Temporal and Kinematic Gait Variables of Thoroughbred Racehorses At or Near Racing Speeds

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For centuries traditional racehorse experts have tried to evaluate the potential ability and future soundness of young animals by qualitatively observing their "way of going." This study was conducted in order to begin the process of quantifying the description of the equine gait, and examining that data's statistical relationships to subsequent performance and racing injuries. This study and studies like it may also prove useful for enhancements to safety and performance in the design and maintenance of future racing surfaces and racehorse equipment from shoes to saddles.

This is the first large scale, longitudinal study of its kind on the gaits of Thoroughbred racehorses actually involved in their racing careers at major racetracks. The Data Supplement attached contains more gait data on Thoroughbreds actually involved in racing and training for racing than all previous studies in this field combined, and should prove to be a lasting, valuable tool for researchers in this field. The multidisciplinary team of experts that participated in this work was also unique in its breadth and depth (see Acknowledgements).

SUMMARY

Kinematic gait data was obtained through the precision motion analysis of over 12,000 lateral view, digitized, high speed filmings of Thoroughbred racehorses at major racetracks in the United States, France, and England. This data was collected over a period of 15 years. Veterinary, training, conformation, and pedigree information was recorded for each subject, along with racing records through each subject's three-year-old year. Ail filmings were recorded during actual workouts and races, including many graded stakes races. For example, over 90% of the Champion Eclipse Award flat horses from 1984 to 1990, many as two-year-olds, were included in this data. Horse velocities ranged from 13.4 to 20.1 m/sec (44 to 66 ft/sec—15 to 10 sec/fur—30 to 45 mph).

Most kinematic gait parameters covered in this study were highly dependent on velocity. For example, stride length, stride frequency, extension variables and respiration variables were all highly dependent on velocity.

There were significant statistical differences between the gait parameters of subsets of the total sample, categorized by sex and age. The authors show that data should therefore be normalized by velocity, age and sex. This study identifies some useful methods to aid in normalizing data, as for example what we call the "EQB Velocity Shift Principle (see Discussion and Conclusions).

Once horses were grouped accordingly, by age, sex and velocity, and multivariate discriminant analysis was applied, temporal and kinematic gait measurements proved to have strong predictive value for subsequent racing performances of two-year-olds unraced at the time of these filmings.

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MATERIALS AND METHODS

A total of more than 6500 different Thoroughbred racehorses were filmed at major racetracks, perpendicular to their path of motion with two high speed Locam cameras (Model 164-4AC, Redlake Corporation, Campbell, Calif), using 16-mm film at a frame rate of 300 frames per second. Digitizing was conducted on more than 12,000 filmings (each horse filmed an average of 1.9 times) using motion analyzer projection equipment (Vanguard Instrument Corporation, Melville, NY; Lafayette Instrument Corporation, Lafayette, Ind; L-W Athena International Corp, Simi Valley, Calif). Data reduction was accomplished with a Prime 2455 mini-computer (Prime, Natick, Mass) and SAS statistical software (SAS Institute, Cary, NC).

For about half of the filmings, two cameras were positioned to record a continuum of strides, such that as the horse left the field of view of the first camera, it entered the field of view of the second camera. The cameras were calibrated for every filming, with frame speed error less than

± 2/300ths of a second. Each filming session concluded with the filming of a high quality, mechanical stopwatch (full, 360 degree sweep = 3 seconds in 1/100ths second increments) by each camera for approximately 20 seconds. These stopwatch measurements enabled the digitizers to note the exact frame rate of each camera, which was recorded onto the records of every digitized horse from that filming session.

For the purposes of this study, only 5724 filmings of horses were used, representing 3,008 unique horses. These 5724 horses were filmed on dry dirt surfaces while in an unimpeded transverse gallop (no lead changes or rotary gallops), at velocities from 13.4 to 20.1 m/sec (44 to 66 ft/sec—15 to 10 sec/fur—35 to 45 mph).[a] All horses had been in training for at least 60 days.

Data from wet surfaces, turf, lead changes, rider interference, and rotary gallops was excluded from this paper. All high speed filmings used had professional jockeys in normal riding positions, who did not use their whip during the recorded performances. The riders and trainers worked independently of the authors, with no a *priori* dictated behavior with respect to this study.

Of the total filmings, 4681 were from early spring two-year-old auctions. These 2699 colts and 1982 fillies were filmed during the final 16th mile of their high speed work-out, which was no longer than 3/8ths of a mile. Each camera recorded from 2.5 to 3 strides of each horse.

A total of 1043 filmings (614 colts and 429 fillies) were of race age horses (some were two-year-olds actually in races in August or later, but most were at least into their three-year-old year, often filmed in races at major, Class 1 racetracks). These horses were generally filmed immediately after going 1/8th to 3/8ths mile of the high speed portion of their work-out, or in races immediately after they had travelled 3/16ths to 1/2 mile, so they were considered not unduly fatigued.

Eighty percent of all horses were using their right lead. Two and one half to three consecutive strides were used to calculate the gait parameters. Temporal measurements were used to describe each horse's gait characteristics in terms including extension, stride length, stride frequency, overlap times between limbs, support and non-support limb phases (see GLOSSARY OF TERMS).

There were two clockers spaced approximately 330 feet apart, with the cameras and camera operators positioned between them. Using "Equitalk" FM wireless communication sets (EQB, Inc, Unionville, Penn), the first clocker called the "on" as the horse passed directly in front of him, perpendicular to his line of sight, at which time both clockers started their stop watches. The second clocker called the "off" as the horse passed directly by him, at which time both clockers stopped their watches. The two times on the clockers' watches were averaged, and compared to the times taken directly from the film. Comparison to electronic timing systems revealed that this timing technique accurately described velocity within 0.15 m/sec (0.5 ft/sec).[b] It also solved the problem of being forbidden by racetrack authorities to place electronic timing devices on the racetracks.

Three technicians (digitizers) digitized all the filmings used for this study, using a standardized technique under the close supervision of the authors. The digitizers had years of digitizing and horse experience. For practically all horses (96.5%), the digitizers acted "blind," not knowing the sex, pedigree, monetary value or racing ability of the horses they were digitizing. The digitizers identified each horse only by a hip number or a filming ID number.

All available information, including sex, age, conformation, pedigree, auction or private purchase price, claiming race level, training and vet records, known drug use, etc, were recorded. Detailed racing records were recorded through the end of these horses' three-year-old year. The horses were later grouped according to subsequent racing earnings as an estimated index of their racing "ability."

The unknowns in the data included, but were not limited to, soundness and conditioning levels not known to the public, drugs, tack and rider weight and ability (although often such information was available and was recorded among the data).

Multiple Filmings of the Same Horse

Student's *t* tests were conducted to justify the use of multiple filmings of the same horse for this study, comparing this study's data to a group of 3008 unique horses (a subset of this study) in which case, the first or fastest filming of each horse was selected from the larger study. Key results of the study comparing the single filming group to the multiple filming group are presented in Tables 1 through 3, showing nearly identical statistical profiles (no significant differences) for the two groups. Likewise, nearly identical statistical profiles were also obtained for other large subsets, ie, divided by the first letter of racing name.

Most horses' multiple filmings were recorded the same day or within a few days of each other. Some horses were

a. Original velocity measurements were made in feet per second, as reflected in tables and figures. Appendix A provides a measurement units conversion table to convert between meters per second, feet per second and seconds per furlong.

b. There were also "internal" variations of velocity within each stride of each horse that, in some cases, were as great as 1.07 m/sec (3.5 ft/sec—0.8 seconds per furlong) in racing speed strides. See Appendix B on velocity error sources.

Table 1 Statistical summary of 5724 study horses (some horses filmed more than once)

Variable	n	Mean	SD	Minimum value	Maximum value	SEM	Sum	Variance	CV
VEL	5724	53.48776904	4.56400775	44.00000000	66.00000000	0.06032489	306163.99000	20.83016677	8.533
TSTRIDE	5724	0.41632888	0.02247151	0.34860000	0.51160000	0.00029702	2383.06650	0.00050497	5.398
TSTANCE	5724	0.08881957	0.00978441	0.06170000	0.13410000	0.00012933	508.40320	0.00009573	11.016
TSWG	5724	0.32748543	0.01814636	0.26750000	0.39330000	0.00023985	1874.52660	0.00032929	5.541
TAIR	5724	0.12022961	0.01804690	0.05330000	0.18500000	0.00023854	688.19430	0.00032569	15.010
TGND	5724	0.29394869	0.01831146	0.20900000	0.37000000	0.00024203	1682.56230	0.00033531	6.229
GNDAIR	5724	2.50621883	0.45239105	1.38730000	6.50000000	0.00597949	14345.59660	0.20465767	18.051
LSTRIDE	5724	22.20912846	1.51942599	18.04010000	27.27020000	0.02008305	127125.05130	2.30865533	6.841
FREQ	5724	2.40856670	0.12929728	1.95470000	2.86840000	0.00170899	13786.63580	0.01671779	5.368
P1	5724	0.68660122	0.07037407	0.03700000	1.15500000	0.00093017	3930.10537	0.00495251	10.250
P2	5724	0.73564473	0.22873370	0.05300000	1.61900000	0.00302329	4210.83043	0.05231910	31.093
P3	5724	0.94378365	0.09851737	0.55800000	1.43700000	0.00130216	5402.21760	0.00970567	10.439
PCTXLAP	5724	0.14689858	0.06531326	0.01290000	0.43950000	0.00086328	840.04750	0.00426582	44.461
AVGSTN	5724	4.72380874	0.37635446	3.68280000	6.46530000	0.00497448	27039.08120	0.14164268	7.967
INSP	5724	0.24748404	0.01638310	0.19500000	0.31000000	0.00021654	1416.59865	0.00026841	6.620
EXP	5724	0.16869698	0.01529061	0.12130000	0.23666600	0.00020210	965.62149	0.00023380	9.064

Table 2 Statistical summary of 3008 unique study horses

Variable	n	Mean	SD	Minimum value	Maximum value	SEM	Sum	Variance	CV
VEL	3008	53.62418218	4.87373531	44.00000000	66.00000000	0.08886342	161301.54000	23.75329591	9.089
TSTRIDE	3008	0.41651124	0.02295557	0.34860000	0.51160000	0.00041855	1252.86580	0.00052696	5.511
TSTANCE	3008	0.08967287	0.01055629	0.06170000	0.12660000	0.00019247	269.73600	0.00011144	11.772
TSWG	3008	0.32682011	0.01816654	0.26910000	0.38750000	0.00033123	983.07490	0.00033002	5.559
TAIR	3008	0.11999162	0.01805327	0.06100000	0.18500000	0.00032917	360.93480	0.00032592	15.045
TGND	3008	0.29431260	0.01918931	0.20900000	0.37000000	0.00034988	885.29230	0.00036823	6.520
GNDAIR	3008	2.51442204	0.45609113	1.38730000	5.16210000	0.00831597	7563.38150	0.20801912	18.139
LSTRIDE	3008	22.26954448	1.59960208	18.12250000	27.18720000	0.02916574	66986.78980	2.55872682	7.183
FREQ	3008	2.40770838	0.13209524	1.95470000	2.86840000	0.00240851	7242.38680	0.01744915	5.486
P1	3008	0.68390971	0.07183610	0.39200000	0.96100000	0.00130980	2057.20040	0.00516043	10.504
P2	3008	0.72285956	0.23737390	0.05714200	1.61900000	0.00432807	2174.36157	0.05634637	32.838
P3	3008	0.93446156	0.10300755	0.64200000	1.43700000	0.00187815	2810.86036	0.01061056	11.023
PCTXLAP	3008	0.15374202	0.06979036	0.02070000	0.43950000	0.00127250	462.45600	0.00487069	45.394
AVGSTN	3008	4.77697799	0.40733948	3.76060000	6.46530000	0.00742707	14369.14980	0.16592545	8.527
INSP	3008	0.24688864	0.01619688	0.19500000	0.30333300	0.00029532	742.64102	0.00026234	6.560
EXP	3008	0.16952946	0.01626483	0.12130000	0.23000000	0.00029656	509.94460	0.00026454	9.594

filmed as many as a dozen times over the period of their two-year-old and three-year-old racing years. The multiple films of individual horses were used to examine the reproducibility and reliability of the data collection techniques and equine gait characteristics.

Reproducibility

The gait parameters studied were acceptably reproducible by individual horses at similar velocities in multiple filmings (from one stride to the next, from day to day and from year to year (taking into account age related changes).[c] See Tables 4a and 4b for reproducibility examples (ie, stride regularity).

Important Influences on Data That Are Not Related to Ability

Before the authors studied complex relationships between gait and racing ability (as measured by earnings, distance run, surface preference, etc), they first examined important sources of influence on the data that were independent of ability. The most easily, statistically identified

c. A full discussion on reproducibility of kinematic gait parameters in individual horses at specific velocities is beyond the scope of the discussion of this paper. EQB's extensive data on this subject is available for review and will be fully discussed in a separate paper.

Table 3 Statistical Comparison of 5724 Total vs. 3008 Unique Horses

Variable	Mean n = 5724	Mean n = 3008	SD n = 5724	SD n = 3008
VEL	53.48776904	53.62418218	4.56400775	4.87373531
TSTRIDE	0.41632888	0.41651124	0.02247151	0.02295557
TSTANCE	0.08881957	0.08967287	0.00978441	0.01055629
TSWG	0.32748543	0.32682011	0.01814636	0.01816654
TAIR	0.12022961	0.11999162	0.01804690	0.01805327
TGND	0.29394869	0.29431260	0.01831146	0.01918931
GNDAIR	2.50621883	2.51442204	0.45239105	0.45609113
LSTRIDE	22.20912846	22.26954448	1.51942599	1.59960208
FREQ	2.40856670	2.40770838	0.12929728	0.13209524
P1	0.68660122	0.68390971	0.07037407	0.07183610
P2	0.73564473	0.72285956	0.22873370	0.23737390
P3	0.94378365	0.93446156	0.09851737	0.10300755
PCTXLAP	0.14689858	0.15374202	0.06531326	0.06979036
AVGSTN	4.72380874	4.77697799	0.37635446	0.40733948
INSP	0.24748404	0.24688864	0.01638310	0.01619688
EXP	0.16869698	0.16952946	0.01529061	0.01626483

Table 4a Reproducibility of gait: eg, Spectacular Bid (as 3-year-old Delaware Park). 6 sequential strides at an average velocity of 60 ft/sec (11 sec/furlong; 18.29 meters/sec)

	Stride					
Variable	1	2	3	4	5	6
P1	78.8	87.5	82.4	77.8	83.3	65.7
P2	52.9	66.7	56.3	75	53.3	70.6
P3	100	106.3	106.3	94.1	105.6	
TAIR	0.135	0.145	0.14	0.1575		

Sequential leg swing times (in seconds) for Spectacular Bid corresponding to Table 4a: 0.3375, 0.3400, 0.3500, 0.3450, 0.3600, 0.3575, 0.3500, 0.3400, 0.3550, 0.3300, 0.3450, 0.3525, 0.3500, 0.3600. Sequential leg support times (seconds) for Spectacular Bid corresponding to Table 4a: 0.0825, 0.0850, 0.0850, 0.0900, 0.0800, 0.0825, 0.0800, 0.0850, 0.0850, 0.0900, 0.0800, 0.0850, 0.0800, 0.0900, 0.0750, 0.0850, 0.0800, 0.0875, 0.0850, 0.0800.

Table 4b Reproducibility of gait: eg, 2-year-old named Murmuration for Sale in the Month of February at a Florida-Bred Select "in-traing" Sale Data from Multiple Filmings in 1 Week

Velocity			Frequency			
Sec/ furlong	Meters/ sec	Feet/ sec	Strides/ sec	TSWG Sec	P1 %	P3 %
12.2	16.49	54.1	2.22	0.36	0.71	1.00
12.2	16.49	54.1	2.21	0.36	0.72	1.08
11.73	17.15	56.25	2.23	0.366	0.71	1.11
11.64	17.29	56.72	2.28	0.357	0.735	1.18
11.62	17.31	56.8	2.27	0.359	0.73	1.08
11.58	17.37	56.99	2.26	0.363	0.76	1.14

sources of influence on the data that were independent of ability were *age*, *sex*, and *velocity*.

The strong influences of age, sex, and velocity on the gait parameters of horses, as described in this study, indicate that for complex studies, it would be valuable to use the most uniform groups of horses possible, tightly controlled by age, sex and velocity. A uniform group of horses might contain only two-year-old colts filmed at nearly identical velocities. A non-uniform group of horses might contain two and three-year-old colts and fillies filmed at a wide range of velocities.

