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Thoroughbreds deemed to be most at risk by inertial measurement unit sensors suffered a fatal musculoskeletal injury at a higher rate than other racehorses

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Objective
To determine whether screening of racing Thoroughbreds with accelerometer-based inertial measurement unit sensors and a specifically trained algorithm identified horses most at risk for fatal musculoskeletal injury (FMI) and whether age, gender, race distance, and track surface were associated with increased risk.

Methods
Stride data from 28,481 races by 11,834 Thoroughbreds from July 25, 2021, until May 4, 2024, were assigned an algorithm-based risk score from 1 to 6 (6 = greatest risk). Logistic regression models examined the association between incidence of fatal injuries and risk scores within the previous 120 days, gender, age, race distance, and track surface. The Tukey adjustment assessed differences across risk score groups, track surfaces, and genders.

Results
74 horses were fatally injured. Risk score and probability of fatal injury were exponentially related. The most at-risk horses had risk scores of 6 and 0.4% of starts, but 4% of the musculoskeletal fatalities. Their probability of suffering a fatal injury was 44.6 times greater than horses with a risk score of 1. Age was not associated with injury risk. Males were at higher risk of fatality than females. Horses racing shorter distances had a greater risk of incurring a fatal injury. The fatality rate was higher on dirt and turf than a synthetic all-weather track.

Conclusions
Horses receiving a risk score of 6 were at significantly greater risk of suffering an FMI than other horses.

Clinical Relevance
Identification of the most at-risk horses with data derived from inertial measurement units followed by thorough lameness examinations and, when indicated, advanced diagnostic imaging should decrease the FMI rate.

Keywords: racehorses, musculoskeletal fatality, sensors, injury risk, equine

Fatal musculoskeletal injuries (FMIs) are responsible for a high rate of racehorse attrition. In 2009, the incidence of race day–related fatalities in the US was 2 in every 1,000 starts.[1] This figure decreased to 1.32 for every 1,000 starts in 2023,[1] although reporting of fatalities is not mandated across all American racing jurisdictions and does not account for fatalities while training. Despite this commendable reduction in FMIs, their continued occurrence threatens the industry's social license to operate.[2,3]

Necropsy data indicate that approximately 93% of fatalities had preexisting bone pathology, indicating that FMIs result from an acute or chronic ongoing disease process rather than isolated accidents.[4,5] Although this improvement in the understanding of the pathophysiology of racehorse injuries has been reflected in decreasing fatality numbers, Thoroughbred racehorses still suffer FMIs while racing and training because these preexisting pathologies and disease processes are not overtly clinically apparent. If they were, affected horses would not continue to train and race. When racing, each of the 4 limbs of a Thoroughbred contacts the ground for 50 to 80 milliseconds approximately once

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every 400 milliseconds. Consequently, postural adjustments made by a horse for any reason at the gallop occur in milliseconds, making them difficult or impossible to detect visually. As a result, horses with underlying pathology in 1 or more limbs are not identified by their trainers or veterinarians and continue to race. Eventually, some of them suffer a life-ending injury. A method to better identify these high-risk horses is needed to help make racing safer.

It is now the norm to see human athletes wear biometric sensors that record their biodata while they perform in order to monitor performance or as a means of identifying potential injury risks.[6,7] The same has not been true for racehorses until recently. A 2021 study[8] involving 131 Thoroughbred racehorses competing at Saratoga Race Course demonstrated the feasibility of using accelerometer-based inertial measurement unit (IMU) biometric sensors to screen racing Thoroughbreds en masse in order to identify those suspected of being at increased risk of serious musculoskeletal injury. A more recent case series report[9] used risk scores (1 to 5) assigned by a machine-trained algorithm modeled on data from 6,618 race starts, with higher scores indicating increased injury risk. According to the algorithm, the relative risk of a horse with a score of 5 suffering a fatal or career-ending musculoskeletal injury was 950 times greater than that associated with a risk score of 1.

The objective of the current study was to further evaluate the odds of incurring an FMI associated with risk scores assigned by the next iteration of the algorithm used in the aforementioned case series report,[9] and to investigate possible associations between factors such as age, gender, and track surface in relation to risk score. With these data, trainers, veterinarians, and racetrack managers could better identify horses at high risk and also address track-related factors to reduce fatalities. Leveraging IMU sensor data in this way could substantially lower injury rates and enhance Thoroughbred racehorse welfare.

