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The association between exercise-induced pulmonary haemorrhage and race-day performance in Thoroughbred racehorses

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Summary

Background: Exercise-induced pulmonary haemorrhage (EIPH) is commonly implicated as a cause of poor athletic performance but there is limited and conflicting evidence for this association.
Objectives: The aim of this study was to determine if EIPH, based on endoscopic examination after racing, is associated with a variety of novel and established performance parameters.
Study design: Prospective, observational cross-sectional study.
Methods: Thoroughbred racehorses competing between 2012 and 2015 were examined on-course no earlier than 30 min after racing. Examinations were recorded and graded blindly by experienced veterinarians using a 0–4 scale. Linear mixed effect models were used for analysis of continuous response variables with horse name incorporated as a random effect to account for repeated sampling and horse variability. Generalised estimating equations were used for analysis of binary responses. Performance variables were examined in 2 models, comparing EIPH grade 0 to grades 1–4, and EIPH grade ≤2 compared with EIPH grades ≥3, controlling race factors that could influence performance.
Results: There were 3794 observations collected from 1567 horses. EIPH was detected in 55.1% of observations. Horses with grade 4 EIPH were significantly more likely to have a lower finishing position and finish further behind the winner, less likely to place in the first 3 positions and collect race earnings, collected less earnings per race start and were slower over the last 600 m of the race than horses without EIPH (grade 0). Similar associations were seen in Model 2, with horses with EIPH grade ≥3 having inferior performance when compared to horses with EIPH ≤2.
Main limitations: Enrolment was voluntary.
Conclusion: Mild to moderate haemorrhage was not associated with inferior race day performance in this population of Thoroughbred racehorses.

Keywords: horse; Thoroughbred; exercise-induced pulmonary haemorrhage; pulmonary haemorrhage; performance; poor performance

Introduction

Exercise-induced pulmonary haemorrhage (EIPH) is anecdotally regarded within racing communities as a major cause of poor athletic performance, but until recently there had been minimal scientific evidence to support this. Early studies investigating EIPH and finishing position could not identify an association, but these studies had methodological limitations or large type II error [1–4], whilst others that did identify an association had selection bias or failed to control for potential confounding [5,6].

There are inherent challenges in defining variables to evaluate race day performance objectively. The characterisation of performance based on finishing position alone is overly simplistic. Individual performance is ultimately determined by the ability of the competitors as well as other unrelated factors, including race class and conditions, jockey skill, and race tactics. Consideration of other parameters, including distance finished behind the winner, sectional times, ratings, earnings per start and finishing in the first three positions mitigate some of the challenges faced in quantifying performance.

Recent epidemiological surveys [7,8] investigating EIPH and performance have applied a more comprehensive appraisal of race day performance. This, in combination with larger sample sizes and improved statistical methods, has identified significant associations between EIPH and athletic performance. Evidence of this association was identified in an Australian study examining 744 Thoroughbreds post-race with endoscopy [7]. In that study associations were examined using two models based on EIPH presence and severity: horses with EIPH grades ≤1 were significantly more likely to win, place in the first three positions and be in the 90th percentile of race earnings compared to horses with EIPH grades ≥2. EIPH-positive horses also finished further from the winner than horses without tracheobronchoscopic evidence of EIPH. A similarly designed study of 886 Thoroughbreds concluded that horses with endoscopic EIPH were less likely to win, finished further behind the winner and were less likely to be in the 90th percentile for race earnings than horses without endoscopic EIPH.

The aim of this study was to define further an association between tracheobronchoscopic EIPH on a range of routine and uninvestigated performance parameters in a population of racing Thoroughbreds not medicated with furosemide. Our hypothesis was that EIPH would be associated with inferior performance.

Materials and methods

Study design

A prospective, observational study design was used to examine a population of Thoroughbreds racing at two metropolitan and one provincial racecourse in Western Australia between May 2012 and April 2013, and July 2014 and December 2015.

Horses

Information regarding the study was promoted to racing participants through radio interviews, advertising in the racing calendar, presentations, and postal and direct communication on race day. Enrolment was voluntary, and trainers and owners could enrol horses at their discretion. Trainers were encouraged to enrol all horses in their care to limit bias associated with volunteering only certain horses to be examined. Any horse racing on the day of examination was eligible to be enrolled. Enrolled horses must have finished the race to then be included in the study.