As an example of how age, sex and velocity affect gait, consider Horse A and Horse B, filmed at the same velocity:

Horse A is a high-earner with a 25-foot stride length.

Horse B is a low-earner with a 23-foot stride length.

The data for Horses A and B may indicate that length of stride affects earning potential. Before making this assumption, consider known factors, unrelated to ability, that affect stride length. Three factors almost always play a role, as follows:

Sex: A filly will typically have a shorter stride than a colt of the same age at the same velocity.

Age: A spring two-year-old typically has a shorter stride than a race-age horse of the same sex at the same velocity.

Velocity: Stride length generally increases with velocity. If Horse A was going substantially faster than Horse B, then it is perfectly normal for Horse A to have a longer stride length (comparing horses of the same age and sex).

Uniform Data Groups Were Defined Which Minimized the Effect on Gait Measurements of Data Influences Not Related to Ability

Means and related statistical measures were reported for each gait parameter studied, for groups categorized by

Table 5 All high earners: Two-year-old colts versus 2-year-old fillies-*t* test level of significance of differences showing probability >*t*

	Velocity (ft/sec)					
Variable	45-48	48-51	51-54	54-57	57-60	60-63
n (colts)	43	43	87	116	40	23
n (fillies)	33	31	52	89	36	17
VEL	.4583	.8838	.6491	–.2378	–.4853	.0805
TSTRIDE	.1458	.5842	.0001	.0001	.0097	.0225
TSTANCE	.2324	–.2612	.8775	.1074	.6913	.8013
TSWG	.3179	.3122	.0001	.0001	.0210	.0122
TAIR	–.3317	–.4003	–.7530	.0729	.0491	.1557
TGND	.0295	.1349	.0002	.0080	–.9474	.3967
PCTXLAP	–.9374	–.0194	–.0018	–.6564	–.9863	–.2089
LSTRIDE	.0772	.5505	.0001	.0001	.0239	.0108
FREQ	–.1514	–.6323	–.0001	–.0001	–.0098	–.0228
P1	.6556	–.6114	–.8333	.6941	–.2491	–.2707
P2	.4266	.0020	.0026	.2839	.6713	.0678
P3	–.4245	–.7610	.0250	–.0294	.5014	.1355
AVGSTN	.1688	–.2541	.8028	.1751	.9269	.6258
INSP	.2348	.1123	.0026	.0001	.0242	.0218
EXP	.2655	–.0679	.0291	.3152	.3506	–.9295

A positive number shows that the elite colts' mean was higher than the elite fillies' mean for the same variable. A negative number shows that the elite colts mean was lower than the dog group's mean for the same variable. If a P value shown = .0001, the confidence of the elite fillies' of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

Table 6 All High earners: Race-age colts versus fillies-*t* test level of significance of differences showing probability >*t*

	Velocity (ft/sec)				
Variable	51-54	54-57	57-60	60-63	63-66
n (colts)	60	112	61	43	28
n (fillies)	30	73	46	24	31
VEL	.0200	–.7381	.0011	–.2947	.6920
TSTRIDE	.0008	–.8096	–.2638	–.9536	.9035
TSTANCE	.5326	.0746	–.6624	.0290	–.3138
TSWG	.0035	–.2618	–.3184	–.2359	.6412
TAIR	.6679	–.0073	–.0154	–.0472	–.1577
TGND	.0045	.0319	.1169	.0361	.6820
PCTXLAP	–.2622	.3276	–.1564	.2988	–.0378
LSTRIDE	.0001	–.6892	–.8339	–.5523	.7849
FREQ	–.0010	.8175	.2950	.8173	–.8363
P1	.2896	–.1308	.8451	–.4151	.1861
P2	.2428	.6415	.0738	–.6413	.0079
P3	.7264	–.3440	–.7634	–.1184	.2913
AVGSTN	.2962	.0716	–.9761	.0466	.3356
INSP	.0190	–.1180	–.1817	–.0432	.6841
EXP	.3763	.0349	–.7206	.0274	–.7702

A positive number shows that the elite colts' mean was higher than the elite fillies' mean for the same variable. A negative number shows that the elite colts' mean was lower than the elite fillies mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

velocity, age and sex.[d] These statistical measures (presented in Data Supplement) were calculated within 22 separate 0.305 m/sec (1 ft/sec) velocity increments, from 13.4 to 20.1 m/sec (44 to 66 ft/sec—15 to 10 sec/fur—30 to 45 mph) for four main categories of horses, listed below and referred to throughout this text.

Four Main Age and Sex-Related Categories of Horses Examined in This Study

Two-year-old colts (Filmed between Feb 1 and May 5)
Two-year-old fillies (Filmed between Feb 1 and May 5)
Race-age colts (August of 2yo year and older)
Race-age fillies (August of 2yo year and older)

RESULTS

Data

The data itself in this study is an important result that will be useful in setting standards for future investigations. This data is available in its entirety for inspection. Because it fills hundreds of pages of computer printout, it is not included here beyond the charts and tables provided.

Velocity

The first and perhaps most important result was that most gait parameters were highly dependent on velocity. This was strongly indicated by the collective data from the general population in this study. However, individual horses could and did vary widely in their running styles relative to velocity. Gait parameters were studied within 0.305 m/sec (1 ft/sec) velocity groups. The Data Supplement provides a comprehensive statistical summary of the gait parameters studied within these velocity groups, for all 5724 horses studied. Regression analysis was applied to this data, which also helped to determine the most practical velocity ranges within which gaits of different horses could be considered similar.

Tables 11 through 20 and Figures 1 through 12 illustrate the velocity dependence of gait variables in detail, while taking into account age and sex. Some summary examples of velocity dependent gait variables are:

- Stride length
- Stride frequency
- Expiration
- Inspiration
- P1, P2, and P3 extension variables

d. Other variables from our data base that were similarly independent of performance ability, like weight and height, are not discussed in this paper.

Table 7 Two-year-olds: All colts versus all fillies-*t* test level of significance of differences showing probability >*t*

	Velocity (ft/sec)					
Variable	45-48	48-51	51-54	54-57	57-60	60-63
n (colts)	385	377	622	758	334	103
n (fillies)	284	258	464	548	258	88
VEL	.2139	−.6243	−.8538	−.0969	.4012	.5402
COUNT	.0005	.0886	.6894	−.1300	−.0072	.3740
TMONEY	.4820	.4092	−.8406	−.1189	−.1958	.8846
EPS	−.6694	.1750	.6291	−.3112	−.9087	.8440
TSTRIDE	.0001	.0001	.0001	.0001	.0001	.0089
TSTANCE	.0497	.3740	.0043	.0096	.0051	.3551
TSWG	.0001	.0001	.0001	.0001	.0001	.0145
TAIR	.7399	.8570	−.3224	.9561	.4158	.1548
TGND	.0001	.0001	.0001	.0001	.0001	.0924
PCTXLAP	−.0121	−.0035	−.0001	−.0003	−.1538	−.5211
LSTRIDE	.0001	.0001	.0001	.0001	.0001	.0053
FREQ	−.0001	−.0001	−.0001	−.0001	−.0001	−.0090
P1	.0095	−.3226	.9887	.2420	−.2823	−.4154
P2	.0485	.0001	.0001	.0001	.0281	.7757
P3	.2088	.4020	.7852	−.2084	.5756	.6954
AVGSTN	.0170	.4777	.0035	.0323	.0047	.3378
INSP	.0004	.0002	.0001	.0001	.0001	.0691
EXP	.0001	.1318	.0001	.0060	.0001	.0905

A positive number shows that the colts' mean was higher than the fillies' mean for the same variable. A negative number shows that the colts' mean was lower than the fillies' mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

Table 8 Race-age: All colts versus all fillies-*t* test level of significance of differences showing probability >*t*

	Velocity (ft/sec)					
Variable	48-51	51-54	54-57	57-60	60-63	63-66
n (colts)	53	127	215	95	62	39
n (fillies)	27	86	126	75	48	55
VEL	.8927	.0080	−.0995	.0010	−.0818	.8900
COUNT	.1214	.1489	.0355	.7868	.0077	.1480
MONEY	.0614	.3268	.0920	.0431	.0015	.0376
EPS	.2468	.0777	.0918	.0717	.0316	.0911
TSTRIDE	.7594	.0003	.1909	.4745	.0400	.6419
TSTANCE	−.3249	.0978	.0544	−.1234	.0934	−.1358
TSWG	.4802	.0060	.7063	.1227	.2221	.2852
TAIR	−.2117	−.8922	−.1836	.8114	−.3543	−.4740
TGND	.1335	.0001	.0012	.4796	.0339	−.7457
PCTXLAP	−.0403	−.4323	.5829	−.0146	.8297	−.0492
LSTRIDE	.7594	.0001	.4510	.1077	.1729	.6126
FREQ	−.8081	−.0003	−.1773	−.3754	−.0521	−.5918
P1	.4309	−.9772	.9240	.0076	−.9801	.0391
P2	.0245	.0398	−.3323	.2541	.6601	.0211
P3	.1468	−.5792	−.7589	.0357	−.4991	.1323
AVGSTN	−.3342	.0387	.0701	−.3028	.1500	−.1405
INSP	.4612	.0175	−.2476	.5071	.9446	.3268
EXP	.9825	.0589	.0009	−.4722	.0092	−.3334

A positive number shows that the colts' mean was higher than the fillies' mean for the same variable. A negative number shows that the colts' mean was lower than the fillies' mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

Sex

Most of the gait parameters studied were significantly different between colts (colts, geldings, ridglings, and horses) and fillies (fillies and mares). For example, Figures 1 and 2 show that stride length and stride frequency increased with increasing velocity at similar slopes for two-year-old colts and fillies, yet with different intercepts (ie, the resulting plotted lines were different, though parallel to one another). Figures 3 through 6 further illustrate two-year-old sex related differences among key gait variables of inspiration, expiration, P2, and total percent of overlap. Most gait parameters showed similar relationships to velocity differentiated by sex, as further demonstrated with *t* tests in Tables 5 through 8.

Tables 5 and 7 compared two-year-old colts with two-year-old fillies, with many *P* values of .0001. Tables 6 and 8 compared race age colts with race age fillies, where sex biases were not as obvious or significant as among two-year-olds.

Age

Most gait parameters were significantly affected by the age of the horse, in a manner similar to the effects of sex differences. For example, Figures 7 through 10 show that stride length and P2 increased with increasing velocity at similar slopes, but with different intercepts, for two-year-old and race age colts. Similar slopes existed between different age-groups of the same sex, with plotted lines offset and parallel to one another.

Tables 9 and 10 present *t* test results comparing gait parameters of two-year-olds versus race age horses of the same sex at similar velocities. Statistically significant (*P* values in .0001 range) age-related differences were present in nearly every gait parameter studied, for both colts and fillies. However, age related differences were not significant between race age horses of different ages (ie, four-year-olds compared with five-year-olds).

Total ground time (TGND) per stride and the percentage of overlap between the front legs (P3)[e] did not differentiate between age groups as clearly as the other gait parameters studied.

e. P3 was often not linearly related to velocity in a single horse filmed at different velocities. Some horses seemed to "change gears" as they accelerated, alternating the use of stride frequency and extension, causing P3 to go both up and down during acceleration.

Table 9 All older colts versus all two-year-old colts-*t* test level of significance of differences showing probability >*t*

Variable	Velocity (ft/sec) 45-48	48-51	51-54	54-57	57-60	60-63	63-66
n (ynger)	385	377	622	758	334	103	10
n (older)	18	53	127	215	95	62	39
VEL	–.8161	.4084	.2718	–.0001	.0473	.0364	.0001
COUNT	.2074	.0013	.0001	.0001	.0001	.0001	.0002
TMONEY	.1411	.0258	.0001	.0001	.0001	.0001	.0131
EPS	.0577	.0289	.0001	.0001	.0001	.0001	.0616
TSTRIDE	.3537	.0018	.0001	.0001	.0001	.0015	–.9297
TSTANCE	.5265	.2182	.0001	.0001	.0582	.3459	.2517
TSWG	.4951	.0066	.0001	.0001	.0001	.0013	–.5603
TAIR	.1340	.0002	.0001	.0001	.0001	.0001	–.6510
TGND	–.3895	–.8616	.8421	.7174	.2170	–.4342	–.5603
PCTXLAP	.3083	.1586	.0001	.0001	.0830	.2019	.2875
LSTRIDE	.3863	.0010	.0001	.0001	.0001	.0001	.3680
FREQ	–.3989	–.0019	–.0001	–.0001	–.0001	–.0013	.9691
P1	.3588	.0691	.0006	.0001	.0001	.1598	.9499
P2	–.0023	–.0021	–.0001	–.0001	–.0001	–.3149	–.8695
P3	.8789	.1954	–.0667	.7586	–.8045	–.3439	–.0924
AVGSTN	.5385	.1460	.0001	.0001	.0239	.1738	.1292
INSP	.8140	.1192	.0002	.0001	.0001	.0029	–.5501
EXP	.0708	.0037	.0001	.0001	.0242	.3058	.5263

A positive number shows that the older colts' mean was higher than the younger colts' mean for the same variable. A negative number shows that the older colts' mean was lower than the younger colts' mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

Table 10 All older fillies versus all two-year-old fillies-*t* test level of significance of differences showing probability >*t*

Variable	Velocity (ft/sec) 45-48	48-51	51-54	54-57	57-60	60-63	63-66
n (ynger)	284	258	464	548	258	88	11
n (older)	10	27	86	126	75	48	55
VEL	–.5915	.8032	–.0196	–.0121	–.1362	.0001	.0152
COUNT	.2463	.0939	.0243	.0005	.0002	.0004	.0001
TMONEY	.1838	.1279	.0453	.0001	.0001	.0027	.0027
EPS	.0788	.0513	.0255	.0001	.0001	.0027	.0044
TSTRIDE	.2034	.0001	.0001	.0001	.0001	.0003	.0019
TSTANCE	–.9691	.0052	.0003	.0051	.0001	–.7106	.0010
TSWG	.1857	.0045	.0001	.0001	.0001	.0003	.2241
TAIR	.0991	.0001	.0001	.0001	.0001	.0001	.2482
TGND	–.6361	.9860	–.7492	–.7884	.0076	–.0439	.0075
PCTXLAP	.9016	.0115	.0001	.0036	.0002	.5102	.0011
LSTRIDE	.2597	.0005	.0001	.0001	.0001	.0001	.0003
FREQ	–.1884	–.0001	–.0001	–.0001	–.0001	–.0002	–.0028
P1	.0945	.9635	.0008	.0001	.6757	.5960	–.0015
P2	–.1578	–.0002	–.0001	–.0001	–.0001	–.1564	–.0085
P3	.4289	–.7287	–.4561	.9352	–.0171	.7826	–.0172
AVGSTN	–.9343	.0049	.0011	.0160	.0001	.7834	.0003
INSP	.2126	.0712	.0318	.0001	.0001	.0001	.3674
EXP	.7216	.0003	.0001	.0009	.0001	–.5880	.0003

A positive number shows that the older fillies' mean was higher than the two-year-old fillies' mean for the same variable. A negative number shows that the older fillies' mean was lower than the two-year-old fillies' mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