Methods

In this retrospective observational study, accelerometer-based IMUs (StrideSAFE) were worn by Thoroughbred horses competing in races at 10 American tracks in the 145-week period from July 25, 2021, until May 4, 2024. The IMUs were worn by every horse in every race during the period when track management requested use of the sensors, and the ages and genders (intact males, females, or geldings) of all starters were recorded.

Sensor design

The sensors were developed by StrideMASTER and utilized integrated global positioning system (GPS) technology with an accelerometer-based IMU system. Their use in galloping Thoroughbreds has been previously described.[8,9] The IMUs consisted of 3 commercially available micromachined microelectromechanical system accelerometers capable of measuring the rate of change in linear velocity in the form of movement, physical shock, or vibration. The GPS was accurate to within 10 cm and calculated velocities while the IMUs measured accelerations detectable in a horse's lumbar region that were the result of whole-body movements while it raced, with a maximum of 16 G in each dimension at a sampling rate of 800 Hz, for a total of 2,400 individual measurements of acceleration/s. Each 3-axis accelerometer was placed in a pocket in the saddle cloth behind the saddle and measured acceleration in 3 orthogonal directions: dorsoventral (DV; ie, vertical), mediolateral (ML; ie, left to right), and longitudinal (L; ie, head to tail). Filters minimized noise while preserving the essential features of DV, ML, and L movement dynamics, enabling an algorithm to accurately characterize motion and stride patterns for assessment of the horse's risk of fatal injury **(Supplementary Material S1[10])**.

Algorithm development

The risk score regression algorithm was derived with commercially available modeling software that included machine learning capability (MATLAB, MathWorks Inc; and Statistica, TIBCO Software Inc). The model's initial iteration was derived with a machine learning algorithm trained on data from 81 runs by 25 horses that suffered an FMI within 3 months of the sensor recording. Characteristics that separated the starts of these horses from 589 runs by non–grade 1 and 2 winners with no confirmed musculoskeletal fatalities were identified and modeled to best separate fatally injured horses from those that did not suffer fatalities. There had to be a standard with which to compare all strides, and this standard needed to be as free from noise as possible. It was noted that the 2 biggest sources of noise in data from racing horses were related to unsoundness and fatigue. It was also noted that grade 1 and 2 stakes-winning horses had the least variability (and therefore noise) in their strides as they were better able to maintain them throughout a race. Consequently, for the initial model, the decision was made to use stride data from 88 starts by 37 grade 1 and 2 stakes winners as a baseline for comparison to the strides of other horses, as this provided the model with the highest degree of uniformity (Supplementary Material S1).

The results from this process provided a population distribution from which a mean was calculated. The resultant model could be applied to any horse and the outcome compared to the population of stakes-winning horses described herein in terms of SDs from the calculated mean. All horses in the dataset were then assigned risk scores according to the number of SDs by which their data differed from the same mean. This approach proved both accurate and helpful, particularly as all 589 starts by the non–grade 1 and 2 stakes winners fell within 2 SDs of the grade 1 and 2 stakes winners' mean and were separated from the horses that eventually suffered a catastrophic injury, the vast majority of which had strides > 3 SDs from that mean.

The algorithm was then further refined by specifically focusing on sensor-detected stride characteristics associated with individual FMIs. Given that fatalities were almost always associated with preexisting pathology, data from up to 120 days before the injury for each horse for which such data existed was incorporated in the model on the basis of differences in osteoclastic and osteoblastic activities in bone remodeling processes.[11] This shifted the mean and SDs from the original mean and SDs based on the data from the 37 grade 1 and 2 winners to a newly modified mean and SDs. This modified algorithm was applied in the study reported here. Strides were recorded for the entire race. Twenty strides collected from both the back straight of the racetrack and the final or only turn in the track while a horse was on the right and left leads, respectively, were analyzed by the algorithm for the purposes of assessing each horse's risk status by assigning a score that ranged from 1 to 6, with 6 reflecting the greatest risk. A risk score of 1 was assigned when a horse produced a stride pattern that was ≤ 2 SDs from the new mean. Assignments of risk scores 2 to 6 were based on the corresponding number of SDs from this mean. A risk score of 6 was assigned to starts in which a horse produced a pattern that was > 6 SDs from the new mean.

