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4 **Racehorses *are* getting faster**

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24 **Abstract**

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

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37 Keywords: racehorse; heritability; selection; improvement; speed

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50 **Introduction**

51 Winning times of some thoroughbred horse races in Great Britain (GB) are on record from the mid-
52 1800s. Nowadays, winning times are recorded for all races run, and times of beaten horses can be
53 inferred. Notably, the few studies to analyse temporal changes in performance have reported little
54 recent improvement in winning times of elite races in GB [1,2]. Similarly, a study of the three most
55 prestigious races in America reported no increase in winning speed since the early-1970s [3], and
56 concluded that racehorses will reach maximal speed imminently. This conclusion was also reached in
57 a study of the best performances worldwide [4]. The lack of improvement is striking given putatively
58 intensive selective breeding [5] and high heritability estimates for performance traits [4-6],
59 prompting the suggestion that thoroughbreds have reached a selection limit [3,4,7-9]. However,
60 previous studies have been limited. Firstly, they only analysed winning time (or speed) of a small
61 number of middle and long distance elite races. Secondly, no account has been taken for temporal
62 variation in potentially confounding factors such as ground softness [1-4]. Here we address these
63 limitations to test for and characterise improvement both at the elite level and in the racehorse
64 population as a whole.

65

66 **Methods**

67 Data were sourced from Ruff's Guide to the Turf (1850-1951 annual editions), the Raceform Flat
68 Annual (1949-1994) and Raceform Interactive (1996-2012; www.raceform.co.uk). We included only
69 GB flat races run on the turf. For an average of 48 (range 11 - 106) elite races (termed "Group" races
70 since 1971) a year in 47 years between 1850-1996 (2243 races in total) we recorded; winning time,
71 timing method (hand-timed or automatic), race distance, racecourse, official going (ground
72 softness), number of runners (no.runners) and name, age and sex of the winner. Going was
73 converted from its official (categorical) description to a numerical scale using conversion tables
74 provided at [www.britishhorseracing.com/wp-content/uploads/2014/03/Going-Stick-Average-
75 Readings.pdf](http://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

76 every year between 1997-2012. For these races, times of beaten horses were estimated based on
77 distance beaten and conversion scales published at [www.britishhorseracing.com/wp-](http://www.britishhorseracing.com/wp-content/uploads/2014/04/Lengths-Per-Second-Scale-Tables.pdf)
78 [content/uploads/2014/04/Lengths-Per-Second-Scale-Tables.pdf](http://www.britishhorseracing.com/wp-content/uploads/2014/04/Lengths-Per-Second-Scale-Tables.pdf). The full data set comprises 616,084
79 race times run by 70,388 horses.

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

84 $horse\ speed \sim \mu + year + distance + distance^2 + no.runners + no.runners^2 + going + going^2 + age + sex$
85 $+ timing\ method + course + distance:going + distance:no.runners + horse$

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

94 Model 1 tests for a simple (linear) improvement in speed averaged over the distance variation within
95 each dataset. To determine patterns of temporal change without assuming a linear (or other
96 parametric) relationship, and to explicitly characterise improvement rates as a function of race
97 distance, we fitted a modified model (Model 2) with year effect as a multi-level factor and inclusion
98 of year (continuous) by distance and year by distance² interactions. Non-linear improvement has
99 been previously reported (2,3,4) and consistent with this, refitting Model 1 treating year as a factor
100 improved model fits (e.g $\Delta AIC=132.9$ analysing 1850-2012 elite winners; full results not presented).

101 Model 2 was fitted to datasets differing with respect to; races since 1850 versus 1997; inclusion of

102 winners versus all finishers; data from all races versus elite races (table 2), and used to predict
103 average speed by year at 6, 10, and 17 furlongs (representing sprint, middle and long distances).
104 Significance of the horse effect was assessed by likelihood ratio test and among-horse variance was
105 divided by phenotypic variance (conditional on fixed effects) to estimate the (among-horse)
106 repeatability of speed.