All races were conducted on a flat, turf surface. Prerace administration of any medication is prohibited in accordance with the Australian Rules of Racing [9]. Horses were presented to a designated location on course for endoscopic examination. Examination occurred no earlier than 30 min and no later than 220 min after racing. A 1.5 m endoscope (AOHUA model LG-200) was passed through the nares into the trachea to the carina. Videos of all examinations were digitally recorded as well as the time at examination and presence of epistaxis.

Detections and quantification of EIPH

Two experienced veterinarians, blinded to the identity and performance of the horse, reviewed the tracheobronchoscopic examinations independently. A previously described 0–4 graded scoring system was used [10]. Briefly, grade 0 is assigned to cases where no blood is observed in the trachea or nasopharynx; grade 1 has ≥1 blood specks or ≤2 short (<¼ trachea length) and narrow (<10% of the tracheal surface area) streams of blood; grade 2 is a single long stream of blood (>½ tracheal length) or >2 short streams of blood occupying <⅓ of the tracheal circumference; grade 3 is multiple, distinct streams of blood covering more >⅓ of the tracheal circumference, but without blood pooling at the thoracic inlet; and grade 4 is multiple, coalescing streams of blood covering >90% of the tracheal surface, with blood pooling at the thoracic inlet. If there were discrepancy between the primary reviewers' score, a third experienced veterinarian would independently and blindly review and grade the examination. The median score was then adopted for statistical analyses.

Performance variables

Racing records were retrieved from a public database maintained by the racing regulator in Western Australia.[a] Variables captured included trainer, racetrack, time of the race, weight carried, position on the turn (recorded 400 m from the finishing post), finishing place, distance finished behind winner, overall race time, last 600 m sectional time, number of race starters, race distance, track rating, penetrometer reading, age, sex, nonstandard shoes (yes/no), number of starts this preparation (>60 days between racing or trialing was considered the end of a racing preparation), race earnings, number of lifetime starts and lifetime earnings recorded from the horse's first career race start to the endoscopic examination. Categorical outcomes of these variables included winning (yes/no), finishing in the top 3 positions (yes/no) and collecting race earnings (yes/no). Average race speed (m/s), average speed over last 600 m (m/s), and the average early/mid race speed (m/s) were calculated using the horses' race time and the last 600 m time. The early/mid race speed was then compared to the last 600 m speed to ascertain if the horse accelerated or decelerated over the last 600 m of the race. The position on the turn minus the finish position was used to assess field movements relative to other competitors over the final 400 m of the race. The length of the home straight varied between racetracks from 300 to 348 m. To account for variations in the number of competitors in races, finishing position was converted to a decile. The starting price for each horse was retrieved from the betting exchange website, Betfair Australia[b] using the win pool market. Horses were also ranked based upon their starting price (shortest to longest odds) and this rank was used as a prediction of finishing order. If a horse was ranked ≤4 (shortest odds), the horse was examined for the predicted finish minus actual finishing position; a negative value indicated a performance below market expectation; and a positive value, the reverse. Climatic variables were obtained from the Australian Bureau of Meteorology[c] using the closest weather station recording temperature, apparent temperature and humidity at the nearest time point to the race start time.

Data analysis

Continuous response variables were assessed for normality. Distance finished behind the winner was highly right skewed. Rather than assigning a zero value to winners, winners were removed from this outcome and remaining observation values were log transformed. Race and lifetime earnings were also highly right skewed due to the large number of nonearners. One dollar was added to each observation and the value log transformed.

The association between the response performance variable and EIPH were assessed in two models using statistical program R.[d] Firstly, EIPH grade 0 was compared to EIPH grades 1–4; and secondly EIPH grade ≤2 was compared to EIPH grades ≥3. Factors that could potentially predict or affect the outcome of the race or the response variable were considered as potential confounders and were held as fixed effects, specifically weight carried, sex, race distance, lifetime starts, starts this racing preparation, ambient temperature, track rating, nonstandard shoes, and racetrack. Interaction effects between these factors were assessed. Western Australia's metropolitan racetracks are exclusively used for 6 months of the year based on season due to one racetrack having superior drainage. The interaction between racetrack and ambient temperature, and ambient temperature and track rating were incorporated into the model. Collinearity between the fixed effects was considered and if highly correlated the variable that was considered to be the superior predictor was used. For example, age and lifetime starts were highly correlated; age can be considered a proxy measure for lifetime starts and was removed from the model.