The track surface (all-weather synthetic, turf, and dirt) and race associated with each start was obtained from a commercial database.[12] Records on life-ending injuries were, in some cases, supplied by the regulatory bodies governing their respective tracks. In several cases, follow-up data were obtained via direct communication with the horse's trainer.

Statistical analysis

Descriptive statistics were generated relating all race starts to the distribution of risk scores, horse genders and ages at the time of a race, racetrack surface types, and numbers of FMIs.

Because many horses had multiple starts, we initially fitted a mixed-effects model with random horse effects to account for potential within-horse correlation. However, the estimated variance of the random effect was zero, indicating no substantial within-horse correlation. Consequently, we used a logistic regression model to examine the association between incidence of musculoskeletal injuries and potential risk factors for them, including risk scores within the 120 days prior to occurrence of a fatal injury, gender, age, and their interactions. Model selection was guided by the Akaike information criterion, leading to a final model that included the risk scores and gender without interaction terms.

A separate logistic regression model was fitted to evaluate the relationship between rate of fatal injury, risk scores in the previous 120 days, and track surface type. Surface data were aggregated by surface type, with the number of fatal injuries and distribution of risk scores summarized for each surface. Because this model found there was no significant interaction between risk score and racetrack surface (P = .48), an additive model with no interaction was ultimately used. This model assumed that the type of track surface had an independent, consistent effect on the log odds of the FMI, regardless of the risk score.

Binomial regression with a log link was used to model the probability of an FMI as an exponential function of risk score. This modeling framework allowed the probability itself (rather than the odds) to change exponentially. To evaluate model fit, we calculated the McFadden pseudo-R^2 (R^2_{McF}), sometimes called the likelihood ratio index.[13] Unlike traditional R^2 in linear regression, R^2_{McF} does not measure the proportion of explained variance but instead reflects the relative improvement in model fit compared to the null model. It is defined as follows: $R^2_{McF} = 1 - \log L_{model}/\log L_{null}$, where $\log L_{model}$ is the log-likelihood of the fitted model and $\log L_{null}$ is that of a null model containing only an intercept, with R^2_{McF} values between 0.2 and 0.4 considered indicative of a good fit for binomial regression models.

Pairwise comparisons were conducted with the Tukey adjustment to assess differences across risk score groups, track surface types, and genders. The analyses were performed in R (version 4.4.1; The R Project for Statistical Computing). In all instances, statistical significance was assumed to exist when $P \leq .05$.

Results

Accelerometer-based IMUs were worn by 11,835 Thoroughbreds in 28,482 race starts. There were 4,605 horses that wore the sensors in races in more than 1 calendar year. One horse suffered an FMI early in the race without recording enough strides to generate a risk score, so scores were analyzed for 28,481 starts and 11,834 horses. The number of times horses wore the sensors ranged from 1 to 13, and multiple horses that started more than once received multiple different risk scores. The distribution of risk scores among all starts and according to the numbers of starts horses had while wearing the IMUs is summarized in **Table 1**. The number of starts assigned a particular risk score declined as the risk score increased, with only 118 horses associated with 122 risk scores of 6 (0.4% of all starts). Many horses had additional starts at racetracks at which they did not wear the sensors, so the ability to detect longitudinal changes in risk score varied between horses.

Age was not significantly associated with risk score (P = .72) or FMI (P = .81). There were 3,819 horses that started in > 1 calendar year and were therefore included more than once in the analysis of age in relation to risk score assignment and FMI. The average numbers of starts while wearing the sensors per horse in each age group increased with horse age and were 1.58 for 2-year-olds; 1.79 for 3-year-olds; 1.91, 1.90, and 1.91 for 4-, 5-, and 6-year-olds, respectively; and 2.05 for > 6-year-olds. Although 2- and 3-year-old horses were more prone to fatal injuries in terms of the percentage of horses that suffered them and the percentage of their races in which such injuries occurred when compared to 4-, 5-, and 6-year-olds, horses > 6 years old actually represented the age group with the largest percentage of fatal injuries in terms of both the proportion of horses and starts in which they occurred **(Table 2)**. Seven geldings and 3 mares comprised the group of > 6-year-olds that suffered these injuries.