107

108 **Results**

109 Average racehorse speed has improved historically (since 1850) and continues to increase (since
110 1997; Table 1). Under Model 1, year effects were positive in all 15 datasets examined and significant
111 in all but one (winners of elite, long distance races). However, a more nuanced picture is revealed by
112 Model 2. First, historical improvement has not been linear (Figure 1). Rapid improvement occurred
113 from the late-1800s to 1910, followed by comparative stasis to 1975, then relatively greater rates
114 since. Second, significant interactions between year (continuous) and distance/distance² ($|Z| > 1.96$,
115 $P < 0.05$, supplementary table 1) mean that, between 1850 and 2012, elite race winners improved
116 more rapidly at shorter distances (Figure 1) both in absolute and percentage terms. For instance,
117 predicted speed increases at 6, 10 and 17 furlongs respectively were of 2.11, 1.69, and 1.49
118 yards.sec⁻¹, representing increases of 12.9%, 10.6% and 9.7% relative to speed in 1850 (or average
119 yearly gains of approximately 0.080%, 0.065% and 0.060%; Table 2).

120 Examining model predictions for the 1997-2012 data in more detail shows that while winners of elite
121 races continue to improve, this is almost wholly driven by sprint races with winning speed increasing
122 by an average 0.110% per year since 1997 (Table 2). Corresponding average changes in elite winning
123 speed over middle and long distances were estimated at 0.020% and -0.009% per year respectively
124 (Table 2, Figure 2a). Qualitative patterns are broadly similar using data from all finishers in elite races
125 (Figure 2b), winners of all races (Figure 2b), and all finishers in all races (Figure 2d). In all cases
126 improvement is most rapid for sprints. For instance, winning speed of all races has increased by an
127 estimated average of 0.062%, 0.037% and 0.022% per year (of 1997 values) at 6, 10 and 17 furlongs

128 respectively (Table 2). Estimated rates are slightly higher at 0.090%, 0.065% and 0.034% per year
129 when considering all finishers in all races from 1997-2012 (Table 2). See supplemental table 1 for full
130 (fixed) parameter estimates under Model 2 and supplemental table 2 for predicted speed by year at
131 6, 10 and 17 furlongs. Estimates of among-horse repeatability are provided in supplemental table 3.

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133 **Discussion**

134 Our analyses show elite race winning speeds have improved greatly since 1850. Furthermore, 1997-
135 2012 data reveals improvement is on-going but, importantly, rates vary across distances.

136 Contemporary improvement is low for middle and long distances, but winning speed for elite sprint
137 races actually exceeds estimated historical rates. A similar pattern emerges when all elite runners
138 are included, and if the wider population of non-elite performers is considered.

139

140 Three recent studies concluded racehorses are at (or very close to) maximal speed [2-4], with a
141 fourth reporting modest continued improvement (although significant change was limited to 4 of 11
142 races analysed [1]). Given that these studies were limited to elite races run over middle and long
143 distances, our results are broadly consistent (in terms of improvement rates) even if our qualitative
144 conclusion – that horses *are* still getting faster – is different. The qualitative discrepancy likely
145 reflects our greater statistical power combined with explicit modelling of environmental factors
146 known [10] or hypothesised to influence speed. On-going improvement in sprint performance, not
147 previously analysed, is much more rapid. Between 1997-2012, winning speed for elite 6 furlong races
148 have increased by an estimated 0.110% per year, corresponding to an improvement in predicted
149 winning time from 72.92 to 71.74 seconds. On good ground, a difference of 1.18 seconds
150 corresponds to over 7 horse lengths ([www.britishhorseracing.com/wp-](http://www.britishhorseracing.com/wp-content/uploads/2014/04/Lengths-Per-Second-Scale-Tables.pdf)
151 [content/uploads/2014/04/Lengths-Per-Second-Scale-Tables.pdf](http://www.britishhorseracing.com/wp-content/uploads/2014/04/Lengths-Per-Second-Scale-Tables.pdf)), a distinct margin given that we
152 calculated the average winning distance of 6 furlong elite races between 1997 and 2012 to be just
153 1.28 lengths.