Associations between continuous response variables and EIPH were assessed using the lme() function in R for linear mixed effects models. The models were adjusted for potential confounding variables and a random intercept was incorporated to account for repeated sampling of individuals. Model checking when including or removing predictor/confounding variables from the model was performed using the ANOVA() function in R. Underlying distributional assumptions of normality and homogeneity of variance for the models were assessed using QQ plots and residual plots. Maximum likelihood mean estimates and 95% confidence intervals (CIs) were obtained for the effect sizes of EIPH grades, and other confounding variables included in the model.

Associations between categorical response variables (winning, finishing in the top 3, accelerate/decelerate, collect race earnings) and EIPH were examined using multiple logistic regression models using generalised estimating equations. The R function geeglm() was used based on an independent correlation structure to account for the repeated sampling of horses and the models were adjusted for the potential confounding variables. Odds ratios and Wald statistics based 95% CIs were calculated for the regression coefficients of EIPH grades, and other confounding variables included in the model. A P<0.05 was considered significant for both continuous and categorical response variable models. Data are reported as mean and 95% CIs.

Results

Tracheobronchoscopic examinations were performed at 155 metropolitan and 17 provincial race meetings. A total of 3794 tracheobronchoscopic examinations were performed on 1567 horses (Table 1). There were 226 trainers who enrolled between one and 126 horses. There were 587 females, 937 geldings and 43 entire males examined. Age ranged between 2 and 10 years. The mean interval between racing and examination was 48 min (95% CI 47.1–48.4; range 30–220 min; Fig 1). Of the 3794 examinations, 442 (11.6%) examinations were from horses that won, and 1220 (32.2%) were from horses finishing in the first three positions.

Agreement between primary reviewers was very good ($\kappa = 0.75$; 95% CI 0.7–0.8). Disparity between reviewers was limited to one grade on each occasion. The third reviewer always agreed with one of the primary reviewers. Blood was detected in over half of examinations (2092; 55.1%). Of the total population 44.9%, 31.6%, 17.2%, 5.1% and 1.2% were recorded for grades 0–4 respectively (Fig 2). Epistaxis was recorded in 22 horses, of which 13 horses were grade 4, 6 horses were grade 3, 2 horses were grade 2, and one horse grade 0 (epistaxis caused by head trauma in the starting barrier prior to racing).

Model 1: EIPH grade 0 vs. EIPH grades 1–4

Horses with the highest grade of EIPH had significant negative associations with many performance variables (Table 2). Horses with EIPH grade 4, were significantly less likely to finish in the first three positions (P = 0.04; OR 0.3; 95% CI 0.1–0.9; Fig 3) compared to horses graded 0. Horses with EIPH grade 4 had a significantly (P<0.001) higher finishing decile or lower finishing position (mean; 95% CI, 7.2; 6.1–8.4) than horses with EIPH grade 0 (5.6; 5.3–5.6). Horses with EIPH grade 1, 3 and 4 finished significantly (P<0.001, P = 0.02 and P<0.001, respectively) further behind the winner (3.0; 2.5–3.6, 3.3; 2.5–4.3, and 4.8; 3.2–7.3 lengths, respectively) than

TABLE 1: Race and horse characteristics in 1567 Thoroughbreds racing in Western Australia (unless specified observations = 3794)