Gender was significantly associated with risk score (females, 1.65 ± 1.05; intact males, 1.75 ± 1.13; geldings, 1.62 ± 1.04; P = .023). Female horses were more likely to have a lower risk score than intact males (P = .011) and geldings (P = .040; **Table 3**)

Table 1—The number (n) of starts per horse (1 to 13) while wearing inertial measurement unit sensors and the distribution of risk scores (RSs) among all 28,481 starts and the 13 groups of horses.

Starts	Horses	RS = 1	RS = 2	RS = 3	RS = 4	RS = 5	RS = 6	Total starts
1	4,832	3,162	827	450	256	114	23	4,832
2	2,784	3,602	945	563	293	140	25	5,568
3	1,727	3,299	905	530	279	139	29	5,183
4	1,042	2,569	771	474	242	95	17	4,168
5	664	2,149	532	379	172	76	12	3,320
6	375	1,458	378	253	113	43	5	2,250
7	229	1,068	249	173	74	33	6	1,603
8	110	602	147	63	45	19	4	880
9	49	284	68	53	21	14	1	441
10	13	96	16	9	5	4	0	130
11	4	25	10	4	4	1	0	44
12	3	21	8	3	4	0	0	36
13	2	23	1	2	0	0	0	26
Total	11,834	18,358 (64.5%)	4,857 (17.1%)	2,957 (10.4%)	1,509 (5.3%)	678 (2.4%)	122 (0.4%)	28,481

Starts from July 25, 2021, to May 4, 2024, by a total of 11,834 horses are represented. The percentage of all starts associated with a particular RS is shown in the bottom row.

Table 2—Distribution of 28,481 race starts and RSs according to the age of the horse at the time of the start.

	Age (y)					
RS	2	3	4	5	6	> 6
1	2,807	6,350	4,515	2,482	1,220	984
2	689	1,675	1,172	702	339	280
3	428	999	719	401	205	205
4	219	497	371	211	118	93
5	105	219	180	88	44	42
6	18	39	36	20	5	4
Total starts	4,266 (.26%)	9,779 (.33%)	6,993 (.16%)	3,904 (.20%)	1,931 (0%)	1,608 (.62%)
Total horses	2,699 (.41%)	5,451 (.59%)	3,656 (.30%)	2,055 (.39%)	1,008 (0%)	785 (1.3%)

Of the total number of 11,834 horses, 4,605 had > 1 start in > 1 calendar year and so were counted more than once. Numbers in parentheses indicate the percentages of horses in each age group that suffered a fatal musculoskeletal injury (FMI) and the percentage of starts by horses in each age group in which these injuries occurred.

Table 3—The distribution of 28,481 race starts and RSs associated with each of the 11,834 horses making those starts according to the gender of the horse at the time of the start.

RS	Intact male	Female	Gelding	Total
1	2,834	8,131	7,393	18,358
2	843	2,236	1,778	4,857
3	543	1,364	1,050	2,957
4	304	621	584	1,509
5	138	286	254	678
6	25	55	42	122
Total	4,687	12,693	11,101	28,481

and less likely to suffer an FMI than males (P = .029) but not geldings (P = .099). The probability of a horse suffering an FMI increased exponentially with risk score, regardless of gender (females, R^2_{McF} = 0.56; intact males, R^2_{McF} = 0.28; geldings, R^2_{McF} = 0.53; **Supplementary Figure S1**). Fatal injuries occurred in 19 males, 32 geldings, and 23 females.

Race distances associated with assignments of risk scores of 6 were shorter (1,372 ± 237 m) than those run by horses receiving risk scores of 1 to 5 (P < .001). Mean distances associated with risk scores of 4 (1,459 ± 268 m; P = .012) and 5 (1,438 ± 282 m; P < .001) were shorter than those run by horses that received risk scores of 3 (1,486 ± 257 m).

Fatal musculoskeletal injuries

Fatal musculoskeletal injuries occurred in 52 of the 28,481 starts (0.18%) during which sensors were worn. Of the 11,834 horses that wore a sensor in at least 1 race start, 74 (0.63%) suffered an FMI within 120 days of their most recent risk score assignment. The type of injury and the track surface on which it occurred are summarized in **Supplementary Table S1**. Fractures of the sesamoids, distal metacarpal condyle, or both structures in a front fetlock were the leading cause of FMI (48 of 74 [65%]), and all horses with a highest risk score of 6 that incurred an FMI suffered a fracture involving the fetlock.