154 There are several possible explanations for sprint race speeds continuing to improve rapidly relative
155 to middle and long distance races. Racehorse performance over longer distances could be reaching a
156 selection limit as has been previously suggested [3,4,7-9], but we also note that the focus of
157 breeding in GB may also have shifted towards producing sprint horses. More generally, care should
158 be taken not to attribute changes in speed to breeding alone. For instance, very rapid improvement
159 in the early 1900s (Fig 1a) was attributed by Pfau et al. [11] to the introduction (in 1897) and
160 universal adoption (by 1910) of an altered riding style. Further changes in riding style may well have
161 facilitated comparatively rapid improvement between the mid-1970s and the mid-1990s as a
162 posture pioneered by the jockey Lester Piggott was adopted [12]. However, commercialisation of
163 racehorse breeding also occurred during this period, with increased importing of well-bred American
164 horses [13]. We also note that jockey tactics undoubtedly influence race speed and acknowledge
165 that we could not control for all potentially confounding variables. For example, we elected not to
166 include handicap weights in our model because it was confounded with horse identity, with better
167 runners tending to carry more weight. Nonetheless, average weight carried actually increased
168 between 1997 and 2012 in both elite races (estimated $0.194 \pm 0.006 \text{ lb}\cdot\text{year}^{-1}$, $F_{1,19193}=1183$,
169 $p<0.001$) and across all races (at $0.255 \pm 0.002 \text{ lb}\cdot\text{year}^{-1}$, $F_{1,613839}=14956$, $p<0.001$; Supplementary
170 Figure 1). Since more weight should reduce speed, this could potentially be masking underlying
171 genetic improvement.

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173 Noting the above caveats, if we accept that contemporary improvement is driven by selection, it is of
174 interest to know whether the rates reported are in line with expectations [7]. Unfortunately, this is
175 difficult to assess at present since uncertainty surrounds both selection strength on, and heritability
176 of, thoroughbred performance. While Gaffney and Cunningham [5] reported high heritabilities (0.39-
177 0.76) for thoroughbred performance measured as Timeform rating, these estimates exceed our
178 estimated repeatabilities (e.g., $R=0.26 \pm 0.002$ for whole population since 1997; supplemental table
179 3). Furthermore, several recent studies reported much lower heritability estimates for performance

180 traits in other horse populations [14-16]. To determine whether improvement in speed is
181 underpinned by a genetically-based selection response, and whether shifting selection strategies
182 might explain our findings, a more nuanced quantitative genetic analysis is required.

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

Dataset	Years	Classes	Runners	Distance (furlongs)	Temporal Trend \pm SE (yards.sec ⁻¹ .year ⁻¹)	χ^2_1	P
1.1	1850-2012	Elite	Winners	5-7	0.014 \pm 5x10 ⁻⁴	659	<0.001
1.2	1850-2012	Elite	Winners	8-12	0.013 \pm 4x10 ⁻⁴	677	<0.001
1.3	1850-2012	Elite	Winners	14-20	0.011 \pm 0.001	106	<0.001
1.4	1997-2012	Elite	Winners	5-7	0.020 \pm 0.002	64.3	<0.001
1.5	1997-2012	Elite	Winners	8-12	0.006 \pm 0.002	5.8077	0.016
1.6	1997-2012	Elite	Winners	14-20	0.007 \pm 0.005	2.71	0.100
1.7	1997-2012	Elite	All	5-7	0.023 \pm 0.001	409	<0.001
1.8	1997-2012	Elite	All	8-12	0.006 \pm 0.001	26.0	<0.001
1.9	1997-2012	Elite	All	14-20	0.008 \pm 0.002	12.3	<0.001
1.10	1997-2012	All	Winners	5-7	0.014 \pm 6x10 ⁻⁴	466	<0.001
1.11	1997-2012	All	Winners	8-12	0.006 \pm 7x10 ⁻⁴	70.6	<0.001
1.12	1997-2012	All	Winners	14-20	0.005 \pm 0.002	11.2	<0.001
1.13	1997-2012	All	All	5-7	0.018 \pm 4x10 ⁻⁴	2212	<0.001
1.14	1997-2012	All	All	8-12	0.010 \pm 4x10 ⁻⁴	634	<0.001
1.15	1997-2012	All	All	14-20	0.009 \pm 8x10 ⁻⁴	114	<0.001

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232 Table 2: Predicted rates of speed improvement at 6, 10 and 17 furlongs determined from Model 2
 233 fitted to datasets. Average yearly improvement is expressed in absolute units (yards.sec⁻¹.year⁻¹) and
 234 as a percentage of speed in the first year of analysis (1850 or 1997).