Variable	Minimum	Q1	Median	Q3	Maximum	Mean
Race to examination time (min)	30	34	41	53	220	47.7
Race distance (m)	1000	1200	1400	1600	2400	1405
Number of starters	4	9	11	13	16	11
Weight carried (kg)	50	55	56	57	62	56
Penetrometer (mm)	4	6.3	6.5	6.5	8.3	6.5
Track rating (1 fast–10 very heavy)	2	3	3	4	8	3.5
Number of horses enrolled by trainer/owner	1	1	2	6	126	7.5
Number of examinations enrolled by trainer	1	1	3	9	441	16.8
Horse age (years)	2	3	4	5	10	4.4
Number of examinations per horse	1	1	2	4	19	2.8
Race starts this racing preparation	1	2	3	5	23	3.8
Lifetime race starts	1	6	13	23	95	16.6
Ambient temperature (°C)	11	18.9	22.6	26.9	38.9	22.6
Nonstandard shoes (n = 169)	N/A	N/A	N/A	N/A	N/A	N/A
Race prize money earned ($)	0	0	400	3500	619,500	4492
Lifetime prize money earned ($)	0	14,821	42,947	107,201	1,616,600	82,128
Finishing position (of field)	1	3	5	8	16	5.8
Finishing position as decile (of field)	0.1	0.4	0.6	0.9	1	0.6
Distance finished behind the winner in lengths (n = 3352)	0.05	2	3.75	6.25	86.75	4.8
Turn position minus finish position	–15	–2	0	3	13	0.1
Last 600 m speed (m/s; n = 3580)	12.5	16.5	16.8	17.1	18.6	16.8
Average race speed (m/s; n = 3791)	13.9	17.6	16.1	16.4	16.6	16.3
Average early/mid race speed (m/s; n = 3580)	12.3	15.7	16	16.3	17.45	16.0
Betfair starting price ($)	1.23	5.9	11.9	26	874	29.6

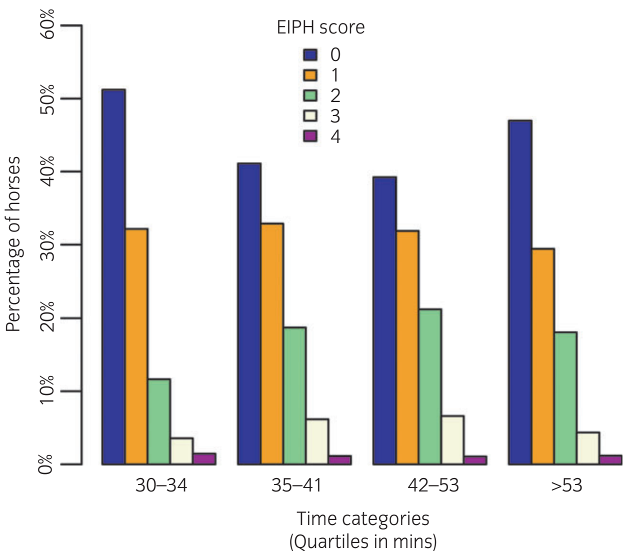

Fig 1: Time elapsed from race to tracheobronchoscopic examination compared with the severity of haemorrhage detected in Thoroughbreds racing in Western Australia (3794 observations collected from 1567 horses).

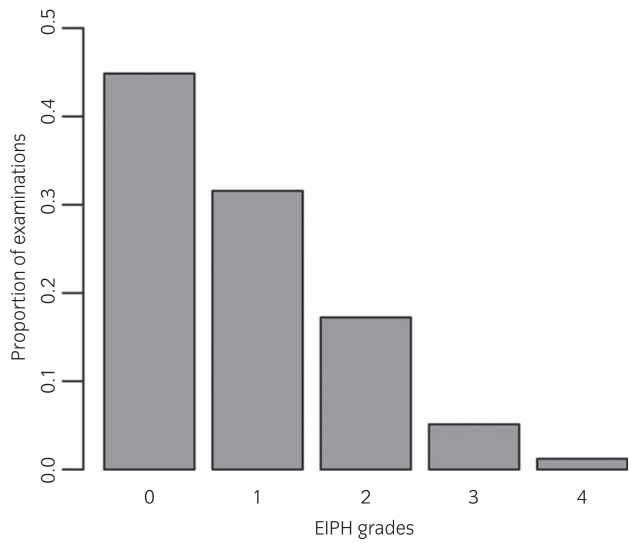

Fig 2: Severity of exercise-induced pulmonary haemorrhage detected post-race among Thoroughbreds racing in Western Australia (3794 observations collected from 1567 horses).

horses with EIPH grade 0 (2.7; 2.4–3 lengths). Horses with EIPH grade 4 were significantly (P = 0.003) less likely to collect race earnings (OR 0.3; 95% CI 0.2–0.7), and collected significantly (P<0.001) less race earnings per start (9.1; 1.9– 43.9) than horses with grade 0 (72.4; 46.8–112.2).