Table 11 Means and regression equations for two-year-old colts (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	TSTRIDE	TSTANCE	TSWG	TAIR	TGND	GNDAIR	AVGSTN	FREQ	INSP	EXP	n
44-45	44.4605	0.4458	0.1064	0.3394	0.1315	0.3144	2.4388	4.7309	2.245	0.249	0.1962	110
45-46	45.6043	0.4467	0.1032	0.3435	0.1329	0.31405	2.4073	4.7077	2.2415	0.2543	0.1918	128
46-47	46.4761	0.4425	0.101	0.3413	0.1296	0.3128	2.4641	4.6935	2.2639	0.2539	0.1885	104
47-48	47.495	0.4361	0.0984	0.3377	0.1305	0.3052	2.3847	4.6746	2.297	0.2517	0.1844	153
48-49	48.4824	0.4324	0.0966	0.3358	0.1281	0.3037	2.4199	4.6855	2.3172	0.2507	0.1807	122
49-50	49.5358	0.431	0.0966	0.3344	0.1214	0.3088	2.5999	4.7943	2.3238	0.2501	0.1808	100
50-51	50.4517	0.4267	0.0918	0.3349	0.1234	0.3026	2.496	4.6336	2.3466	0.2525	0.1736	155
51-52	51.5228	0.4246	0.0906	0.3341	0.1231	0.3007	2.4884	4.6679	2.3586	0.2521	0.1724	165
52-53	52.5256	0.4182	0.0878	0.3304	0.1187	0.2985	2.5536	4.6166	2.3941	0.2492	0.1685	217
53-54	53.4932	0.415	0.0871	0.3279	0.1164	0.2972	2.599	4.6626	2.4129	0.2482	0.1668	240
54-55	54.4555	0.4142	0.0858	0.3284	0.1169	0.2954	2.5724	4.677	2.4173	0.2502	0.1642	226
55-56	55.482	0.4072	0.0845	0.3226	0.1133	0.2915	2.6307	4.692	2.4588	0.2452	0.1618	301
56-57	56.5531	0.4057	0.083	0.3226	0.1127	0.2899	2.6231	4.6993	2.4683	0.2453	0.16	231
57-58	57.518	0.4043	0.0839	0.3203	0.1097	0.2899	2.6951	4.8287	2.4749	0.2432	0.1608	151
58-59	58.4279	0.4013	0.0826	0.3187	0.1089	0.2877	2.6984	4.8252	2.495	0.2433	0.1585	117
59-60	59.4864	0.3984	0.0808	0.3176	0.1075	0.2851	2.7094	4.8149	2.5136	0.2426	0.1562	66
60-61	60.4015	0.3956	0.0797	0.3158	0.1097	0.2808	2.6051	4.8185	2.5319	0.2423	0.1539	59
61-62	61.42	0.3879	0.0805	0.3072	0.0976	0.2824	2.92605	4.9388	2.5822	0.2351	0.1532	26
62-63	62.4	0.3985	0.0777	0.3207	0.1097	0.2807	2.6406	4.85	2.514	0.2462	0.1512	18
63-64	63.42	0.3928	0.0766	0.3162	0.1071	0.27505	2.643	4.8649	2.55	0.2452	0.1481	10

Regression output

TSTRIDE		TAIR		AVGSTN	
Constant	0.58346	Constant	0.203588	Constant	4.174309
SE of Y estimate	0.003391	SE of Y estimate	0.003071	SE of Y estimate	0.066544
R^2	0.968266	R^2	0.908048	R^2	0.478972
No. of observations	20	No. of observations	20	No. of observations	20
Degrees of freedom	18	Degrees of freedom	18	Degrees of freedom	18
X coefficient(s)	–0.0031	X coefficient(s)	–0.0016	X coefficient(s)	0.01055
SE of coefficient	0.000132	SE of coefficient	0.00012	SE of coefficient	0.002594
TSTANCE		**TGND**		**FREQ**	
Constant	0.168504	Constant	0.403817	Constant	1.447426
SE of Y estimate	0.001965	SE of Y estimate	0.001885	SE of Y estimate	0.018511
R^2	0.953888	R^2	0.976303	R^2	0.971395
No. of observations	20	No. of observations	20	No. of observations	20
Degrees of freedom	18	Degrees of freedom	18	Degrees of freedom	18
X coefficient(s)	–0.00148	X coefficient(s)	–0.002	X coefficient(s)	0.017838
SE of coefficient	7.66E–05	SE of coefficient	7.35E–05	SE of coefficient	0.000721
TSWG		**GNDAIR**		**INSP**	
Constant	0.415119	Constant	1.600678	Constant	0.283138
SE of Y estimate	0.003155	SE of Y estimate	0.075947	SE of Y estimate	0.002909
R^2	0.906404	R^2	0.675942	R^2	0.653088
No. of observations	20	No. of observations	20	No. of observations	20
Degrees of freedom	18	Degrees of freedom	18	Degrees of freedom	18
X coefficient(s)	–0.00162	X coefficient(s)	0.018138	X coefficient(s)	–0.00066
SE of coefficient	0.000123	SE of coefficient	0.00296	SE of coefficient	0.000113
EXP					
Constant	0.298127				
SE of Y estimate	0.002633				
R^2	0.968145				
No. of observations	20				
Degrees of freedom	18				
X coefficient(s)	–0.0024				
SE of coefficient	0.000103				

Table 12 Means and regression equations for two-year-old colts (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	COUNT	EPS	P1	P2	P3	PCTXLAP	LSTR	FREQ	INSP	EXP	n
44-45	44.4605	7.7455	2015.867	0.6911	0.4175	0.8548	0.2493	19.8299	2.245	0.249	0.1962	110
45-46	45.6043	9.7266	1692.069	0.7017	0.4798	0.8826	0.2222	20.3742	2.2415	0.2543	0.1918	128
46-47	46.4761	9.7981	1434.576	0.7087	0.5149	0.8862	0.2066	20.5646	2.2639	0.2539	0.1885	104
47-48	47.495	11.7059	2156.442	0.6976	0.5327	0.8961	0.2016	20.7141	2.297	0.2517	0.1844	153
48-49	48.4824	9.2213	5301.084	0.6896	0.5737	0.9003	0.1913	20.9633	2.3172	0.2507	0.1807	122
49-50	49.5358	9.86	2117.091	0.6738	0.6332	0.9085	0.1828	21.3484	2.3238	0.2501	0.1808	100
50-51	50.4517	11.0323	2097.39	0.6925	0.6995	0.9308	0.1526	21.5268	2.3466	0.2525	0.1736	155
51-52	51.5228	11.9333	1814.048	0.6872	0.7138	0.9467	0.1464	21.882	2.3586	0.2521	0.1724	165
52-53	52.5256	12.871	2011.38	0.685	0.781	0.9575	0.1277	21.9708	2.3941	0.2492	0.1685	217
53-54	53.4932	11.2042	2230.475	0.6884	0.7976	0.9532	0.125	22.2035	2.4129	0.2482	0.1668	240
54-55	54.4555	12.5644	2038.562	0.6902	0.8261	0.9598	0.1168	22.5602	2.4173	0.2502	0.1642	226
55-56	55.482	11.9435	2505.053	0.6766	0.8569	0.9633	0.1154	22.5993	2.4588	0.2452	0.1618	301
56-57	56.5531	11.6061	2253.484	0.6757	0.8988	0.971	0.1059	22.9482	2.4683	0.2453	0.16	231
57-58	57.518	11.1722	2424.556	0.6591	0.9001	0.9641	0.1117	23.2667	2.4749	0.2432	0.1608	151
58-59	58.4279	9.3162	2893.875	0.6718	0.9118	0.9759	0.1055	23.4498	2.495	0.2433	0.1585	117
59-60	59.4864	9.3939	2466.35	0.6721	0.9535	0.9863	0.0956	23.6984	2.5136	0.2426	0.1562	66
60-61	60.4015	10.2203	2481.54	0.6705	0.9586	0.9769	0.0969	23.8968	2.5319	0.2423	0.1539	59
61-62	61.42	12.5769	3618.2	0.654	1.0079	0.9887	0.0992	23.8253	2.5822	0.2351	0.1532	26
62-63	62.4	9.8889	4567.882	0.6934	1.0073	1.0291	0.0794	24.8667	2.514	0.2462	0.1512	18
63-64	63.42	8.1	6057.5	0.6635	1.0592	1.0287	0.0815	24.9126	2.55	0.2452	0.1481	10

Regression output

COUNT		P2		LSTR	
Constant	9.47058	Constant	–0.99369	Constant	8.826348
SE of Y estimate	1.515638	SE of Y estimate	0.031452	SE of Y estimate	0.16015
R^2	0.00685	R^2	0.975455	R^2	0.988982
No. of observations	20	No. of observations	20	No. of observations	20
Degrees of freedom	18	Degrees of freedom	18	Degrees of freedom	18
X coefficient(s)	0.020814	X coefficient(s)	0.032787	X coefficient(s)	0.2509
SE of coefficient	0.059073	SE of coefficient	0.001226	SE of coefficient	0.006242
EPS		**P3**		**FREQ**	
Constant	–3153.97	Constant	0.52707	Constant	1.447426
SE of Y estimate	1081.606	SE of Y estimate	0.012209	SE of Y estimate	0.018511
R^2	0.269408	R^2	0.937183	R^2	0.971395
No. of observations	20	No. of observations	20	No. of observations	20
Degrees of freedom	18	Degrees of freedom	18	Degrees of freedom	18
X coefficient(s)	108.6101	X coefficient(s)	0.007798	X coefficient(s)	0.017838
SE of coefficient	42.15662	SE of coefficient	0.000476	SE of coefficient	0.000721
P1		**PCTXLAP**		**INSP**	
Constant	0.77872	Constant	0.584474	Constant	0.283138
SE of Y estimate	0.010226	SE of Y estimate	0.015553	SE of Y estimate	0.002909
R^2	0.528267	R^2	0.910863	R^2	0.653088
No. of observations	20	No. of observations	20	No. of observations	20
Degrees of freedom	18	Degrees of freedom	18	Degrees of freedom	18
X coefficient(s)	–0.00179	X coefficient(s)	–0.00822	X coefficient(s)	–0.00066
SE of coefficient	0.000399	SE of coefficient	0.000606	SE of coefficient	0.000113
EXP					
Constant	0.298127				
SE of Y estimate	0.002633				
R^2	0.968145				
No. of observations	20				
Degrees of freedom	18				
X coefficient(s)	–0.0024				
SE of coefficient	0.000103				

Table 13 Means and regression equations for two-year-old fillies (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	TSTRIDE	TSTANCE	TSWG	TAIR	TGND	GNDAIR	AVGSTN	FREQ	INSP	EXP	n
44-45	44.4669	0.4431	0.1062	0.3369	0.1361	0.3067	2.3002	4.7234	2.2607	0.2501	0.1928	71
45-46	45.5216	0.4395	0.1024	0.337	0.1311	0.3078	2.3895	4.6628	2.2795	0.2502	0.1889	88
46-47	46.4826	0.4307	0.0996	0.3311	0.1317	0.2988	2.3126	4.6313	2.3252	0.2469	0.184	102
47-48	47.4629	0.4285	0.0963	0.33205	0.1291	0.299	2.3691	4.5718	2.3371	0.2496	0.179	94
48-49	48.5313	0.4238	0.095	0.3288	0.1262	0.2981	2.4298	4.6171	2.364	0.2457	0.1775	76
49-50	49.484	0.4257	0.0938	0.3319	0.1259	0.2983	2.4229	4.6489	2.3525	0.2486	0.177	77
50-51	50.473	0.4198	0.0936	0.3262	0.1214	0.2977	2.5162	4.7292	2.3872	0.2445	0.1754	105
51-52	51.5922	0.4129	0.0886	0.3243	0.1203	0.2908	2.489	4.5775	2.4248	0.2445	0.1683	125
52-53	52.5296	0.4133	0.0873	0.326	0.1221	0.2897	2.4198	4.585	2.4231	0.2466	0.1666	162
53-54	53.4869	0.408	0.0862	0.3218	0.1178	0.289	2.5274	4.6135	2.4541	0.2445	0.1636	177
54-55	54.4739	0.4035	0.0846	0.319	0.1153	0.2859	2.5464	4.6136	2.4813	0.2401	0.163	157
55-56	55.4239	0.403	0.0842	0.3189	0.1141	0.2877	2.5693	4.6697	2.4832	0.242	0.1608	184
56-57	56.5727	0.4015	0.0826	0.3189	0.1133	0.2861	2.5774	4.6742	2.4937	0.2428	0.1586	207
57-58	57.4236	0.3955	0.0824	0.3133	0.1097	0.2828	2.6365	4.7373	2.5311	0.2384	0.1567	122
58-59	58.4149	0.3945	0.0812	0.3132	0.1082	0.2836	2.6809	4.7507	2.5387	0.2376	0.1567	77
59-60	59.3866	0.3923	0.08	0.3124	0.104	0.2818	2.8325	4.7628	2.5536	0.2388	0.1538	59
60-61	60.4193	0.3894	0.0791	0.31015	0.1048	0.2781	2.7102	4.7845	2.573	0.2374	0.152	58
61-62	61.5406	0.3871	0.0778	0.3092	0.1046	0.27435	2.692	4.8051	2.5855	0.2384	0.1492	16
62-63	62.3757	0.3816	0.0776	0.304	0.098	0.2769	2.8606	4.8458	2.6235	0.2353	0.1475	14

Regression output

TSTRIDE		TAIR		AVGSTN	
Constant	0.582725	Constant	0.220411	Constant	4.166107
SE of Y estimate	0.002338	SE of Y estimate	0.001515	SE of Y estimate	0.063172
R^2	0.984452	R^2	0.981671	R^2	0.438994
No. of observations	19	No. of observations	19	No. of observations	19
Degrees of freedom	17	Degrees of freedom	17	Degrees of freedom	17
X coefficient(s)	–0.00323	X coefficient(s)	–0.00192	X coefficient(s)	0.009692
SE of coefficient	9.83E–05	SE of coefficient	6.37E–05	SE of coefficient	0.002657
TSTANCE		**TGND**		**FREQ**	
Constant	0.168944	Constant	0.380997	Constant	1.425534
SE of Y estimate	0.001915	SE of Y estimate	0.002092	SE of Y estimate	0.011279
R^2	0.953681	R^2	0.956352	R^2	0.989597
No. of observations	19	No. of observations	19	No. of observations	19
Degrees of freedom	17	Degrees of freedom	17	Degrees of freedom	17
X coefficient(s)	–0.00151	X coefficient(s)	–0.0017	X coefficient(s)	0.01908
SE of coefficient	8.06E–05	SE of coefficient	8.8E–05	SE of coefficient	0.000474
TSWG		**GNDAIR**		**INSP**	
Constant	0.413678	Constant	1.072953	Constant	0.286251
SE of Y estimate	0.001698	SE of Y estimate	0.054553	SE of Y estimate	0.001574
R^2	0.971412	R^2	0.893838	R^2	0.896548
No. of observations	19	No. of observations	19	No. of observations	19
Degrees of freedom	17	Degrees of freedom	17	Degrees of freedom	17
X coefficient(s)	–0.00172	X coefficient(s)	0.027455	X coefficient(s)	–0.0008
SE of coefficient	7.14E–05	SE of coefficient	0.002295	SE of coefficient	6.62E–05
EXP					
Constant	0.294646				
SE of Y estimate	0.002196				
R^2	0.97519				
No. of observations	19				
Degrees of freedom	17				
X coefficient(s)	–0.00239				
SE of coefficient	9.24E–05				

Table 14 Means and regression equations for two-year-old fillies (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	COUNT	EPS	P1	P2	P3	PCTXLAP	LSTR	FREQ	INSP	EXP	n
44-45	44.4669	10.2254	1236.738	0.6884	0.3719	0.8442	0.2669	19.7034	2.2607	0.2501	0.1928	71
45-46	45.5216	7.5455	1239	0.6889	0.4686	0.8705	0.2318	20.0049	2.2795	0.2502	0.1889	88
46-47	46.4826	8.5	1961.94	0.6888	0.4533	0.874	0.2319	20.0219	2.3252	0.2469	0.184	102
47-48	47.4629	8.8617	2447.487	0.6896	0.5363	0.8959	0.201	20.34	2.3371	0.2496	0.179	94
48-49	48.5313	9.2632	2803.639	0.6948	0.5598	0.9001	0.1944	20.5673	2.364	0.2457	0.1775	76
49-50	49.484	8.5195	1400.444	0.6956	0.5829	0.9176	0.1826	21.0669	2.3525	0.2486	0.177	77
50-51	50.473	9.1048	1803.477	0.6874	0.6106	0.9085	0.184	21.1874	2.3872	0.2445	0.1754	105
51-52	51.5922	10.416	2128.868	0.6899	0.6826	0.9539	0.1542	21.3062	2.4248	0.2445	0.1683	125
52-53	52.5296	11.9259	1781.759	0.6838	0.714	0.9533	0.1442	21.7141	2.4231	0.2466	0.1666	162
53-54	53.4869	12.548	1958.018	0.6874	0.7422	0.9483	0.1377	21.828	2.4541	0.2445	0.1636	177
54-55	54.4739	13.1911	2267.51	0.673	0.7778	0.9758	0.1302	21.9827	2.4813	0.2401	0.163	157
55-56	55.4239	12.3913	3137.638	0.6746	0.8105	0.9643	0.1238	22.3436	2.4832	0.242	0.1608	184
56-57	56.5727	12.7923	2328.005	0.6794	0.8547	0.9724	0.1115	22.7198	2.4937	0.2428	0.1586	207
57-58	57.4236	12.2377	2470.533	0.6689	0.854	0.9622	0.1189	22.7144	2.5311	0.2384	0.1567	122
58-59	58.4149	11.7532	3017.794	0.6757	0.8865	0.9673	0.1079	23.0437	2.5387	0.2376	0.1567	77
59-60	59.3866	12.1695	2509.91	0.6749	0.9405	0.9831	0.0991	23.3004	2.5536	0.2388	0.1538	59
60-61	60.4193	9.5862	3172.6	0.6755	0.9598	0.9786	0.0994	23.5284	2.573	0.2374	0.152	58
61-62	61.5406	9.75	3832.13	0.6802	0.9803	0.9914	0.0964	23.823	2.5855	0.2384	0.1492	16
62-63	62.3757	9.7143	1701.5	0.6891	1.0159	0.9918	0.0946	23.8056	2.6235	0.2353	0.1475	14