Fifty-two of these 74 injuries (70%) occurred while racing, and 22 (30%) occurred during a training event (ie, fatality ratio of 2.4:1). Because some of the 52 horses that were fatally injured while racing suffered such an injury in starts during which they were not wearing a sensor and the number of such races they had competed in was uncertain, it was not possible to determine the overall rate of musculoskeletal injuries per 1,000 starts for the entire study population. A risk score was available from the race in which the injury occurred for 30 of the 52 horses (57.7%), 18 of which were wearing a sensor for the first time and therefore had no prior risk score assessment. This computed to an FMI rate of 1.05/1,000 starts during which the sensors were worn. In these 30 races, 4 horses had a risk score of 1 (fatality rate of 0.02/1,000 risk score 1 starts), 2 horses had a risk score of 2 (0.04/1,000 risk score 2 starts), 9 horses had a risk score of 3 (1.01/1,000 risk score 3 starts), 6 horses had a risk score of 4 (3.98/1,000 risk score 4 starts), 5 horses had a risk score of 5 (7.37/1,000 risk score 5 starts), and 4 horses had a risk score of 6 (32.8/1,000 risk score 6 starts). These fatality rates were exponentially related to risk scores, with horses receiving a risk score of 6 being most at risk ($R^2 = 0.99$).

Previous racing data that generated a risk score within 120 days of injury were available for 56 of the 74 horses that incurred a fatal injury. Their highest risk scores in this period are shown in **Table 4**. The percentage of starts associated with FMI for each of the highest assigned risk scores increased from 0.12% for risk scores of 1 and 0.08% for risk scores of 2 (not different, 0.11% combined) to 4.2% for horses with a highest risk score of 6. Horses that had received a risk score of 6 while racing in the previous 120 days were significantly more likely to incur an FMI than any other horses, regardless of those horses' highest risk scores in the previous 120 days ($P < .001$ for scores of 1 to 4; $P = .02$ when the risk score was 5; **Table 5**). Overall, the likelihood of a horse incurring an FMI was exponentially related to risk score ($R^2_{McF} = 0.67$).

Of the 74 fatally injured horses, 18 horses did not have any risk score prior to the race in which they sustained an FMI, while 35 horses had only 1 prior start with a risk score (mean ± SD, 2.5 ± 1.7). Of the 21 horses that had 2 or more starts wearing the sensor prior to injury, the mean highest risk score recorded within 120 days of injury was 3.4 ± 1.8. Finally, 10 horses had 3 or more starts in which a risk score was generated within 120 days of injury, with a mean ± SD highest risk score in that period of 4.4 ± 1.6, which was higher than that in either of the other 2 groups ($P = .012$ when compared to those with 1 start wearing sensors; $P = .05$ for those with 2 or more starts).

The ORs plus 95% CIs of a horse incurring an FMI are shown in Table 5 for the highest risk score an individual horse had received in the period of up to 120 days prior to each of its starts for all races in the dataset. The probability of a horse incurring a fatal injury increased exponentially with risk score, with horses receiving a risk score of 6 having a 44.6 times greater probability of suffering an FMI than horses with risk scores of 1.

Table 5—Results of logistic regression analysis of the relative risk, expressed as the OR of an FMI occurring according to the highest risk score assigned to an individual horse compared to a risk score of 1, with 95% CIs.

RS	Relative OR	95% CI	*P* value
1	1.00[a]	1.00–1.00	—
2	1.21[a,b]	0.51–2.57	.64
3	3.99[b,c]	2.09–7.41	< .001
4	5.38[c]	2.54–10.7	< .001
5	8.76[c]	3.68–18.7	< .001
6	44.6[d]	17.5–100	< .001

Odds ratios with the same superscript were not significantly different. *P* values relate to the comparison of the OR associated with an individual risk score of 1. The OR is an expression of the ratio of the probability of an FMI for a given risk score compared to the probability associated with a risk score of 1.