Horses with EIPH grade 4 had a significantly (P<0.001) slower average speed over the last 600 m (16.84; 16.6–17 m/s) compared to horses with grade 0 (17.07; 16.99–17.1 m/s). Horses with grade 4 EIPH were significantly (P = 0.002) more likely to be passed by other competitors over the last 400 m of the race (turn position minus finish position) (−2.0; −3.6 to −0.4) than horses graded 0 (−0.2; −0.7 to 0.2). Horses with EIPH grades 1 and 2 were significantly (P = 0.01 and P<0.001, respectively) more likely to overtake competitors (turn minus finish position) over the last 400 m of the race (0.1; −0.6 to 0.9 and 0.4; −0.4 to 1.2, respectively) compared to horses graded 0.

Horses with EIPH grades 3 and 4 were significantly (P = 0.02 and P = 0.03, respectively) faster over the early/mid sections of the race (16.43; 16.32–16.55 m/s and 16.48; 16.32–16.65 m/s, respectively) compared to a horse with grade 0 (16.37; 16.3–16.43 m/s). When comparing the average early/mid race speed with the average speed over the last 600 m, horses with EIPH grade 3 or 4 were significantly more likely to decelerate (P = 0.03 and P = 0.01, respectively) compared to horses with grade 0.

TABLE 2: Performance variables (mean; 95% confidence interval) in Thoroughbreds racing in Western Australia with exercise-induced pulmonary haemorrhage (EIPH) grade 0 and EIPH grades 1–4 (model 1; 3794 observations collected from 1567 horses)

	EIPH Grade				
Variable	0	1	2	3	4
Average speed last 600 m (m/s; n = 3580)	17.07; 16.99–17.1	17.07; 16.95–17.17	17.09; 16.96–17.2	16.99; 16.85–17.1	16.84; 16.6–17 *
Average early/mid race speed (m/s; n = 3580)	16.37; 16.3–16.43	16.36; 16.27–16.4	16.37; 16.28–16.47	16.43; 16.32–16.55*	16.48; 16.32–16.65*
Finishing position (decile)	5.6; 5.3–5.6	5.8; 5.3–6.3	5.6; 5–6.1	5.9; 5.2–6.7	7.2; 6.1–8.4*
Distance finished behind winner in lengths (n = 3552)	2.7; 2.4–3	3.0; 2.5–3.6*	2.7; 2.2–3.4	3.3; 2.5–4.3*	4.8; 3.2–7.3*
Position on the turn (400 m mark) minus finish position	−0.2; −0.7 to 0.2	0.1; −0.6 to 0.9*	0.4; −0.4 to 1.2*	−0.5; −1.5 to 0.6	−2.0; −3.6 to −0.4*
Amount of race earnings collected ($)	72.4; 46.8–112.2	58.9; 28.7–122.4	74.1; 33–165.7	53.7; 18.9–150.6	9.1; 1.9–43.9*
Average race speed (m/s; n = 3791)	16.32; 16.29–16.35	16.32; 16.28–16.35	16.33; 16.28–16.38	16.34; 16.28–16.4	16.27; 16.17–16.37
Betfair starting price ($)	4.67; 4.33–5.01	4.83; 4.28–5.38	4.96; 4.34–5.57	4.92; 4.13–5.7	4.9; 4.43–6.11
Lifetime earnings ($)	2944; 2335–3713	2996; 2525–4157	2979; 2074–4280	3061; 1946–4817	2419; 1276–4588

*Significantly (P<0.05) different from the control group, EIPH grade 0.