Regression output

COUNT		P2		LSTR	
Constant	2.616951	Constant	−1.12395	Constant	9.054429
SE of Y estimate	1.573536	SE of Y estimate	0.020355	SE of Y estimate	0.097091
R^2	0.228166	R^2	0.989697	R^2	0.995065
No. of observations	19	No. of observations	19	No. of observations	19
Degrees of freedom	17	Degrees of freedom	17	Degrees of freedom	17
X coefficient(s)	0.14839	X coefficient(s)	0.034602	X coefficient(s)	0.239127
SE of coefficient	0.066194	SE of coefficient	0.000856	SE of coefficient	0.004084
EPS		**P3**		**FREQ**	
Constant	−1807.98	Constant	0.533717	Constant	1.425534
SE of Y estimate	572.4177	SE of Y estimate	0.015539	SE of Y estimate	0.011279
R^2	0.371458	R^2	0.888049	R^2	0.989597
No. of observations	19	No. of observations	19	No. of observations	19
Degrees of freedom	17	Degrees of freedom	17	Degrees of freedom	17
X coefficient(s)	76.32466	X coefficient(s)	0.007591	X coefficient(s)	0.01908
SE of coefficient	24.07981	SE of coefficient	0.000654	SE of coefficient	0.000474
P1		**PCTXLAP**		**INSP**	
Constant	0.731623	Constant	0.639211	Constant	0.286251
SE of Y estimate	0.00626	SE of Y estimate	0.014515	SE of Y estimate	0.001574
R^2	0.407477	R^2	0.928735	R^2	0.896548
No. of observations	19	No. of observations	19	No. of observations	19
Degrees of freedom	17	Degrees of freedom	17	Degrees of freedom	17
X coefficient(s)	−0.0009	X coefficient(s)	−0.00909	X coefficient(s)	−0.0008
SE of coefficient	0.000263	SE of coefficient	0.000611	SE of coefficient	6.62E−05
EXP					
Constant	0.294646				
SE of Y estimate	0.002196				
R^2	0.97519				
No. of observations	19				
Degrees of freedom	17				
X coefficient(s)	−0.00239				
SE of coefficient	9.24E−05				

Table 15 Regression equations summary for two-year-old colts and fillies (regression results describing extension variables with velocity as the independent variable for unraced two-year-olds filmed at spring auctions)

Dependent variable	Constant	Velocity coefficent	SE	R^2
Two-year-old colts (18 degrees of freedom) n = 2699				
P1	0.77872	–0.00179	± 0.010226	.53
P2	–0.99369	+0.032787	± 0.031452	.98
P3	0.52707	+0.007798	± 0.012209	.94
PCTXLAP	0.58447	–0.008822	± 0.015553	.91
LSTRIDE	8.82635	+0.2509	± 0.16015	.99
FREQ	1.44743	+0.017838	± 0.018511	.97
INSPPSTR	0.28314	–0.00066	± 0.002909	.65
INSPPSEC	0.44400	+0.002819	± 0.004843	.93
EXP	0.29813	–0.0024	± 0.002633	.97
TSTRIDE	0.58346	–0.0031	± 0.003391	.97
TSTANCE	0.16850	–0.00148	± 0.001965	.95
TSWG	0.41512	–0.00162	± 0.003155	.91
TAIR	0.20359	–0.0016	± 0.003071	.91
TGND	0.40382	–0.002	± 0.001885	.98
GNDAIR	1.60068	+0.018138	± 0.075947	.68
Two-year-old fillies (17 degrees of freedom) n = 1982				
P1	0.73162	–0.0009	± 0.00626	.41
P2	–1.12395	+0.034602	± 0.20355	.99
P3	0.53372	+0.007591	± 0.015539	.89
PCTXLAP	0.63921	–0.00909	± 0.014515	.93
LSTRIDE	9.05443	+0.239127	± 0.097091	.995
FREQ	1.42553	+0.01908	± 0.011279	.99
INSPPSTR	0.28625	–0.0008	± 0.001574	.90
INSPPSEC	0.45140	+0.002676	± 0.003277	.96
EXP	0.29465	–0.00239	± 0.002196	.98
TSTRIDE	0.58272	–0.00323	± 0.002338	.98
TSTANCE	0.16894	–0.00151	± 0.001915	.95
TSWG	0.41368	–0.00172	± 0.001698	.97
TAIR	0.22041	–0.00192	± 0.001515	.98
TGND	0.38100	–0.0017	± 0.002092	.96
GNDAIR	1.07295	+0.027455	± 0.054553	.89

Regression Equations Showed Velocity Dependence of Gait Parameters

Regression equations were created relating individual gait parameters to each of the 22 0.305 m/sec (1 ft/sec) velocity intervals for each of the four main age and sex categories of horses.[f] Tables 11 through 15 present gait data for two-year-old colts and fillies, whereas Tables 16 through 20 present gait data for race age colts and fillies (data for Tables 11 through 14 and Tables 16 through 19 were summarized from Data Supplement). This data was averaged within each of the 0.305 m/s (1 ft/sec) velocity intervals for each of the four main age and sex categories. The means of the gait parameters within each velocity interval were regressed against the mean velocity of each velocity intervals.[g] Results for each gait parameter regressed with velocity as the independent variable are labeled and shown on the bottom half of Tables 11 through 14 and Tables 16 through 19, and summarized on Tables 15 and 20. The R^2 values (many exceeding 0.90) for each regression demonstrate these gait parameters' strong relationship to velocity.

Examining Complex Relationships Between Gait and Performance

Ability: High Earner versus Low Earner Thoroughbred Racehorses

Significant differences existed when age and sex groups were further classified into racing ability groups called "high earners"[h] and "low earners."[i] Tables 21 through 24 provide *t* test results comparing the gait parameters of high earners versus low earners.

Inspiration time within each stride (INSP) was a common differentiating variable when comparing high earners with low earners among two-year-old colts (Table 21), race-age colts (Table 23), and race-age fillies (Table 24). It was more difficult to identify one or two key ability differentiating gait parameters among two-year-old fillies (Table 22), except at slower velocities of 13.7 to 15.5 m/sec (45 to 51 ft/sec—14.7 to 12.9 sec/fur).

The same gait parameter, in Tables 21 through 24, did not produce significant, or even similar results at all velocities. Different gait parameters became significant at different velocities.

The racing speed gait of these Thoroughbreds produced individual gait parameters which, used alone, easily

f. Note that, instead, one could create regression models relating gait variables to velocity and sex, rather than subsets related to velocity alone.

g. Taking averages within groups is a standard way to perform regression analysis when there is a high degree of variation from one subject to the next, yet a strong underlying trend. For example, weight variation from one person to the next among people 10 to 25 years old would be high, yet weight generally increases with age during that period. Thus, the *averaqe weight* within each single year age category could be regressed against *year of age* to better measure age's relationship to weight.

h. High earners were horses with: earnings per racing start ≥$10,000 and number of racing starts ≥5 through three-year-old year; or total earnings ≥$50,000 through three-year-old-year (some charts in this study may call this group "elite").

i. Low earners were horses with earnings per racing start ≤$1000 through three-year-old year.

Table 16 Means and regression equations for race-age colts (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	TSTRIDE	TSTANCE	TSWG	TAIR	TGND	GNDAIR	AVGSTN	FREQ	INSP	EXP	n
44-45	44.61	0.4517	0.1052	0.3467	0.1348	0.3158	2.3762	4.6972	2.2181	0.2552	0.1945	5
45-46	45.5325	0.4587	0.1066	0.3518	0.1411	0.3162	2.4224	4.8645	2.186	0.25725	0.201	4
46-47	46.538	0.4401	0.1014	0.3387	0.1353	0.3067	2.3019	4.7176	2.2787	0.2521	0.1886	10
47-48	47.585	0.4534	0.0987	0.3546	0.1504	0.3014	2.0404	4.7019	2.2107	0.2577	0.1952	4
48-49	48.6147	0.4442	0.0998	0.3443	0.1374	0.3065	2.2422	4.849	2.2548	0.2523	0.1894	15
49-50	49.35	0.4394	0.0952	0.3446	0.1351	0.3025	2.2927	4.7083	2.2812	0.2583	0.1813	13
50-51	50.4812	0.4361	0.0949	0.3413	0.1316	0.3036	2.3623	4.7988	2.2976	0.2556	0.1817	25
51-52	51.537	0.4302	0.0922	0.3377	0.134	0.2953	2.2385	4.7529	2.3283	0.2549	0.1773	30
52-53	52.5187	0.4406	0.0952	0.3447	0.1358	0.3046	2.2939	5.0083	2.2727	0.2591	0.1809	38
53-54	53.4549	0.4288	0.0916	0.3372	0.1292	0.297	2.3385	4.8958	2.3343	0.2535	0.1749	59
54-55	54.4918	0.4275	0.0904	0.3372	0.1289	0.2966	2.3567	4.9314	2.3433	0.2537	0.1739	104
55-56	55.3773	0.4239	0.0885	0.3355	0.1299	0.2914	2.2924	4.9067	2.3617	0.2542	0.1695	56
56-57	56.424	0.4192	0.0842	0.335	0.1285	0.2863	2.2735	4.7576	2.3901	0.2559	0.1626	55
57-58	57.441	0.4217	0.085	0.3365	0.126	0.2927	2.3524	4.8872	2.3736	0.2571	0.1638	31
58-59	58.588	0.4152	0.0862	0.3291	0.1217	0.2928	2.4315	5.0547	2.4127	0.2501	0.1641	46
59-60	59.6756	0.4142	0.08	0.3341	0.1263	0.2816	2.24845	4.773	2.4165	0.2587	0.1551	18
60-61	60.3231	0.4096	0.0871	0.3226	0.1188	0.2884	2.464	5.2583	2.444	0.246	0.1643	29
61-62	61.4	0.4006	0.757	0.3248	0.1247	0.2687	2.16275	4.64735	2.5017	0.2551	0.1466	8
62-63	62.5096	0.3961	0.075	0.3216	0.1108	0.271	2.4801	4.6948	2.5287	0.2496	0.1473	25
63-64	63.4142	0.3935	0.0813	0.3122	0.1042	0.2845	2.7956	5.164	2.5429	0.2398	0.1536	19
64-65	64.5181	0.3902	0.0808	0.3089	0.1007	0.282	2.8649	5.3134	2.5831	0.2362	0.1509	26

Regression output

TSTRIDE		TAIR		AVGSTN	
Constant	0.597075	Constant	0.219053	Constant	4.023054
SE of Y estimate	0.004787	SE of Y estimate	0.00581	SE of Y estimate	0.167817
R^2	0.945553	R^2	0.769005	R^2	0.258519
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	–0.00315	X coefficient(s)	–0.00167	X coefficient(s)	0.01564
SE of coefficient	0.000173	SE of coefficient	0.00021	SE of coefficient	0.006077
TSTANCE		**TGND**		**FREQ**	
Constant	0.16688	Constant	0.39724	Constant	1.395141
SE of Y estimate	0.002881	SE of Y estimate	0.005514	SE of Y estimate	0.029761
R^2	0.905332	R^2	0.824179	R^2	0.934244
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	–0.00141	X coefficient(s)	–0.00188	X coefficient(s)	0.017706
SE of coefficient	0.000104	SE of coefficient	0.0002	SE of coefficient	0.001078
TSWG		**GNDAIR**		**INSP**	
Constant	0.430151	Constant	1.497964	Constant	0.284424
SE of Y estimate	0.005163	SE of Y estimate	0.161177	SE of Y estimate	0.004908
R^2	0.820529	R^2	0.28042	R^2	0.357032
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	–0.00174	X coefficient(s)	0.015881	X coefficient(s)	–0.00058
SE of coefficient	0.000187	SE of coefficient	0.005836	SE of coefficient	0.000178
EXP					
Constant	0.312142				
SE of Y estimate	0.004246				
R^2	0.936234				
No. of observations	21				
Degrees of freedom	19				
X coefficient(s)	–0.00257				
SE of coefficient	0.000154				

Table 17 Means and regression equations for race-age colts (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	COUNT	EPS	P1	P2	P3	PCTXLAP	LSTR	FREQ	INSP	EXP	n
44-45	44.61	18.8	27583	0.7646	0.3866	0.8904	0.233	20.1521	2.2181	0.2552	0.1945	5
45-46	45.5325	9	136118	0.73075	0.37925	0.86175	0.24315	20.88243	2.186	0.25725	0.201	4
46-47	46.538	13.1	10468	0.716	0.4443	0.8717	0.2262	20.4803	2.2787	0.2521	0.1886	10
47-48	47.585	23	25970	0.7369	0.3686	0.9779	0.2099	21.5749	2.2107	0.2577	0.1952	4
48-49	48.6147	19.2	10789	0.7241	0.4624	0.9131	0.2114	21.5976	2.2548	0.2523	0.1894	15
49-50	49.35	21.4615	33123	0.7081	0.5693	0.9434	0.1798	21.6836	2.2812	0.2583	0.1813	13
50-51	50.4812	13.08	9715	0.6973	0.5946	0.9463	0.1764	22.0181	2.2976	0.2556	0.1817	25
51-52	51.537	16.8	15694	0.7203	0.5705	0.9409	0.1701	22.1737	2.3283	0.2549	0.1773	30
52-53	52.5187	20.79	7067	0.7037	0.5907	0.9217	0.1819	23.1415	2.2727	0.2591	0.1809	38
53-54	53.4549	18.2	10143	0.7153	0.6426	0.9382	0.1618	22.9251	2.3343	0.2535	0.1749	59
54-55	54.4918	22.4	19555	0.7087	0.6665	0.9615	0.1537	23.2952	2.3433	0.2537	0.1739	104
55-56	55.3773	20.7	19088	0.7059	0.6968	0.95795	0.1487	23.4768	2.3617	0.2542	0.1695	56
56-57	56.424	15.5	20019	0.7235	0.7851	0.9879	0.1205	23.6531	2.3901	0.2559	0.1626	55
57-58	57.441	16.7	23955	0.7247	0.7943	0.9823	0.113	24.2264	2.3736	0.2571	0.1638	31
58-59	58.588	22.5	20663	0.6912	0.7876	0.9417	0.1293	24.3272	2.4127	0.2501	0.1641	46
59-60	59.6756	18.1	41002	0.7223	0.9026	1.0197	0.0932	24.723	2.4165	0.2587	0.1551	18
60-61	60.3231	27.2	18883	0.6702	0.7842	0.9093	0.1454	24.7081	2.444	0.246	0.1643	29
61-62	61.4	27.9	24288	0.694	0.9905	0.9799	0.086	24.6032	2.5017	0.2551	0.1466	8
62-63	62.5096	20.8	24386	0.7019	1.1116	1.0444	0.0664	24.7609	2.5287	0.2496	0.1473	25
63-64	63.4142	26.3	17225	0.6575	1.0007	0.9318	0.109	24.9571	2.5429	0.2398	0.1536	19
64-65	64.5181	21.8	6406	0.6227	0.9643	0.9215	0.1182	25.019	2.5831	0.2362	0.1509	26

Regression output

COUNT		P2		LSTR	
Constant	−4.54793	Constant	−1.19782	Constant	9.438741
SE of Y estimate	3.946935	SE of Y estimate	0.057433	SE of Y estimate	0.327424
R^2	0.337493	R^2	0.935924	R^2	0.959037
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	0.444639	X coefficient(s)	0.034645	X coefficient(s)	0.250061
SE of coefficient	0.14292	SE of coefficient	0.00208	SE of coefficient	0.011856
EPS		**P3**		**FREQ**	
Constant	95237.73	Constant	0.734033	Constant	1.395141
SE of Y estimate	26391.86	SE of Y estimate	0.039024	SE of Y estimate	0.029761
R^2	0.087681	R^2	0.283013	R^2	0.934244
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	−1291.39	X coefficient(s)	0.00387	X coefficient(s)	0.017706
SE of coefficient	955.661	SE of coefficient	0.001413	SE of coefficient	0.001078
P1		**PCTXLAP**		**INSP**	
Constant	0.899799	Constant	0.570464	Constant	0.284424
SE of Y estimate	0.020644	SE of Y estimate	0.018792	SE of Y estimate	0.004908
R^2	0.541975	R^2	0.867963	R^2	0.357032
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	−0.00354	X coefficient(s)	−0.0076	X coefficient(s)	−0.00058
SE of coefficient	0.000748	SE of coefficient	0.00068	SE of coefficient	0.000178
EXP					
Constant	0.312142				
SE of Y estimate	0.004246				
R^2	0.936234				
No. of observations	21				
Degrees of freedom	19				
X coefficient(s)	−0.00257				
SE of coefficient	0.000154				