Relationship between FMI and track surface

Fifty-five percent of all recorded starts were on dirt tracks, 24% were run on turf, and the remaining 21% were run on a synthetic track (Tapeta; **Supplementary Table S2**). The additive regression model found that track surface had a significant association with the rate of FMI ($P < .001$). The probability of a fatal injury rate (turf, 0.0023/start; dirt, 0.0035/start; and synthetic, 0.0005/start) was significantly lower on the synthetic track than on dirt ($P = .002$) or turf ($P = .03$) surfaces. Musculoskeletal injury rates for dirt and turf surfaces were not statistically different, although turf tended to be safer ($P = .06$). Fifty-five of the 74 FMIs (74%) occurred on dirt tracks, 16 (22%) occurred on turf tracks, and 3 (4%) occurred on the synthetic track. For races run on dirt surfaces, the likelihood of FMI and risk score were exponentially related ($R^2_{McF} = 0.64$), with horses previously assigned a highest risk score of 6 being significantly more likely to suffer such an injury than horses with highest risk scores of 1 to 5 ($P < .001$; **Figure 1**). An insufficient number of FMIs occurred on the synthetic and turf tracks to determine whether there was a significant relationship between a horse's highest risk score and the likelihood that it would suffer an FMI.

Table 4—The total starts (n) assigned each risk score and the percentage of those starts associated with an FMI, as well as the number of horses (n) for which the associated risk score was their highest assigned risk score and the number and percentage of all horses in each risk score group that suffered an FMI while racing or training.

RS	Starts (n)	Starts with FMI (%)	All horses (n)	Horses with FMI (n)	Horses with FMI (%)
1	18,358	0.12[a]	5,463	21	0.23[a]
2	4,857	0.08[a,b]	2,406	4	0.11[a,b]
3	2,957	0.37[b,c]	1,927	11	0.45[b,c]
4	1,509	0.46[c]	1,278	7	0.5[c]
5	678	1.2[c]	642	8	1.2[c]
6	122	4.1[d]	118	5	4.2[d]

Horses were assigned to the risk score group corresponding to the highest score they received within 120 days before they incurred the injury. A total of 11,834 horses made 28,481 starts. Fifty-six of these horses suffered an FMI. Numbers with the same superscript are not significantly different.