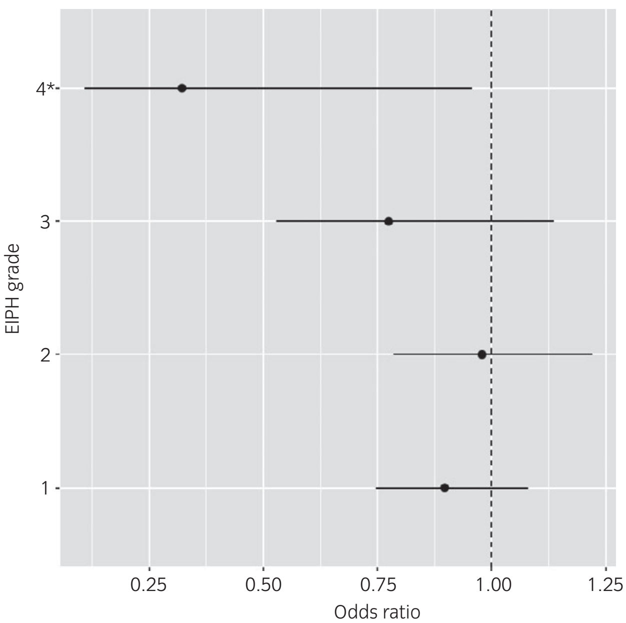

Fig 3: Forest plot depicting odds ratio and 95% confidence intervals for the likelihood of finishing in the top three positions compared with the severity of exercise-induced pulmonary haemorrhage detected, graded using a 0–4 scale (n = 3794). *Significantly (P<0.05) different from the control group grade 0.

Horses with EIPH grade 0 were between 1.6 (95% CI 1.1–2.5) and 2.4 (95% CI 1.2–4.8) times more likely to accelerate their average speed over the last 600 m than a horse with EIPH grade 3 and 4, respectively.

Model 2: EIPH grades ≤2 vs. EIPH grades ≥3

Similar findings were seen in model 2, whereby horses with EIPH≥3 were significantly (P = 0.002) faster over the early/mid sections of the race (mean; 95% CI 16.45; 16.34–16.55 m/s) compared to horses with EIPH≤2 (16.37; 16.32–16.43 m/s). Horses with EIPH grades ≥3 were significantly more likely to decelerate their average speed over the last 600 m (P = 0.006) compared to horses with EIPH grade ≤2. Horses with EIPH≤2 were 1.7 (95% CI 1.2–2.4) times more likely to accelerate their average speed over the last 600 m then horses with EIPH≥3.

Horses with EIPH≥3 were significantly (P<0.001; Table 3) slower over the last 600 m (16.96; 16.82–17.1 m/s) than horse with EIPH≤2 (17.07; 16.99–17.15 m/s). Horses with EIPH≥3 were more likely to have a higher finishing decile (lower finishing position; P = 0.005), to finish further behind the winner (P = 0.002), to be passed by other competitors over the last 400 m of the race (P = 0.001), were less likely to collect race earnings (P = 0.03) and collected less race earnings per start (P = 0.03) than horse with EIPH≤2 (Table 3). Horses with EIPH≥3 were not more or less likely to place in the top 3 positions than horse with EIPH≤2 (P = 0.06). Lifetime earnings, winning, Betfair starting price, Betfair rank minus finishing position and average race speed were not significantly associated with EIPH in either model.

There was a direct, positive relationship between weight carried and collecting race earnings (P<0.001), the amount of race earnings collected (P<0.001), lifetime earnings (P<0.001), winning (P<0.001) and finishing in the top 3 positions (P<0.001). An inverse relationship existed between weight carried and distance finished from the winner (P<0.001) and decile finish position (P<0.001). An inverse relationship existed between the number of lifetime starts and collecting race earnings (P<0.001), the amount of race earnings (P<0.001), winning (P<0.001) and finishing in the top three positions (P<0.001). In contrast, the number of starts in the current racing preparation had a direct positive association with collecting race earnings (P<0.001), the amount of race earnings (P<0.001), winning (P = 0.02) and finishing in the top 3 positions (P = 0.001). As expected, there was a significant inverse relationship between all speed measurements and race distance (P<0.001), and track rating (P<0.001). Horses wearing nonstandard shoes were less likely to collect race earnings (P = 0.01), collected less race earnings (P = 0.01), finished further behind the winner (P = 0.04) and had a lower finishing position (P = 0.03; Supplementary Items 1 and 2).

Discussion

This study supports the finding of other investigators that severe EIPH is associated with inferior athletic performance, but differs in respect to being unable to detect a significant difference between lower grades of EIPH and grade 0 [7,8]. The difference in findings could be attributed to a multitude of factors, including differences in population, the time interval between race and examination, and sample size.