Table 18 Means and regression equations for race-age fillies (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	TSTRIDE	TSTANCE	TSWG	TAIR	TGND	GNDAIR	AVGSTN	FREQ	INSP	EXP	n
44-45	44.645	0.4557	0.10115	0.3541	0.1582	0.29645	1.87765	4.5067	2.2011	0.2648	0.1907	2
45-46	45.5367	0.4559	0.1057	0.3503	0.1535	0.3059	2.0724	4.8257	2.1979	0.2569	0.198	3
46-47	46.402	0.4345	0.0958	0.3387	0.1428	0.2906	2.0614	4.4488	2.3031	0.2546	0.1789	5
47-48	47.545	0.4376	0.0982	0.3395	0.13225	0.30175	2.4211	4.6846	2.2899	0.256	0.1841	2
48-49	48.485	0.4334	0.0983	0.33525	0.1368	0.2963	2.2435	4.7723	2.3096	0.2483	0.1828	6
49-50	49.448	0.4374	0.09985	0.3376	0.1399	0.297	2.1504	4.9424	2.2903	0.2504	0.1841	10
50-51	50.4655	0.4408	0.0966	0.3444	0.1399	0.3	2.1676	4.88	2.2717	0.2564	0.1839	11
51-52	51.4479	0.4277	0.0908	0.3366	0.1355	0.2904	2.1611	4.6756	2.3411	0.2531	0.1753	34
52-53	52.4665	0.4194	0.09165	0.3278	0.1306	0.2877	2.2694	4.8162	2.3917	0.2443	0.1748	26
53-54	53.5535	0.4216	0.0899	0.3318	0.1308	0.2888	2.2497	4.8257	2.37615	0.2507	0.1718	26
54-55	54.468	0.4274	0.0889	0.3386	0.1339	0.2903	2.2225	4.8435	2.3425	0.258	0.1688	41
55-56	55.3783	0.4203	0.0863	0.3339	0.1313	0.285	2.2172	4.783	2.3843	0.255	0.1652	54
56-57	56.5597	0.4165	0.0826	0.3338	0.1292	0.2825	2.226	4.6657	2.4072	0.2585	0.1588	31
57-58	57.4754	0.4146	0.0868	0.3277	0.1228	0.289	2.4075	4.9857	2.4188	0.25115	0.1645	41
58-59	58.4812	0.4192	0.0869	0.332	0.1265	0.2891	2.3329	5.073	2.38935	0.2575	0.1628	26
59-60	59.37	0.4032	0.0862	0.3166	0.1155	0.2859	2.6497	5.1077	2.4944	0.2408	0.1627	8
60-61	60.27	0.4003	0.0769	0.3238	0.1275	0.266	2.1373	4.659	2.4982	0.2523	0.1483	8
61-62	61.4465	0.3983	0.0782	0.3201	0.1205	0.2723	2.3313	4.8042	2.51345	0.25	0.1495	20
62-63	62.42	0.3948	0.0786	0.316	0.1145	0.2729	2.4405	4.9011	2.535	0.2453	0.1508	20
63-64	63.5262	0.3945	0.0802	0.3142	0.1122	0.2783	2.5502	5.107	2.5384	0.243	0.1527	21
64-65	65.8792	0.3902	0.0808	0.3089	0.1007	0.282	2.3649	5.3134	2.5646	0.2399	0.1508	12

Regression output

TSTRIDE		TAIR		AVGSTN	
Constant	0.581615	Constant	0.237704	Constant	3.655434
SE of Y estimate	0.005538	SE of Y estimate	0.005209	SE of Y estimate	0.15789
R^2	0.921733	R^2	0.856508	R^2	0.440732
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	–0.00294	X coefficient(s)	–0.00197	X coefficient(s)	0.021704
SE of coefficient	0.000197	SE of coefficient	0.000185	SE of coefficient	0.005609

TSTANCE		TGND		FREQ	
Constant	0.157409	Constant	0.362446	Constant	1.47581
SE of Y estimate	0.003064	SE of Y estimate	0.006232	SE of Y estimate	0.030346
R^2	0.873077	R^2	0.665161	R^2	0.926209
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	–0.00124	X coefficient(s)	–0.00136	X coefficient(s)	0.016648
SE of coefficient	0.000109	SE of coefficient	0.000221	SE of coefficient	0.001078

TSWG		GNDAIR		INSP	
Constant	0.424691	Constant	0.879146	Constant	0.285907
SE of Y estimate	0.004931	SE of Y estimate	0.148309	SE of Y estimate	0.005214
R^2	0.833564	R^2	0.558664	R^2	0.375514
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	–0.00171	X coefficient(s)	0.025839	X coefficient(s)	–0.00063
SE of coefficient	0.000175	SE of coefficient	0.005269	SE of coefficient	0.000185

EXP	
Constant	0.290543
SE of Y estimate	0.004613
R^2	0.90614
No. of observations	21
Degrees of freedom	19
X coefficient(s)	–0.00222
SE of coefficient	0.000164

Table 19 Means and regression equations for race-age fillies (averaged data by velocity group and regression analysis of this table of data)

VELGRP	VEL	COUNT	EPS	P1	P2	P3	PCTXLAP	LSTR	FREQ	INSP	EXP	n
44-45	44.645	5	413	0.76	0.3313	0.8723	0.24225	20.3348	2.2011	0.2648	0.1907	2
45-46	45.5367	3	18808	0.6943	0.3117	0.8703	0.2615	20.7585	2.1979	0.2569	0.198	3
46-47	46.402	8.4	17325	0.7442	0.4078	0.9198	0.2106	20.1648	2.3031	0.2546	0.1789	5
47-48	47.545	11.5	3332	0.742	0.4995	0.889	0.203	20.80945	2.2899	0.256	0.1841	2
48-49	48.485	9.1667	19382	0.697	0.448	0.8898	0.2232	21.0183	2.3096	0.2483	0.1828	6
49-50	49.448	14.4	7961	0.685	0.4394	0.8826	0.2363	21.6258	2.2903	0.2504	0.1841	10
50-51	50.4665	12.6364	2759	0.6927	0.4875	0.9275	0.1963	22.2464	2.2717	0.2564	0.1839	11
51-52	51.4479	18.59	8787	0.7167	0.5538	0.9593	0.1724	22.0029	2.3411	0.2531	0.1753	34
52-53	52.4665	16.154	5289	0.6972	0.549	0.929	0.1909	22.0032	2.3917	0.2443	0.1748	26
53-54	53.5535	10.81	2855	0.725	0.5963	0.9335	0.1691	22.578	2.37615	0.2507	0.1718	26
54-55	54.468	18.02	8474	0.7132	0.6667	0.9648	0.1539	23.2819	2.3425	0.258	0.1688	41
55-56	55.3783	17.1111	384129	0.7008	0.718	0.9675	0.1439	23.2774	2.3843	0.255	0.1652	54
56-57	56.5597	15.7	16227	0.7253	0.8275	0.9878	0.1138	23.5561	2.4072	0.2585	0.1588	31
57-58	57.5754	22.3	12134	0.6655	0.78	0.9309	0.1395	23.8268	2.4188	0.25115	0.1645	41
58-59	58.4812	16.4	17341	0.686	0.7902	0.9405	0.1359	23.5139	2.38935	0.2575	0.1628	26
59-60	59.37	11.5	24034	0.7017	0.7321	0.935	0.1521	23.9408	2.4944	0.2408	0.1627	8
60-61	60.27	11.75	18462	0.7091	0.8642	1.0101	0.1114	24.1309	2.4982	0.2523	0.1483	8
61-62	61.4465	14.1	10422	0.6853	0.9243	0.9817	0.0993	24.4762	2.51345	0.25	0.1495	20
62-63	62.42	23	9836	0.6785	0.9473	0.989	0.1048	24.6434	2.535	0.2453	0.1508	20
63-64	63.5262	16.4	9229	0.642	0.9516	0.9578	0.11	24.0588	2.5384	0.243	0.1527	21
64-65	65.8792	18.8	16315	0.6668	1.0337	0.9358	0.1043	25.7075	2.5646	0.2399	0.1508	12

Regression output

	COUNT		P2		LSTR
Constant	–15.6044	Constant	–1.19915	Constant	8.699294
SE of Y estimate	3.915598	SE of Y estimate	0.4335	SE of Y estimate	0.30278
R^2	0.445501	R^2	0.962673	R^2	0.968403
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	0.543479	X coefficient(s)	0.03409	X coefficient(s)	0.259564
SE of coefficient	0.139102	SE of coefficient	0.00154	SE of coefficient	0.010756

	EPS		P3		FREQ
Constant	–8755.23	Constant	0.684209	Constant	1.47581
SE of Y estimate	83581.23	SE of Y estimate	0.02802	SE of Y estimate	0.030346
R^2	0.002885	R^2	0.53251	R^2	0.926209
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	696.2328	X coefficient(s)	0.004631	X coefficient(s)	0.016648
SE of coefficient	2969.225	SE of coefficient	0.000995	SE of coefficient	0.001078

	P1		PCTXLAP		INSP
Constant	0.863494	Constant	0.577284	Constant	0.285907
SE of Y estimate	0.021689	SE of Y estimate	0.018039	SE of Y estimate	0.005214
R^2	0.439352	R^2	0.87964	R^2	0.375514
No. of observations	21	No. of observations	21	No. of observations	21
Degrees of freedom	19	Degrees of freedom	19	Degrees of freedom	19
X coefficient(s)	–0.00297	X coefficient(s)	–0.00755	X coefficient(s)	–0.00063
SE of coefficient	0.000771	SE of coefficient	0.000641	SE of coefficient	0.000185

	EXP
Constant	0.290543
SE of Y estimate	0.004613
R^2	0.90614
No. of observations	21
Degrees of freedom	19
X coefficient(s)	–0.00222
SE of coefficient	0.000164

Table 20 Regression equations summary for race-age colts and fillies (regression results describing extension variables with velocity as the independent variable for horses of racing age

Dependent variable	Constant	Velocity coefficent	SE	R^2
Race-age colts (19 degrees of freedom) n = 614				
P1	0.89980	−0.00354	± 0.020644	.54
P2	−1.19782	+0.034645	± 0.057433	.94
P3	0.73403	+0.00387	± 0.039024	.28
PCTXLAP	0.57046	−0.0076	± 0.018792	.87
LSTRIDE	9.43874	+0.250061	± 0.327424	.96
FREQ	1.39514	+0.017706	± 0.029761	.93
INSPPSTR	0.28442	−0.00058	± 0.004908	.36
INSPPSEC	0.42997	+0.003057	± 0.009705	.80
EXP	0.29465	−0.00257	± 0.004264	.94
TSTRIDE	0.59708	−0.00315	± 0.004787	.95
TSTANCE	0.16688	−0.00141	± 0.002881	.91
TSWG	0.43015	−0.00174	± 0.005163	.82
TAIR	0.21905	−0.00167	± 0.005810	.77
TGND	0.39724	−0.00188	± 0.005514	.82
GNDAIR	1.49796	+0.015881	± 0.161177	.28
Race-age fillies (19 degrees of freedom) n = 429				
P1	0.86349	−0.00297	± 0.021689	.44
P2	−1.19915	+0.03409	± 0.04445	.96
P3	0.68421	+0.00463	± 0.02802	.53
PCTXLAP	0.57728	−0.00855	± 0.018039	.88
LSTRIDE	8.699294	+0.25956	± 0.30278	.97
FREQ	1.47581	+0.01665	± 0.030346	.93
INSPPSTR	0.285907	−0.00063	± 0.005214	.38
INSPPSEC	0.453419	+0.00268	± 0.009836	.76
EXP	0.290543	−0.00222	± 0.004613	.91
TSTRIDE	0.581615	−0.00294	± 0.005538	.92
TSTANCE	0.157409	−0.00124	± 0.003064	.87
TSWG	0.424691	−0.00171	± 0.004931	.83
TAIR	0.237704	−0.00197	± 0.005209	.86
TGND	0.362446	−0.00136	± 0.006232	.67
GNDAIR	0.879146	+0.02584	± 0.148309	.56

Fig 1 2YO COLTS VS. 2YO FILLIES AT SALES*

LENGTH OF STRIDE VS. VELOCITY

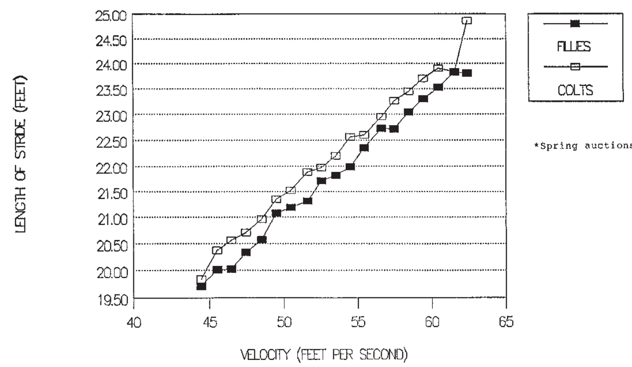


Fig 2 2YO COLTS VS. 2YO FILLIES AT SALES*

FREQUENCY OF STRIDE VS. VELOCITY

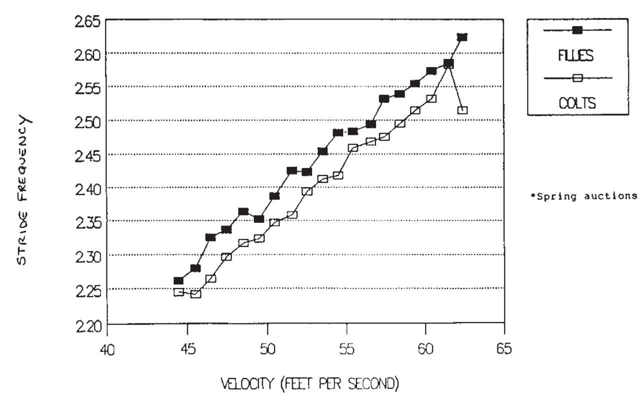
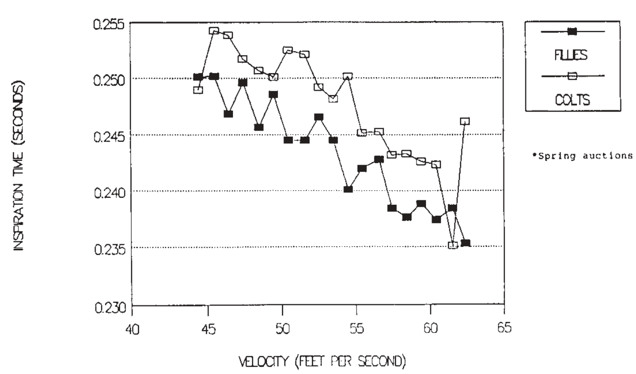


Fig 3 2YO COLTS VS. 2YO FILLIES AT SALES*

INSPIRATION TIME VS. VELOCITY



differentiated between age, sex and velocity groups in many instances. However, univariate statistical techniques, such as the *t* tests used in Tables 21 through 24, lacked the sophistication needed to identify and quantify complex differences, ie, ability levels, among these Thoroughbreds.

Multivariate Discriminant Analysis

How were gait parameters and their relationships to velocity, age, and sex, as demonstrated in this paper, used to draw predictive conclusions about subsequent racing performance?

Test sets of data that included all horses filmed at specific horse auctions, or that were randomly chosen, were formed. From these data sets, multivariate discriminant analysis successfully differentiated between two or more well defined groups in many instances when more than two or three descriptive gait parameters were involved and univariate tests, such as *t* tests, couldn't discriminate between the groups.