Dataset	Years	Classes	Runners	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

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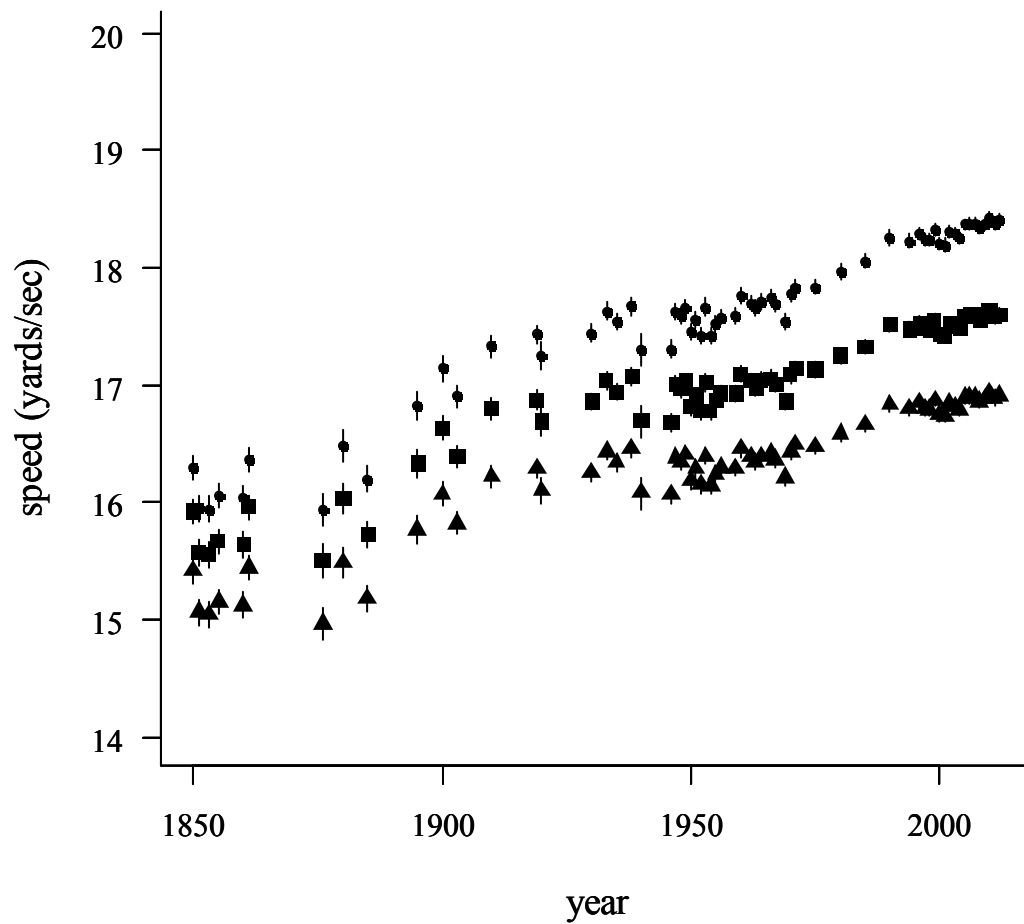
237 Figure 1. Patterns of temporal change in speeds of elite race winners since 1850. Circles, squares and
238 triangles represent average speed predicted from Model 2 at 6, 10 and 17 furlongs respectively (bars
239 indicate ± 1 standard error).

240

241 Figure 2. Patterns of temporal change in speeds for (a) elite race winners since 1997, (b) elite race
242 finishers since 1997, (c) all race winners since 1997, (d) all race finishers since 1997. Circles, squares
243 and triangles represent average speed (relative to 1997 mean) predicted from Model 2 at 6, 10 and
244 17 furlongs respectively (bars indicate ± 1 standard error).

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251 Figure 2

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