Successful racing performances are often determined by relatively small margins and the prevalence of EIPH post-race using tracheobronchoscopy is reported between 44 and 75% [1,3,6,11,12]. Consequently, large sample sizes are required to detect significant associations between disease and performance. This is the largest EIPH study, conducted prospectively and observationally under race day conditions and controlled for confounding variables that could affect performance. This study also recruited a relatively larger proportion of winners and top-3 placed horses compared to others [7], which was likely because of blanket enrolment of horses from several large racing stables. Differences in the performance demographic

TABLE 3: Performance variables (mean; 95% confidence interval) in Thoroughbreds racing in Western Australia with exercise-induced pulmonary haemorrhage (EIPH) grades ≤2 and grades ≥3 (model 2; 3794 observations collected from 1567 horses)

Variable	EIPH Grades ≤2	EIPH Grades ≥3
Average speed last 600 m (m/s; n = 3580)	17.07; 16.99–17.15	16.96; 16.82–17.1*
Average early/mid race speed (m/s; n = 3580)	16.37; 16.32–16.43	16.45; 16.34–16.55*
Finishing position (decile)	5.7; 5.3–6	6.2; 5.5–6.9*
Distance finished behind winner (lengths; n = 3352)	2.8; 2.5–3.15	3.5; 2.75–4.5 *
Position on the turn (400 m mark) minus finish position	−0.2; −0.4 to 0.4	−0.9; −1.82 to 0.07 *
Amount of race earnings collected ($)	67.6; 44.5–102.8	38.0; 14.7–97.5*
Lifetime earnings ($)	2965; 2360–3724	2926; 1920–4459
Average race speed (m/s; n = 3791)	16.32; 16.30–16.34	16.33; 16.27–16.38
Starting price ($)	4.77; 4.44–5.1	4.87; 4.15–5.59

*Significantly (P<0.05) different from the control group EIPH grades ≤2.

as well as horse, race and environmental variation could account for differences between studies.

A minimum interval of 30 min between racing and examination was used in this study. The ideal time to detect EIPH has not been conclusively established, although it is recommended that examinations be performed 30–120 min after racing [13]. A risk factor study where horses were examined between 13 and 175 min (median 30 min) after racing concluded that examinations conducted too soon after racing were significantly less likely to detect blood and underestimated disease severity [11]. In a similarly designed study, imposing a minimum time lapse of 30 min (median 48 min), the time between racing and examination was not significantly associated with EIPH detection or severity [14].

In the current study, horses with grade 4 EIPH had impaired athletic performance over many of the examined performance parameters. This is not proof of a causal relationship between severe EIPH and poor performance, but strengthens arguments in support of this. Career implications of tracheobronchoscopic EIPH based on a single observation has been reported [15]. In that study, it was reported that horses with grade 4 EIPH had fewer race starts after endoscopy diagnosis and fewer lifetime starts than horses with grade 0. Although these findings are suggestive that EIPH negatively impacts long-term performance, almost half of the horses diagnosed with grade 4 EIPH never raced again after examination, obscuring whether this is due to incapacity to race or management decisions limiting the opportunity.

In the current study, horses with EIPH grade 1 and 2 were significantly more likely to improve their position in the field over the final 400 m compared to horses with grade 0. In barrel racing horses, those with EIPH grade 4 were significantly faster than EIPH grade 0 animals when all race distances were considered together [16]. While it is highly improbable that EIPH confers an athletic advantage to these horses, the results warrant the use of secondary models comparing categorised groups of EIPH based upon severity.

We were unable to detect an association between average overall race speed and EIPH, which is consistent with others [17]. The capacity to now report sectional times creates opportunities to examine speed over different sections of the race. Horses with EIPH grades ≥3 were significantly faster over the early/mid sections of the race and were more likely to decelerate over the last 600 m in both models. The causality of these findings is unclear: is the deceleration due to EIPH, or to fatigue associated with a faster early/mid average race speed, and could this racing pattern contribute to severe EIPH? It is known that rapid acceleration triggers higher pulmonary vascular pressures than a gradual incremental increase to the same speed [18]. Although all racing would be considered rapid acceleration, perhaps horses that race at faster speeds initially, reach the breaking threshold of the pulmonary capillaries at an earlier stage in the race compounding the severity of the disease compared to horses that start the race at a slower speed. It could also be possible that horses in which a positive pacing strategy is adopted (i.e. fast start with declining speed) fatigue and decelerate over the last 600 m of the race irrespective of EIPH.