Discriminant analysis produced up to a ten-fold in-

Fig 4

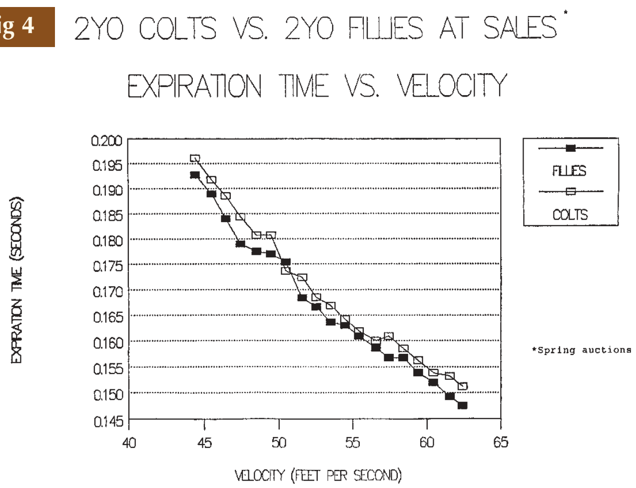


Fig 6

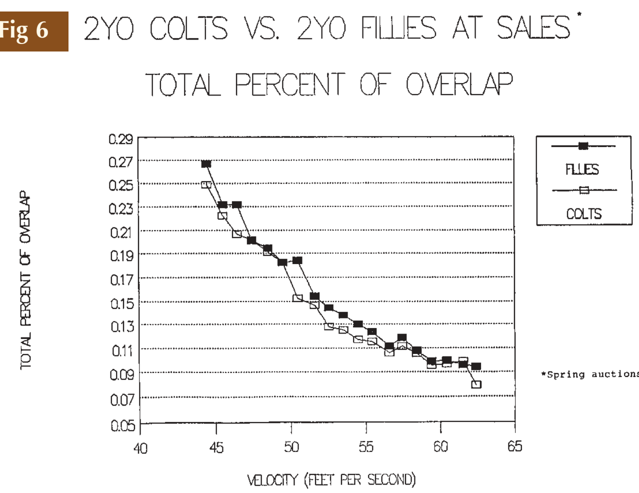


Fig 5

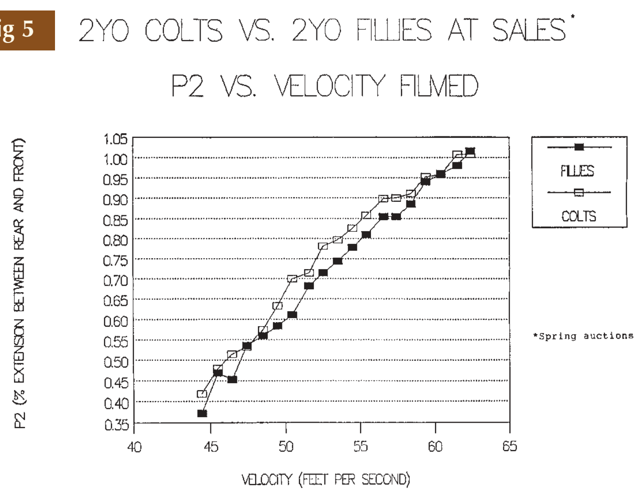
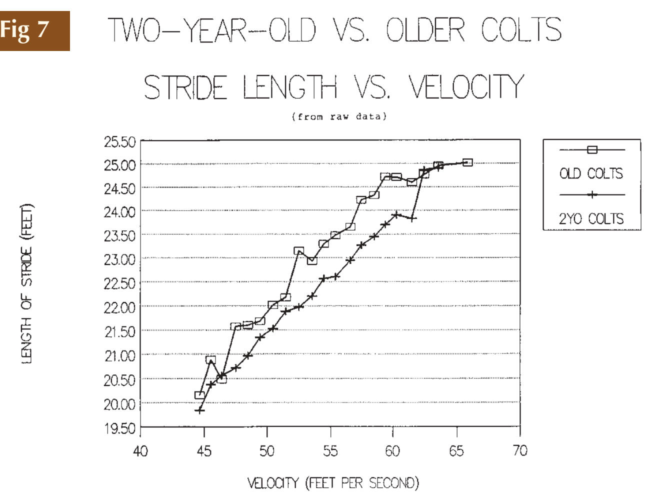


Fig 7



crease in the chances of selecting a horse that subsequently became a high earner from a group of unraced two-year-olds versus the random chance, when using up to 12 gait parameters at once (Tables 25 through 27).

Typical discriminant results, however, only increased the chances from 2 to 3 times.[j] Tables 25 through 27 show discriminant results typical of age, sex and ability groupings. Effective discriminant analysis results could only be obtained using data from groups specified by age, sex and controlled tightly by filmed velocity or by regression to a uniform velocity.

The original sample ratio of high earners to low earners must be known to make use of the fact that discriminant analysis increased the chances of correctly identifying a high earner horse "from 2 to 3 times." "Odds Beaten" may be a more acceptable way to present such information (see Appendix C).

j. Another way to say this is that multivariate discriminant models, based on racing speed temporal gait parameters alone, did as well as beating random odds of 532 to 1 when differentiating between some subsets of the data base (subsets were not used in the formation of the discriminant models, ie, these were "blind" models. See Appendix C).

DISCUSSION AND CONCLUSIONS

Trying to Simplify

As complex as all this may seem, there appear to be some simple methods for normalizing data between horses of different sexes, ages, abilities, and velocities.

The first such "rule" the authors suggest is the "EQB gait normalization rule." That is, if other major variables are held constant, eg, age, sex, and size, then compare gaits between horses only at similar velocities.

The second example of such a "rule" offered by the authors is what they have named the "EQB velocity shift principle," in which the regressed graph line is simply shifted to the right or left to see the average effect of sex on a gait parameter at a given velocity. This velocity shift principle is illustrated in Figure 1, which plots the stride length of two-year-old auction fillies and colts against velocity (see also

Fig 8

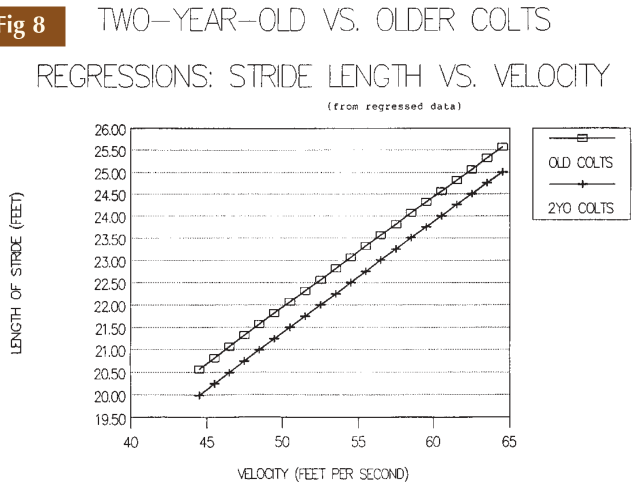


Fig 10

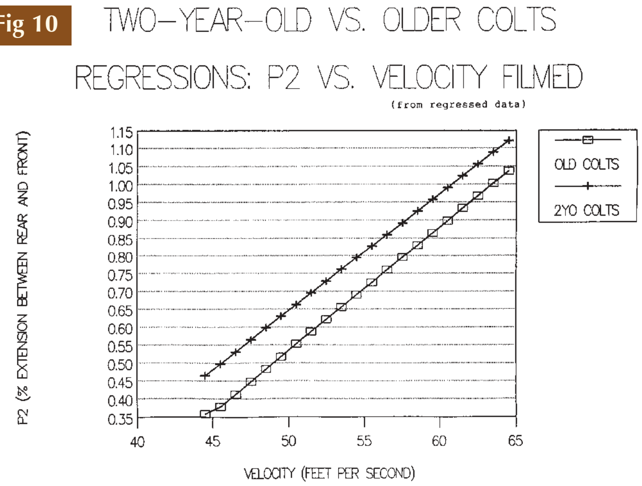
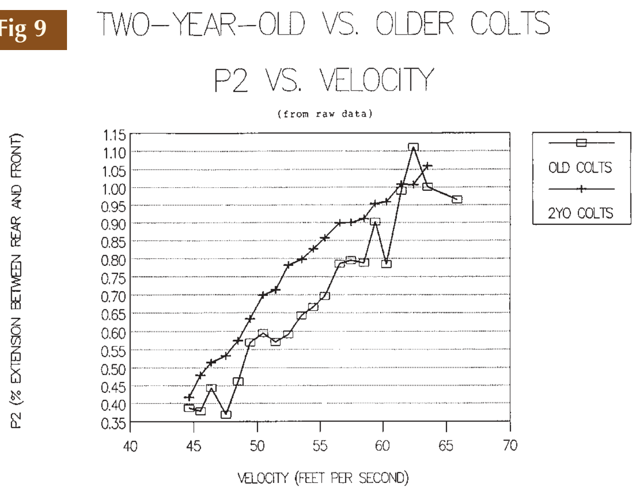


Fig 9



Figs 2 through 6). The same simple velocity shift will also work for *age* differences, eg, result in an overlay of gait parameters for two-year-olds versus three-year-olds, and will work for other key gait parameters, eg, stride frequency (see Figs 1 through 10). It also works for group differences in ability, eg, high earners versus low earners.

It is interesting to note that, for example, this means a "velocity shift" increase of two feet per second may normalize a small two-year-old filly to any one of the following: (1) a three-year-old filly of equal talent (age difference); (2) a two-year-old colt (sex difference); (3) a more talented two-year-old filly (ability difference); or (4) a large two-year-old filly (size dffference).

This means, for example, that when more than one of the variables of age, sex, ability, or size are different, of course the "velocity shift principle" is no longer so simply applied.

The "velocity shift" effect of each of those variables can be estimated independently, and perhaps the average velocity effect of all those variables together could also be calculated, although the authors have not calculated such tables and equations for this paper.

Note, the above also indicates some "velocity shift effects" caused by differences between two horses that may cancel each other out.

Furthermore, although the methods used in this study were time consuming, data intensive, and complex, many of the results can also be expressed as simply as the "EQB velocity shift principle" and can be represented usefully by two-dimensional linear relationships. Figures 1 through 6 show some of these simple relationships between gait variables and velocity. The relationships shown in Figures 1 through 6 are also shown as regression equations in Table 15, which lists many high R^2 values produced using velocity as the independent variable and individual gait variables as the dependent variables.

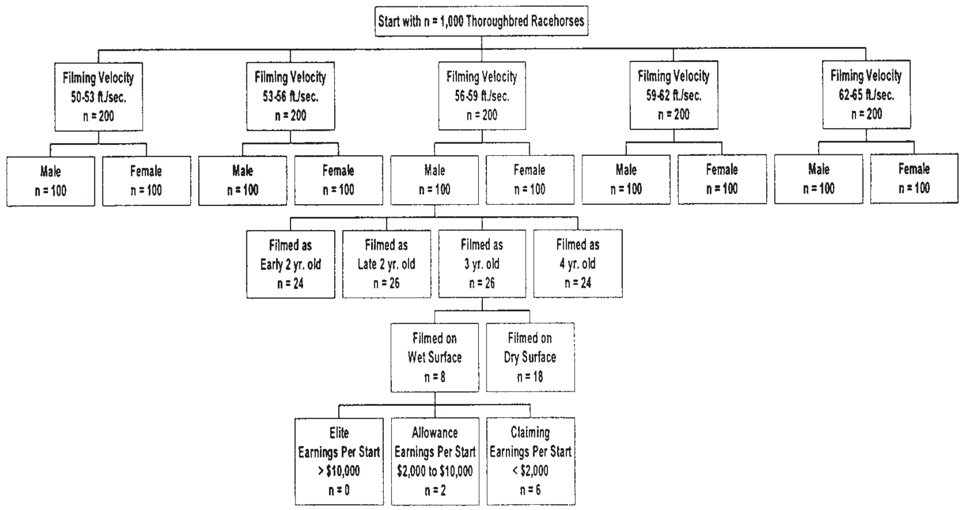
Why Was So Much Data Required for this Study?

The authors believe the sheer quantity of data assembled here for analysis was required because it is especially important not to group together horses of different ages, sexes, and abilities, and especially not to do so across even relatively small velocity differences, if one wishes to understand the complicated relationships between gait parameters and subsequent racing performance. A seemingly large data base, once it is divided into subsets of age, sex, ability, and velocity, becomes small samples from which it is impossible to properly draw conclusions. Figure 11 shows how a hypothetical large sample of filmings with n = 1000, ends up with unusable samples of the necessary specificity, with a few horses each.

We hope the size of this study's data base need not be repeated, and will facilitate future studies of Thoroughbred racehorses by allowing researchers to continue to use smaller samples, normalizing gait parameters for velocity, age and sex.

Fig 11

Why Does One Need a Large Data Base for Gait Analysis?



Why Hasn't "Gait Analysis" Been "Commercially" Used?

The required size of the data base, the theoretical state of the scientific literature on equine locomotion, the complexity of multivariate discriminant analysis methods, and the fact that a very large, expensive computer system and complex, expensive filming and digitizing equipment were required to process this data until recently, may help to explain why "gait analysis" has not been pursued commercially in the past, nor been used in any practical manner in the horse racing industry.

For example, the literature on equine locomotion is primarily *not* inclusive of racing velocity gaits. Even more important, it has generally either not acknowledged the existence of velocity sensitivity of gait parameters, or has failed to realize the true level of velocity dependence. It has therefore often erred in extrapolations, regressions, and conclusions. This can be seen even in what were otherwise the best papers by the finest scientists. For example, Leach's 1986 discussion of gait parameters without precise velocities (see Appendix E).[1] Also, note Deuel's award-winning presentation of a study on Quarter horses galloping on cracked gravel at below racing speed, after a sharp turn, carrying above jockey weight.[2] From that data, during her presentation at the 1985 Association for Equine Sports Medicine (AESM) conference, Deuel commented on work done by Pratt,[3] regarding racing speed films of the Triple Crown winner, Secretariat, saying she believed she had found errors in Pratt's conclusions.

Finally, see Table 29, showing the importance of using Thoroughbred racehorses actually involved in their racing careers at major racetracks. Table 29 compares gait parameters found in this study with those from a previous study conducted on a small sample at a non-major racetrack (ie, not Class 1 according to The Daily Racing Form) and/or minor private training center.[4]

Spokes of the Wheel[k]

Pratt, a "father" of modern equine gait analysis, when he discussed the "spokes of the wheel" gait pattern of Secretariat at racing speed, as a superior, more efficient way of going, did not specify the rigid velocity dependence of that style.[3] In fact, EQB has shown from the same group of horses used in this study that most[l] sound racehorses at major racetracks can run "like the spokes of the wheel."[6] The real question is: At what velocity do they do so?

Figures 12 and 13 show the velocities at which horses normally exhibit the "spokes of the wheel" running pattern. Table 30, titled "Slow Secretariat Model Effect," lists gait parameters for several horses that exhibited the "spokes of the wheel" running style.

k. This is the transverse gallop at extension values of P2 = 1.00 and P3 = 1.00, which visually appears as extreme extension with one single airborne phase per stride. Each leg appears to touch down just as the previous leg leaves the ground.

l. Nearly all two-year-olds and almost 1/2 of older horses racing at major USA racetracks can exhibit the "spokes of the wheel" style.

