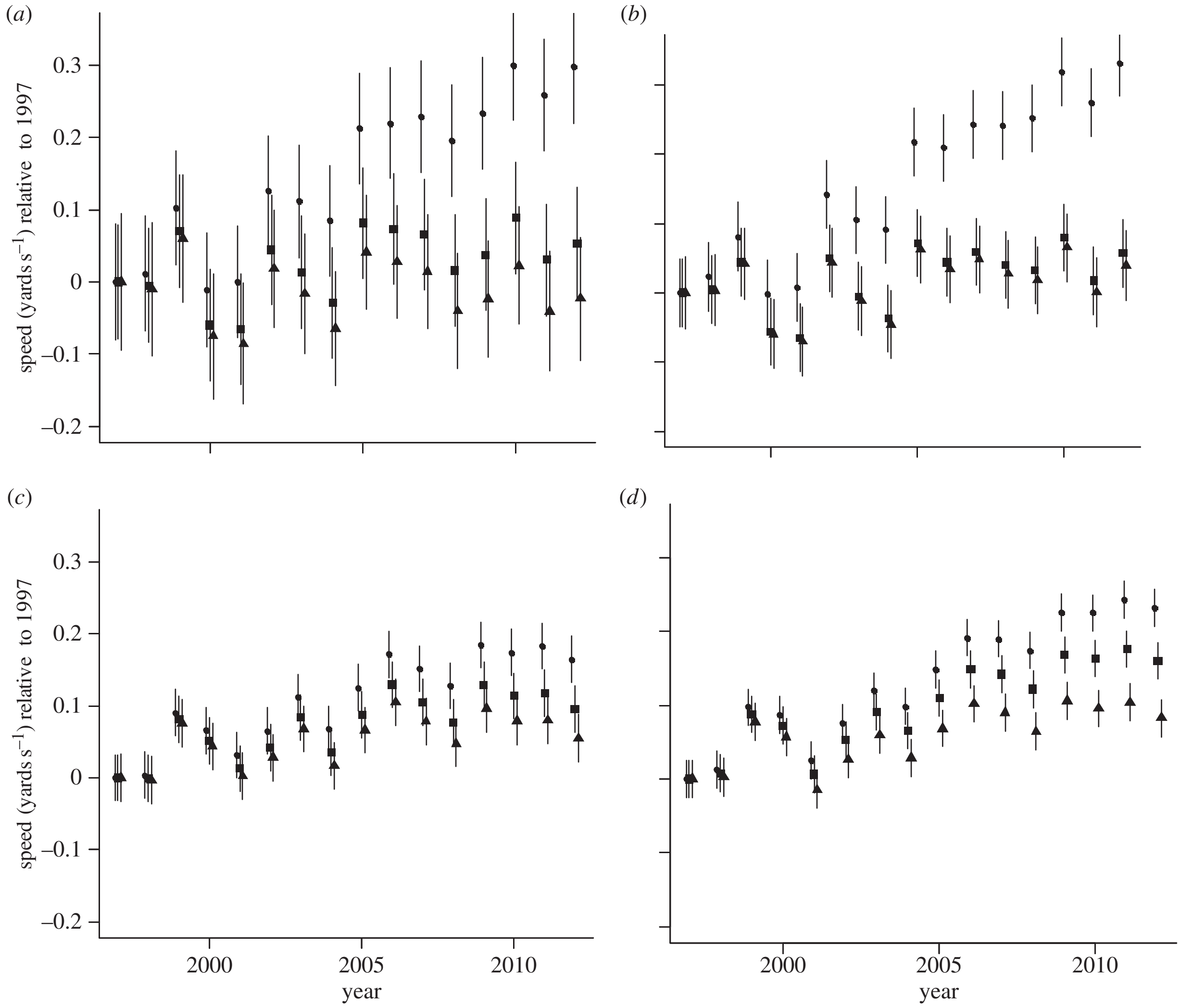

Figure 2. Patterns of temporal change in speeds for (*a*) elite race winners since 1997, (*b*) elite race finishers since 1997, (*c*) all race winners since 1997, (*d*) all race finishers since 1997. Circles, squares and triangles represent average speed (relative to 1997 mean) predicted from model 2 at 6, 10 and 17 furlongs, respectively (bars indicate ± 1 s.e.).

attribute changes in speed to breeding alone. For instance, very rapid improvement in the early 1900s (figure 1) was attributed by Pfau *et al.* [11] to the introduction (in 1897) and universal adoption (by 1910) of an altered riding style. Further changes in riding style may well have facilitated comparatively rapid improvement between the mid-1970s and the mid-1990s as a posture pioneered by the jockey Lester Piggott was adopted [12]. However, commercialization of racehorse breeding also occurred during this period, with increased importing of well-bred American horses [13]. We also note that jockey tactics undoubtedly influence race speed and acknowledge that we could not control for all potentially confounding variables. For example, we elected not to include handicap weights in our model because it was confounded with horse identity, with better runners tending to carry more weight. Nonetheless, average weight carried actually increased between 1997 and 2012 in both elite races (estimated 0.194 ± 0.006 lb year^{-1}, $F_{1,19193} = 1183$, $p < 0.001$) and across all races (at 0.255 ± 0.002 lb year^{-1}, $F_{1,613839} = 14956$, $p < 0.001$; electronic supplementary material, figure S1). Because more weight should reduce speed, this could potentially be masking underlying genetic improvement.

Noting the above caveats, if we accept that contemporary improvement is driven by selection, it is of interest to know whether the rates reported are in line with expectations [7]. Unfortunately, this is difficult to assess at present, because uncertainty surrounds both selection strength on, and heritability of, thoroughbred performance. While Gaffney & Cunningham [5] reported high heritabilities (0.39–0.76) for thoroughbred performance measured as handicap rating, these estimates exceed our estimated repeatabilities (e.g. $R = 0.26 \pm 0.002$ for whole population since 1997; electronic supplementary material, table S3). Furthermore, several recent studies reported much lower heritability estimates for performance traits in other horse populations [14–16]. To determine whether improvement in speed is underpinned by a genetically based selection response, and whether shifting selection strategies might explain our findings, a more nuanced quantitative genetic analysis is required.

Data accessibility. Data used for analyses in this manuscript are available in Dryad: http://dx.doi.org/10.5061/dryad.qn82p.

Authors' contributions. P.S. designed the study, collected the data, performed the analyses and wrote the manuscript. A.J.W. designed the study and wrote the manuscript. Both authors approve the final version of the manuscript.

Competing interests. The authors have no competing interests.

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