Not all horses have an equal chance of winning irrespective of the handicapper's best intentions. Results of this study would indicate that horses that carried more weight were more likely to be associated with positive performance outcomes, implying weight allocation was not enough to compensate for differences in ability, a finding that has been identified elsewhere [19]. Australian racing imposes a minimum weight that must be carried in handicap races [9]. Lower rated horses contesting races above their class are at a distinct disadvantage, as they cannot be allocated a weight below the minimum. Weight allocation is therefore not proportional to ability and reduces their chances of winning. Studies comparing performance, relying on the assumption that horses are weighted proportional to ability, could be unreliable and misinformed when racing under these conditions if they have not considered this confounding factor. Similarly, 'lifetime starts' and 'starts this racing preparation' were significantly associated with many performance variables, although in opposing directions. Horses that are unplaced at one start have a higher chance of earning at their next start because the race selected is usually more suited to the aptitude of the horse [20]. Lifetime starts are inversely associated with performance parameters due in part to restricted sex and age races available to younger horses, often with purse supplementation [21]. Average earnings decline with age [22], a proxy measurement for lifetime starts.

A horse's likelihood of winning is not solely dependent upon their ability, but also the innate ability of its competitors and the set conditions of the race. The starting price can be regarded as the public summation of the individual's ability, the opposition and the race conditions reflecting the subjective probability of that horse winning. There is a large body of evidence that suggests that betting markets efficiently incorporate all publicly and monopolistically held information into the starting price [23,24]. A strong positive relationship exists between the market odds and the likelihood of winning [25]. Betting exchange markets are regarded as the most efficient financial betting market [26–28]. Ignoring the social stigma attached to horse race gambling, the market provides a subjective probability of winning, and could highlight horses performing below their anticipated performance. Despite a lack of significant associations between this marker and EIPH, this novel approach has potential applicability in performance analyses.

Voluntary recruitment requires careful management due to biases associated with owners or trainers preferentially permitting access to certain horses, and not others. We attempted to curb this by encouraging trainers to enrol all horses in their care. The large proportion of winners and top 3 placed horses is testament to the attempt to manage this bias.

This population does not receive prerace furosemide. Trainers are permitted to use furosemide during training, abiding by withdrawal times when racing. Despite the Australian rules of racing permitting the use of nasal flair strips in Thoroughbred racing, their use has been almost negligible in Western Australia. In conclusion, our results add weight to the findings that severe EIPH is associated with impaired performance, as defined by placing in the first 3 positions, decile finishing position, distance finished from the winner, collecting race earnings, the amount of race earnings, being passed by competitors in the last 400 m of the race and slower average last 600 m speed. Mild to moderate haemorrhage was not associated with inferior race day performance in this population of Thoroughbred racehorses.

Authors' declaration of interests

No competing interests have been declared.

Ethical animal research

Approval for this study was obtained from Murdoch University's Animal Ethics Committee (R2651/14, R2474/12). Owner informed consent was given for each horse included in this study.

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Authorship

E.J. Crispe contributed to study design and execution, data collection, statistical analysis and manuscript preparation. G.D. Lester contributed to study design and execution, statistical analysis and manuscript preparation. C.J. Secombe contributed to study design and execution and manuscript preparation. D.I. Perera contributed to the statistical analysis and manuscript preparation.

Manufacturers' addresses

[a]Racing and Wagering Western Australia http://www.rwwa.com.au/cris/
[b]Betfair Exchange Australia https://www.betfair.com.au/racing
[c]Australian Government Bureau of Meteorology http://www.bom.gov.au
[d]RStudio (2015) Version 0.99.467. Integrated Development for R. RStudio, Inc., Boston, Massachusetts, USA.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Supplementary Item 1: Significance of associations between variables in Model 1.

Supplementary Item 2: Significance of associations between variables in Model 2.