Table 21 Two-year-old colts filmed at spring auctions (*t* test level of significance of differences between high earners and low earners showing probability >*t*)

	Velocity (ft/sec)					
Variable	45-48	48-51	51-54	54-57	57-60	60-63
n (low)	229	233	361	357	161	49
n (high)	43	43	87	116	40	23
VEL	.0106	.7761	.3099	–.7387	–.4394	.0243
TSTRIDE	.8071	.2049	.0023	.0384	.4642	.0002
TSTANCE	–.0963	–.0262	–.0580	–.5737	–.0586	.7901
TSWG	.2804	.0268	.0001	.0134	.1154	.0001
TAIR	.1765	.0134	.0013	.0134	.0059	.0246
TGND	–.2785	–.1162	–.3650	–.9990	–.0286	.2892
PCTXLAP	–.1373	–.0438	–.0449	–.4847	–.4362	–.0377
LSTRIDE	.1154	.1699	.0004	.0348	.7281	.0001
FREQ	–.7944	–.1934	–.0014	–.0278	–.4950	–.0002
P1	.0131	.3915	.7240	.0745	.4601	.2290
P2	.6615	.1327	.6381	–.2588	–.8532	.0129
P3	.9597	.6410	.0010	–.9704	.0768	.0294
AVGSTN	–.2671	–.0250	–.0782	–.5195	–.0319	.5883
INSP	.0232	.0023	.0012	.0213	.0596	.0001
EXP	–.0617	–.0068	–.8299	–.8845	–.3232	.8492

A positive number shows that the "high" group's mean was higher than the "low" group's mean for the same variable. A negative number shows that the "high" group's mean was lower than the "low" group's mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

Table 22 Two-year-old fillies filmed at spring auctions (*t* test level of significance of differences between high earners and low earners showing probability >*t*)

	Velocity (ft/sec)					
Variable	45-48	48-51	51-54	54-57	57-60	60-63
n (low)	174	154	263	257	112	43
n (high)	33	31	52	89	36	17
VEL	.0174	–.6962	–.8511	.8525	–.8017	.7721
TSTRIDE	.1233	.0017	.3133	.6898	.6979	.5952
TSTANCE	–.0220	–.5769	–.9796	–.1432	–.9230	.5390
TSWG	.0043	.0007	.3248	.3878	.7038	.8008
TAIR	.0003	.0032	.1027	.6465	–.8555	.9829
TGND	–.0747	–.1690	–.6424	–.6250	.2945	.4628
PCTXLAP	–.0478	–.7610	.6998	–.0729	–.4466	–.8025
LSTRIDE	.0148	.0062	.3785	.6331	.6551	.5464
FREQ	–.0968	–.0010	–.2756	–.6008	–.6899	–.6276
P1	.0617	.3442	.7695	.0898	.2186	–.9631
P2	–.6870	–.2694	–.4372	–.9527	.7926	–.7920
P3	.0877	.0543	–.7793	.0983	.7900	–.8667
AVGSTN	–.0735	–.5475	–.9413	–.1290	–.9997	.5912
INSP	.0023	.0067	.3726	.8035	–.8577	.8434
EXP	–.3070	.8071	–.5936	–.6277	.5410	–.4028

A positive number shows that the "high" group's mean was higher than the "low" group's mean for the same variable. A negative number shows that the "high" group's mean was lower than the "low" group's mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

A practical example of the importance of this point is as follows. One might find horses that moved with a "spokes of the wheel" gait nearly identical to Secretariat's, but which did so at a somewhat slower racing speed velocity than that at which Secretariat exhibited that style (eg, they were at 53 feet per second and Secretariat was at 57 feet per second).

This means that, for some reason, those horses generated less velocity than Secretariat did while using generally the same motions as Secretariat. EQB, Inc. did, in fact, purchase horses like that at major Thoroughbred auctions one year, and discovered they were not good racehorses (a list is available on request). They could not go fast enough to be successful racehorses in major races.

In retrospect, if those horses were 100% extended at approximately 53 feet per second (ie, P2 = 100% and P3 = 100%, which is the "spokes of the wheel" motion) so as to look like Secretariat did at 57 feet per second, yet did not generate high speed, then they could not speed up much further using extension (ie, stride length). Rather, they had to increase stride frequency to go faster. Usually, at that kind of racing velocity range, an increase in frequency from a starting point of 100% P2 and P3 extension results in a *reduction* in extension to give the desired increase in velocity. That higher stride frequency gait style than Secretariat's, to achieve the same velocity as Secretariat, theoretically uses more energy than Secretariat used to achieve that velocity.

The "Stress Test" of Racing Gait

Multivariate discriminant analysis most effectively predicted subsequent racing performance on data collected at 16.2 to 17.4 m/sec (53 to 57 ft/sec—12.4 to 11.6 sec/fur—36 to 39 mph). This may be because that is fast enough to eliminate "playing around," but not so fast as to make all the subjects work at high physiologic, biomechanical stress levels.

No Single Kinematic Gait Parameter was Powerfully Predictive of Subsequent Racing Performance

This study required the complex statistical tool of multivariate discriminant analysis. This was because although some single racing speed gait parameters studied in this paper were in fact generally representative of a style of running, and were therefore somewhat predictive of performance by themselves, several gait parameters had to be studied together to predict racing performance at reliability

Table 23 Race-age colts (*t* test level of significance of differences between high earners and low earners showing probability >*t*)

	Velocity (ft/sec)			
Variable	48-51	51-54	54-57	57-60
n (low)	22	35	52	18
n (high)	18	60	112	61
VEL	.2105	.1381	.7956	.2384
TSTRIDE	.5350	.0842	.0312	.8093
TSTANCE	.1892	–.3406	–.2194	–.2869
TSWG	.9724	.0168	.0055	–.7503
TAIR	.3911	.1958	.0992	–.8616
TGND	–.5649	–.8004	–.5715	.6417
PCTXLAP	.0550	–.1429	–.1368	.4423
LSTRIDE	.8318	.0343	.0221	.5126
FREQ	–.5516	–.0862	–.0301	–.8533
P1	.1723	.6126	.0165	–.4557
P2	–.0011	.3016	.4636	–.3583
P3	–.9520	.2024	.0113	–.2415
AVGSTN	.2326	–.5330	–.2113	.2451
INSP	–.5517	.0053	.0077	–.6367
EXP	.0387	.1088	–.8535	.1370

A positive number shows that the "high" group's mean was higher than the "low" group's mean for the same variable. A negative number shows that the high group's mean was lower than the "low" group's mean for the same variable. We have too few "lows" at higher velocities. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

Table 24 Race-age fillies (*t* test level of significance of differences between high earners and low earners showing probability >*t*)

	Velocity (ft/sec)			
Variable	51-54	54-57	57-60	60-63
n (low)	42	27	14	10
n (high)	30	73	46	24
VEL	–.2796	–.7011	–.2430	.1110
TSTRIDE	.6620	.0001	.0007	.4755
TSTANCE	–.7575	–.3767	.8156	–.0559
TSWG	.6073	.0001	.0008	.2063
TAIR	.4307	.0006	.0001	.5650
TGND	–.8187	.4908	.8949	–.2117
PCTXLAP	–.6767	–.0449	.7790	–.0241
LSTRIDE	.9988	.0001	.0007	.2130
FREQ	–.6002	–.0001	–.0014	–.4593
P1	–.9160	.0001	.0023	–.7729
P2	.5288	–.4024	–.0160	.0692
P3	.7205	.0579	.0843	.0649
AVGSTN	–.5607	–.3542	.9150	–.0824
INSP	.5759	.0001	.0087	.0543
EXP	–.5851	.8125	.1359	–.1491

A positive number shows that the "high" group's mean was higher than the "low" group's mean for the same variable. A negative number shows that the "high" group's mean was lower than the "low" group's mean for the same variable. If a P value shown = .0001, the confidence of the significance of that difference is at the 99.99% level. If a P value shown = .8500, then the confidence level of the significance of the difference between means = 15%. For further explanation of this table, see Appendix F.

levels appropriate for commercial applications. This is perhaps because the total gait produced is so complex.

For an example of how even the seemingly most powerful single gait parameter at a single velocity does not differentiate well between horses, Table 30 shows a list of horses that match Secretariat in many gait parameters, but were awful as racehorses. As another example, Table 31 shows that at a single given velocity, high earners had virtually the entire known racehorse range of stride frequencies; and, further, at a given frequency, this same group of all high earners had a huge variation in the velocity produced.

In Sum, How Good is Gait Analysis?

Yearling racehorses, purchased at the most expensive auctions, based on the most stringent measures of pedigree and conformation, applied by the most experienced and successful racehorse industry professionals, historically produce, at most, 19% stakes winners,[7] versus a random probability of such success of about 10%, ie, about 1.9 times random chance.

By way of comparison with the above results of the best practitioners of such traditional pedigree and conformation methods, performance characterization and forecasting using discriminant analysis of gait parameters alone, from a few strides on film, achieved results typically as well as the finest traditional methods, with some results as high as 10 times better than random (see Tables 25 through 27 and Appendix C). This means it was therefore sometimes over 5 times better than the best traditional experts, and it should be emphasized that that was with absolutely no data but a few strides on film. It is not inappropriate to consider how good the results might be combining traditional methods with this new form of gait analysis.

A final, general consideration might be a speculation on how well refinement of gait analysis and exercise physiology could become at predicting the results of individual races. The investigators believe racetrack handicapping will still not become an "exact science." Many types of complex phenomena, as, for example, the weather, do in fact still obey a small, defined set of simple laws, and therefore might be believed to be modeled accurately and therefore be predictable. The mathematics of Chaos Theory have shown why the precise fact of knowing the causative relationships of such a complex phenomenon actually explains why the phenomenon is not predictable.[8] That is because the results are so sensitively dependent on initial condi-

Table 25 Discriminant analysis model results (two-year-old fillies, high earners versus low earners, 54-57 ft/sec

Discriminant analysis
Classification summary for calibration data: work.drydirt

Generalized squared distance function:
$D^2_J(X) = (X-\overline{X}_J)' \; COV^{-1} \; (X-\overline{X}_J)$

Posterior probability of membership in each earncat:
$PR(J|X) = EXP(-.5 \; D^2_J(X))/SUM \; EXP(-.5 \; D^2_K[X])$

Number of observations and percents classified into earnings categories:

From earncat	Low	High	Total
Low	133	42	175
	76.00%	24.00%	100.00%
High	4	11	15
	26.67%	73.33%	100.00%
Total %	137	53	190
	72.11%	27.89%	100.00%
Priors	0.5000	0.5000	

tions, and there are so many unknowable relevant initial conditions (eg, the "Butterfly Effect"[8]).

Still, in closing, it seems remarkable that so little data on a young, unraced horse (2.5 to 3 strides filmed laterally) can yield so much in describing and predicting performance. Perhaps this is because gait, the "way of going" at or near racing velocities, is the sum total resulting manifestation of so many other variables.

GLOSSARY OF TERMS

Many of the abbreviations listed here appear in tables and figures throughout this paper.

Air Time (TAIR): Total time in seconds during a complete stride that no legs bear weight.

Average Stance (AVGSTN): Distance in feet, calculated as the average of 4 stance times (one for each leg) multiplied times velocity to provide a measure of distance traveled during each leg's stance time.

Average Swing Time (TSWG): The average time in seconds spent by each leg during each complete stride while the leg is not bearing weight.

Ground Time (TGND): Total time in seconds during a complete stride that at least one leg bears weight.

Inspiration (INSP): Time in seconds beginning when the lead foreleg stops bearing weight and ending when the non-lead foreleg bears weight. A horse's inhalation of air occurs during this time and is mechanically linked to this phase of the horse's stride.

Expiration (EXP): Time in seconds beginning when the non-lead foreleg begins bearing weight and ending when the lead foreleg last bears weight. A horse's expiration of air occurs during this time and is mechanically linked to this phase of the horse's stride.

Table 26 Discriminant analysis model results (two-year-old fillies, high earners vs low earners, 48-51 ft/sec)

Discriminant analysis
Classification summary for calibration data: work.drydirt

Generalized squared distance function:
$D^2_J(X) = (X-\overline{X}_J)' \; COV^{-1} \; (X-\overline{X}_J)$

Posterior probability of membership in each earncat:
$PR(J|X) = EXP(-.5 \; D^2_J(X))/SUM \; EXP(-.5 \; D^2_K[X])$

Number of observations and percents classified into earnings categories:

From earncat	Low	High	Total
Low	69	6	75
	92.00%	8.00%	100.00%
High	0	3	3
	0.00%	100.00%	100.00%
Total %	69	9	78
	88.46%	11.54%	100.00%
Priors	0.5000	0.5000	

N.B. 3/9 = 33% actual "highs" in group labeled as "high" versus 3/78 = 3.8% "highs" found in the group as a whole, i.e. the percentage of "highs" that could be expected to be selected by a random choice method.

Table 27 Discriminant analysis model results (two-year-old fillies, high earners versus low earners, 51-54 ft/sec)

Discriminant analysis
Classification summary for calibration data: work.drydirt

Generalized squared distance function:
$D^2_J(X) = (X-\overline{X}_J)' \; COV^{-1} \; (X-\overline{X}_J)$

Posterior probability of membership in each earncat:
$PR(J|X) = EXP(-.5 \; D^2_J(X))/SUM \; EXP(-.5 \; D^2_K[X])$

Number of observations and percents classified into earnings categories:

From earncat	Low	High	Total
Low	108	47	155
	69.68%	30.32%	100.00%
High	4	7	11
	36.36%	63.64%	100.00%
Total %	112	54	166
	67.47%	32.53%	100.00%
Priors	0.5000	0.5000	

N.B. 7/54 = 12.96% actual "highs" in group labeled as "high" versus 11/7166 = 6.63% "highs" found in the group as a whole, i.e. the percentage of "highs" that could be expected to be selected by a random choice method.

Total Percentage of Overlap (PCTXLAP): Percentage of time within a complete stride that any 2 legs simultaneously bear weight.

Extension: Serves as a measure of how "stretched out" a horse's legs are. Extension between each of a horse's legs are measured in terms of P1, P2, and P3, as defined later.

Table 28 EQB's data versus data seen in other studies

Sample size	Type horse	Avg freq	SD	Range	Avg Lstr	SD	Range	Avg vel
n = 45	Breeder's Cup	2.36	0.78	2.28-2.44	23.55	0.82	22.73-24.37	55.58 ft/sec
n = 32	Low earners	2.39	0.12	2.27-2.5	23.26	1.08	22.18-24.3	55.59 ft/sec
n = 7	Ratzlaff*	2.58	N/A	N/A	21.0	N/A	18.37-24.6	54.18 ft/sec

**Compare with Ratzlaff et al. Equine Vet Sci;5:279-283.*

Table 29 Slow Secretariat model effect

Racing name	Sex	Earnings per start ($)	Total money earned ($)	No. of races	Velocity (sec/ furlong)	Obs: TGND	Stride FREQ/ sec	P1: Obs	P2: Obs	P3: Obs	Obs: LXLAP/ LSTR in frames	Avg swing time	Time fully in air
Secretariat	C	62,705	1,316,808	21	11.00	.3044	2.3725	.732	.677	.941	.1369	.3306	.1164
Loverboy Blues	C	1115	29,012	26	14.00	.3000	2.3477	.717	.660	.980	.1369	.3353	.1233
Market Crash	F	4111	16,445	4	13.76	.3066	2.3455	.728	.690	1	.1263	.3350	.1266
Ananda	F	3202	102,485	32	12.90	.2996	2.4011	.763	.666	.944	.1372	.3277	.1165
Dine in Darkness	C	923	14,772	16	12.86	.2970	2.3900	.814	.692	.903	.1301	.3306	.1171
Actresso	F	1440	7200	5	12.76	.2923	2.4097	.714	.666	.961	.1321	.3275	.1179
Particular Style	F	525	2100	4	12.70	.2983	2.3904	.714	.692	1.038	.1354	.3311	.1200
Central Casting	F	748	5990	8	12.70	.3010	2.3421	.762	.673	.979	.1383	.3366	.1321
Country Lassie	F	3122	24,980	8	12.35	.2934	2.4137	.707	.660	1.023	.1424	.3262	.1180
Complete Circle	C			0	12.16	.2906	2.4287	.737	.680	.96225	.1298	.3257	.1236
Coastliner	C	8330	74,975	9	12.04	.3033	2.413	.789	.673	.923	.1327	.3255	.1133
Accurate Prospect	C			0	11.96	.3049	2.4307	.740	.666	.956	.1369	.3208	.1060
Hot Operator	C	8755	78,800	9	11.82	.2983	2.3890	.714	.686	1.019	.1273	.3293	.1150
Buck Light	C	1431	52,965	37	10.88	.3060	2.3667	.732	.698	.964	.1319	.3316	.1137

Down: Used to indicate that the leg is bearing weight (not just touching the surface of the racetrack).

High-Speed Film Analysis: Involves the use of a camera that opens and closes its shutter at very fast rates. For the purposes of this study, the shutter opened and closed 300 times per second, taking 300 pictures during that time. These individual pictures, in our case, were recorded on 16-mm movie film as separate frames. Because each frame represents 1/300th of a second, we can measure the time between successive limb positions of the horse by counting the frames and entering those numbers (digits) into a computer, and thus "digitizing" the information.

Lead Change: Occurs when a horse switches the order of leg placement, such that if the lead rear and foreleg were the right legs, subsequent strides would use the left legs as the lead legs.

Lead Leg: The last rear and the last foreleg to bear weight. If the lead foreleg is the right leg, then the lead rear leg will also be the right leg until a lead change occurs.

Limb Contact ("on"): Occurs when the hoof first begins to bear weight. This moment is recorded as the first frame preceding rapid extension of the fetlock joint.

Limb Non-Contact ("off"): Occurs the moment the limb contact is broken and lasts until limb contact (defined previously) re-occurs. The moment is recorded as the frame closest to the point when the fetlock joint (palmar or plantar angle?) exceeds 90 degrees.

Non-lead Leg: The first rear and the first foreleg to bear weight. If the non-lead foreleg is the left leg, then the non-lead rear leg will also be the left leg until a lead change occurs.