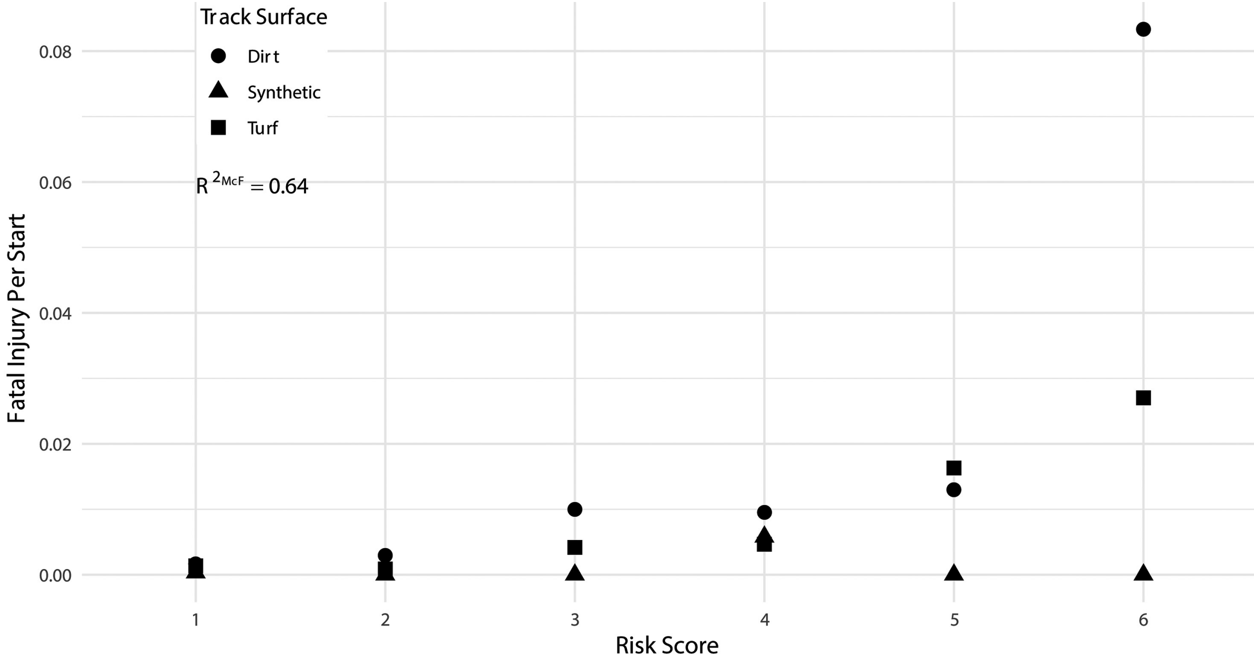

Figure 1—Relationships between fatal musculoskeletal injury rates and risk scores assigned to 11,834 Thoroughbred racehorses from 28,481 race starts from July 25, 2021, to May 4, 2024, according to the track surfaces on which the races were run. On dirt tracks, the odds of a horse with a risk score of 6 suffering a fatal injury were 43.4 times greater than for a risk score of 1. The odds of horses with risk scores of 3 to 5 suffering a fatal injury were greater than for a risk score of 1 but not for a risk score of 2 on dirt. There was no difference in injury probability between risk scores of 1 and 2 on dirt surfaces. On turf tracks, there was insufficient statistical power to allow valid comparisons between different risk scores with respect to the odds of a fatal injury occurring. The odds of a horse racing on the all-weather synthetic (AW) surface suffering a fatal musculoskeletal injury were not different for risk scores from 1 to 6.

Discussion

The use of robust iterative racing risk management efforts in the US has substantially reduced the incidence of FMI in Thoroughbred racehorses over the past decade. Nonetheless, the ability to identify Thoroughbreds at high risk for FMI remains a top priority for the racing industry. Despite best practices now in place,[14] accurate identification of individual horses at high risk for FMI remains elusive. A scalable multimodal screening process encompassing a thorough lameness examination of horses with elevated risk by an experienced veterinarian followed by advanced diagnostic imaging, when indicated, is needed to identify these most at-risk horses. The first step in such a screening process is the use of IMU sensors to help identify individual horses at increased risk for FMI that cannot be detected by routine inspection or observation. This step was the subject of this report.

The results indicated that the greater a horse's highest risk score in the preceding 120 days, the greater the probability that it would suffer an FMI. This likelihood increased exponentially as the risk score rose, with horses with any risk score of 6 within a 120-day period clearly being most at risk, as reflected by the comparatively high R^2_{McF} values, given that R^2_{McF} in the range of 0.2 to 0.4 is regarded as a strong exponential correlation. The mean highest risk score in horses that experienced FMIs increased with the number of starts during which they wore the IMU sensors, suggesting that the greater the amount of longitudinal data associated with a horse, the more accurate the algorithm's assessment of a horse's risk of fatal injury. Overall, these findings indicated that the greatest percentage of FMIs are experienced by a very small percentage of the actively racing Thoroughbred population and that the more often a horse wears a sensor while racing, the better the accuracy of the assessment of its risk of incurring an FMI. The results also suggested that calculating risk score averages based on scores obtained from 3 or more starts might provide a better indication of a horse's risk status than its single highest score in the previous 120 days. This possibility warrants further investigation.

Approximately 1 in 25 (4.2%) of the 118 horses with a highest risk score of 6 within the previous 120 days sustained a fatal metacarpophalangeal or metatarsophalangeal joint injury. As this anatomical region is readily imaged with a standing PET scan, such imaging might have identified an impending injury to the fetlock in these horses and the fatality rate from fetlock injuries might have been mitigated, as has been described previously.[9] Given the limited number of racetrack veterinary practitioners in the US and the increased workload associated with a thorough diagnostic lameness evaluation, the results of this study indicated that the best practice to reduce the rate of FMIs is to focus increased diagnostic efforts on the small group of starters that receive the highest risk scores and are deemed to be most at risk. On the basis of the results of this study in which only 122 risk scores of 6 were assigned at 10 racetracks over the 145-week study period (< 1 case/week or approx 1 case every 10 weeks/track), increasing the clinical scrutiny that is afforded these horses should be possible without imposing an excessive veterinary workload. Had it been possible to avoid fatal injuries in the small number of risk score 6 horses, the fatality rate associated with the 28,481 starts in the database would have dropped from 1.05:1,000 starts to 0.88:1,000 starts, or by 19%. This would represent a major reduction in the fatality rate for what should be a sustainable increase in workload.

Age was not identified as a significant risk factor for FMI. Previous reports have indicated that 2-year-olds (and 3-year-olds that did not race when aged 2-years-old) are most susceptible to fatal injuries.[15] However, with respect to the horses represented in this study (ie, those that wore the IMU sensors in at least 1 race), while 2- and 3-year-olds suffered FMIs more frequently than 4-, 5-, and 6-year-olds, despite racing less frequently, it was the oldest group of horses (those > 6 years old) that had the highest fatal injury rate in terms of horses that suffered these injuries and the percentage of race starts in which they occurred. This finding was consistent with the results of a previous meta-analysis[16] indicating that horses > 6 years old were at greater risk of suffering an FMI. It was also noteworthy that over the almost 3 years of this study, no 6-year-old horse that wore an IMU sensor in a race suffered an FMI, to our knowledge. The extent to which these findings regarding the association between age and the risk of FMI reflect those of all American racing horses is not known, as the horses involved in this survey raced at just 10 of the approximately 80 racetracks that contribute data to the Jockey Club Equine Injury Database and ran in only about 29% of the nearly 100,000 races that were run during the study period.[1]

Identifying that females were assigned lower risk scores than intact males and geldings conforms with the findings from previous reports that also showed they are less likely to suffer an FMI than intact males.[1,16,17] Female horses accounted for approximately 18% of the race starts in this investigation and started more times than did intact males. Consequently, while there may be a purported tendency for females to be retired as broodmare prospects rather than continuing in a racing career if soundness or injury becomes a concern, it seems unlikely that this was the only reason for the lower likelihood of sustaining an FMI. The highest risk scores were associated with shorter races. Whether mares are more likely to race over longer distances and consequently receive lower risk scores than the other genders is unknown and deserves investigation.

The increased likelihood of a horse suffering an FMI when racing on a dirt track has been reported in previous studies and is currently supported by the Jockey Club's Equine Injury Database.[1,18] In 2023, the incidence rate of FMI on dirt tracks was 1.43/1,000 starts, compared with 1.13/1,000 starts on turf and 0.97/1,000 starts on synthetic tracks.[1] In the current study, there was no statistical difference between dirt and turf ($P = .06$), likely because of a lack of statistical power due to the disproportionate number of races on dirt (55% of all starts; turf, 24% of all starts) and the relatively low number of fatal injuries (n = 16) that occurred on turf tracks. It is also possible that the current algorithm may be more tailored toward horses running on dirt because of the number of races on this surface that contributed data to it. As the total number of races during which IMUs are worn continues to increase, the future development of surface-specific algorithms may be warranted and feasible.

These IMUs are the first to effectively record the forces and vibrations experienced by a horse's body during a gallop at maximum speed and to detect deviations from usual movement patterns in racing Thoroughbreds. The key to this recording and detection and the identification of horses at increased risk of fatal injury was the high-frequency recording of movements across the DV, ML, and L planes. The combination of this capability and the application of a refined algorithm to the data collected enabled precise identification of motion abnormalities that may indicate an increased risk of sustaining an FMI. The degree of elevation of this risk was categorized into scores ranging from 2 to 6, with the probability of sustaining a fatal injury rising exponentially with increasing risk score relative to the minimal risk score of 1. Neither these IMU sensors nor their associated algorithm should be regarded as a diagnostic instrument but rather a "check engine light" (ie, a risk assessment tool) with which to screen horses during high-speed exercise (races and breezing) and to offer some guidance to veterinarians with respect to identifying horses on which to focus their clinical diagnostic efforts.

The results of this study indicated that any horse that had received a risk score of 6 in the previous 120 days had a substantially higher risk of suffering an FMI than a horse that received a lower risk score. The 118 horses with a risk score of 6 accounted for only 0.4% of 28,481 starts, but 4% (1 in 25) of those horses suffered a fatal injury. These odds were disturbing. This small cohort, accumulated at an average rate of < 1/wk, should make the veterinary workload manageable in terms of ensuring that such cases get thorough diagnostic evaluations. Diagnosing potential fractures before they occur would make an immediate contribution to the Thoroughbred racing industry's efforts to reduce the incidence rate of FMI in Thoroughbred racehorses, as demonstrated by the calculated theoretical decrease of 19% in this fatality rate had all horses associated with a risk score of 6 been optimally evaluated and identified and their fatal injury prevented.

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Supplementary Materials

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