Overlap Time: The time in seconds that 2 or more limbs simultaneously bear weight.

P1: Percentage of weight-bearing stance time of the non-lead rear leg that elapses before the lead rear leg's stance time begins.

P2: Percentage of weight-bearing stance time of the lead rear leg that elapses before the non-lead foreleg's stance time begins.

P3: Percentage of weight-bearing stance time of the non-lead foreleg that elapses before the lead foreleg's stance time begins.

Rotary Gallop: Occurs when the sequence of steps during the gallop stride occurs counter-clockwise in the order of LR, RR, RF, LF.

Stance Time: The total time in seconds that an individual limb bears weight during limb contact.

Stride Frequency (FREQ): The number of strides per second.

Table 30 Is predictive gait analysis as simple as frequency or stride length?

Racing name (n = 45)	Velocity (sec/fur)	Length of stride	Stride freq/sec	Earnings per start
Saros Brig	11.85	25.3206	2.1998	16,717
Magnificent Lindy	11.78	25.3935	2.2601	30,887
Saros Brig	11.87	25.2099	2.2063	16,717
Park Express	11.98	24.6191	2.2373	37,612 Europe
Fran's Valentine	11.90	24.7693	2.2391	41,453
Sacahuista	11.77	24.9591	2.2473	61,273
Sacahuista	11.99	24.5003	2.2473	61,273
Manilla	11.97	24.2866	2.2696	149,599
Dontstop Themusic	11.90	24.3645	2.276	22,406
Skywalker	11.82	24.3751	2.2905	111,337
Ride Sally	11.98	23.9924	2.296	17,553
Nostalgia's Star	11.77	24.3492	2.2989	38,768
Family Style	11.90	24.0206	2.3089	52,332
Isayso	11.90	23.6601	2.3440	18,023
Gulch	11.78	23.8097	2.3537	96,735
Gulch	12.00	23.3495	2.3555	96,735
Agacerie	11.92	23.5041	2.3558	18,900
Alphabatim	11.82	23.638	2.3623	59,933
Gulch	12.00	23.2787	2.3627	96,735
Endear	11.84	23.5626	2.3656	20,642
Aberuschka	11.93	23.2324	2.3812	22,465
Flip's Pleasure	11.98	23.1275	2.382	16,314
Right Con	11.86	23.3448	2.3838	18,796
Life's Magic	11.90	23.2552	2.384	70,475
Nostalgia's Star	12.01	23.0302	2.3860	38,768
Lady's Secret	11.90	23.1997	2.39	64,460
Hail Bold King	11.78	23.3939	2.3951	29,691
Eastland	11.90	23.1443	2.396	12,215
Lady's Secret	11.78	23.2816	2.4062	66,460
Stately Don	12.02	22.7953	2.4088	53,198
Zero Minus	11.86	23.1032	2.4096	10,758
Herat	11.84	23.0956	2.4126	24,884
Fiesta Lady	11.92	22.8674	2.421	17,956
Salt Spring	12.00	22.671	2.4260	25,756
Pine Circle	11.86	22.7493	2.4462	22,587
Minneapple	11.90	22.6008	2.453	13,534
Seat Dancer	11.80	22.4176	2.494	42,176
Infinidad	11.97	21.8817	2.5190	22,700
Bolshoi Boy	11.84	22.0687	2.525	40,125

Sorted by frequency of stride. All are elite performers at more than a mile, but data varies widely.

Table 32 Tiny 2-year-old filly (Thank you Mark) vs. big 2-year-old colt (Murmuration)

Racing name	Velocity (ft/sec)	Length of stride	Stride freq/sec	Avg swing time	Obs TGND	P1: Obs	P2: Obs	P3: Obs
Murmuration	54.10	24.3142	2.2250	.3561	.3183	.712	.703	1.038
Murmuration	54.10	24.5276	2.2057	.3623	.3118	.724	.6921	.076
Murmuration	56.25	25.2329	2.2292	.3661	.2966	.706	.958	1.106
Thank You Mark	54.71	22.4736	2.4344	.3361	.2 591	.708	.680	1.000
Thank You Mark	55.72	22.4568	2.4812	.3288	.2516	.818	.583	.909

Stride Length (LSTR): The distance in feet traveled during a stride, measured from 2 successive limb contacts of the same leg.

Transverse Gallop: Occurs when the horse uses the leg placement sequence: LR, RR, LF, RF or RR, LR, RF, LF. All horses used for this study were using the Transverse Gallop.

Two-year-old: All Thoroughbred racehorses' birthdays are celebrated on January 1 each year. Therefore, the oldest a two-year-old can be on January first is 24 months old, and practically speaking, few are younger than 19 months old (few are born later than May because of the dynamics of the marketplace). The two-year-olds in this study should range in age from 19 to 29 months at the time of filming, given that they were filmed sometime between January and May at public auctions.

Velocity (VEL): Usually measured in feet per second in figures and tables within this report.

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Appendix A

MEASUREMENT UNITS CONVERSION TABLE

Convert from	Convert to	Calculation
FPS	SPF	660/FPS = SPF
FPS	MPH	FPS · 0.6818182 = MPH
FPS	MPS	FPS · 0.3048 = MPS
SPF	FPS	660/SPF = FPS
SPF	MPH	450/SPF = MPH
SPF	MPS	201.168/SPF = MPS
MPH	FPS	MPH/0.6818182 = FPS
MPH	SPF	450/MPH = SPF
MPH	MPS	MPH/2.2369363 = MPS
MPS	FPS	MPS/0.3048 = FPS
MPS	SPF	201.168/MPS = SPF
MPS	MPH	MPS · 2.237 = MPH

FPS, *Feet per second;* MPS, *meters per second;* MPH, *miles per hour;* SPF, *seconds per furlong. 1 mile = 5280 feet; 1 mile = 8 furlongs; 1 furlong = 660 feet; 1 foot = 0.3048 meters; 1 meter = 3.2808 feet; 1 meter = 39.37 inches.*

Appendix B

THE EFFECTS OF INTERNAL ERROR ON VELOCITY MEASUREMENTS OF GALLOPING HORSES

Two types of errors are possible in the calculations of these horses' velocities. One is external, when the clockers are wrong. The other is internal. Horses accelerate and decelerate within each stride by as much as 3.5 feet per second (unpublished studies by EQB indicate that the degree of within-stride velocity fluctuation varies widely from horse to horse.) In fact, the actual velocity at any point in a stride appears quite dynamic.

Most deceleration during an individual stride comes from air resistance during the primary airborne phase, which occurs after the lead foreleg leaves the ground and before the non-lead rear leg comes down. Galloping horses get all of their propulsive force while their legs are on the ground, achieving peak velocity before the main airborne phase. Horses that are galloping, during a single stride, achieve their slowest velocity as the non-lead rear leg comes down (at the end of the airborne phase). This can create a bias when working with the film.

For example, assume the same horse is filmed at the same time by 2 cameras for approximately 2.5 strides. For one filming, this may include 2 complete primary airborne phases (lead foreleg off to non-lead rear leg on) and 3 ground contact phases (non-lead rear leg "on" to lead foreleg "off"). The other filming may include three full airborne phases and just 2 full ground contact phases. Because of the ratio of slow airborne phases to faster ground contact phases, the same horse with true average velocity of about 57 feet per second may really have different averages during the exact time he appears on film. A horse may have average ground contact velocity of 58 feet per second and average airborne phase velocity of 55 feet per second. The filming with 3 ground contact phases and 2 airborne phases might have these average velocities:

Camera 1: 58, 55, 58, 55, 58

The same horse filmed for 3 airborne phases and 2 ground contact phases might have these velocities:

Camera 2: 55, 58, 55, 58, 55

Ground contact time accounts for about 70% of a stride, whereas air-time accounts for about 30% of a stride at these speeds.

Thus, for the horse discussed above, average velocity could be calculated as:

Calculation 1: 58(70) + 55(30) = 571/100 = 57.1 feet per second, which would be reported by the clockers.

Velocity calculations from Cameras 1 and 2 could be shown as:

Calculation 2: [58(70) + 55(30) + 58(70) + 55(30) + 58(70)]/270 = 57.33 feet per second

Calculation 3: [55(30) + 58(70) + 55(30) + 58(70) + 55(30)]/230 = 56.83 feet per second

This results in a 0.5 foot per second difference in velocity calculations between Camera 1 and Camera 2 because of a filming bias. The true, longer-term average velocity is somewhere in between, ie, 57.1 ft/sec, which the clockers should report, and as would be calculated with Calculation 1. Digitizers calculating velocity directly from film might consider using just 2 numbers, which are the average ground time velocity · 0.70 and average air time velocity • 0.30.

The smaller the interval of time examined (for example, the instant the first rear lifts off), the higher the variation in the measurements made of the same gait parameter (ie, velocity). It may be that instantaneous velocities at certain points in the stride may vary by 10 or more feet per second.

It may also be that the degree of velocity variation within the strides of horses is also related to their efficiency, class, and ability levels.

Appendix C

INTERPRETING AND EVALUATING RESULTS (FROM EQB'S UNPUBLISHED STUDY [AVAILABLE UPON REQUEST] TITLED 1988 BREEDERS' CUP BLIND TEST STUDY)

The multivariate discriminant analysis models' exact degree of effectiveness is difficult to quantify. For example, if the models can beat 1 in 532 odds in a certain situation, how do we interpret this advantage? With what do we compare these odds? To place the terminology of "beating the odds" into perspective, consider the following:

Pick Six Lottery

In New York State's Pick Six Lottery, players choose 6 numbers from among the numbers 1 through 40. Players can expect to get at least 1 matching number from among 6 picks 60% of the time. Players' chances of selecting the same 6 numbers as the lottery commission are 1 in 3.84 million. Getting 1 matching number is likely to occur, but getting 3 to 6 matching numbers becomes increasingly unlikely. Similarly, the benefits of using gait analysis via discriminant analysis becomes increasingly valuable as one attempts to select several high earners from among a mixed group of high and low earners.

The following is a breakdown of "Pick Six" odds:

At least 6 correct = 1 in 3,846,154 odds
At least 5 correct = 1 in 18,724 odds
At least 4 correct = 1 in 455 odds
At least 3 correct = 1 in 30 odds
At least 2 correct = 1 in 4.7 odds
At least 1 correct = 1 in 1.54 odds

If there were 6 high earners in a group of 40 horses, and the gait analysis models discussed in this paper (and nothing else) were used to select 6 horses, how well could the models do? In this example, the random odds of selecting all 6 high earners are the same as in the lottery table above (assuming you can pick each number only once).

If attempting to select horses with earnings per start (EPS) above $10,000, the discriminant models, based on this paper and EQB's experience using the models at racehorse auctions, have historically beaten 1 in 46 odds. Comparing these odds with those in the lottery table, the discriminant models would correctly identify at least 3 high earners (on average) from among 6 picks (chosen from a group of 40 horses that included just 6 with EPS above $10,000).

If attempting to select horses with EPS above $6000, the discriminant models have historically beaten 1 in 532 odds, meaning the models would correctly identify 4 horses (on average) with EPS greater than $6000, from among six picks (chosen from a group of 40 horses that included just 6 with EPS above $6000).

Appendix D

PARTIAL LIST OF GENERAL DESCRIPTIONS OF OTHER EQB STUDIES ON THOROUGHBRED RACEHORSES (THIS LIST REPRESENTS MANY YEARS WITH THOUSANDS OF HORSES)

1. Blind test using gait analysis by itself from slow motion film at Breeder's Cup Races and morning workouts, to identify ability level of horses.
2. Race chart analysis: Handicapping by PACE.
3. Track gradients: ie, surface effects on racing gaits
4. Turf versus dirt horses' gaits at racing speeds
5. Distance versus sprint horses' gaits at racing speeds
6. Raced versus unraced horses' gaits at racing speeds
7. Speed of work at 2-year-old auctions versus subsequent earnings and number of races run
8. Velocity fluctuations within each stride at racing speeds
9. Stride frequency anomalies on racing velocity gradient
10. Veterinary rankings of auction 2 year-olds conformation and soundness versus subsequent number of races run
11. Anomalous stride patterns of auction 2 year-olds versus subsequent number of races run
12. Muscle fiber types in main propulsive muscles of select auction yearlings
13. Aerodynamic silks design and effects
14. Aerodynamic silks
15. Development of on-board heart rate monitors
16. Kinematics of equine knee bones
17. Cardiovascular organ and flow measurement studies including: (a) colts vs fillies; (b) measurements relative to age of horse; (c) measurements relative to earnings; (d) stakes winners versus non-stakes winners; and (e) measurements relative to preferred racing distances
18. Gait analysis of lame versus sound horses
19. Analysis of the effects of drugs on horses' gaits
20. Analysis of the accuracy of EQB's timing methods that are used to measure horse velocity at racetracks
21. Reproducibility of Thoroughbred racing gait parameters in multiple filmings, and on different racetracks and over a period of years
22. Double and triple fully airborne phases in the gaits of racing-speed Thoroughbreds (published in 1993 AESM proceedings)

Appendix E

[NOTES ON LEACH] (RE: LEACH, 1986, ON "LOCOMOTION OF THE ATHLETIC HORSE," EQUINE EXERCISE PHYSIOLOGY 2, PROCEEDINGS, AUGUST 1986)

The authors have the highest respect for the fine work of Dr Leach. Leach's article was chosen for comment because it was so good, yet still demonstrated lack of the requisite emphasis on some basic velocity dependencies of data described in the authors' paper. This helps demonstrate why the authors' paper marks a significant break point in the equine locomotion literature about racehorses.

Examples of the effects of using a small data base and/or not recognizing racing gait variables' sensitive dependence on velocity and on other variables like age and sex might include the following:

1. Quotation from Leach paper: "Perhaps the use of the stride measurement calculated for a selected stride frequency as suggested by Leach and Cymbaluk (1986) is appropriate since there is no other acceptable means to standardize stride length measurements for comparison between animals."

The authors believe this study provides an "acceptable"

Fig 12

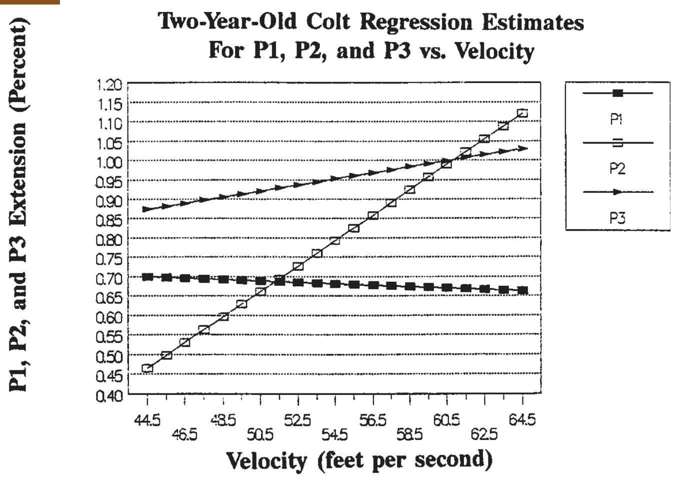
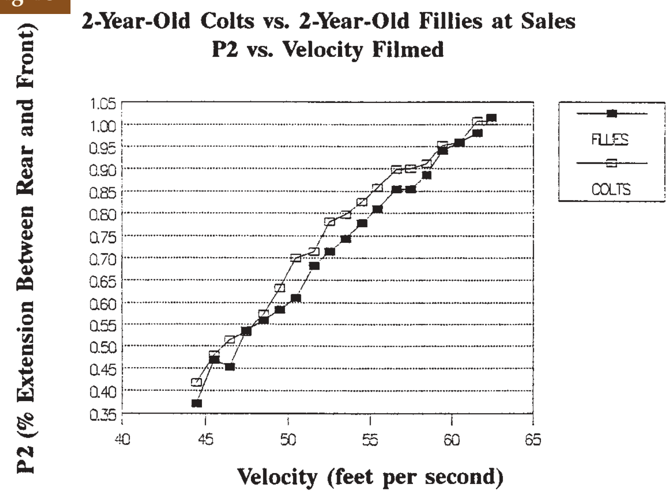


Fig 13



way to standardize gait parameters by normalizing velocity, and if possible, age, sex and racing surface, though the concept of "normalization" based on 1 stride variable may be flawed in itself, which is why the authors used and discussed multivariate discriminant analysis. It is not advisable to use variables like stride length or frequency to try to standardize other kinematic gait parameters (see Tables 30 through 31).

2. Quotation from Leach paper: "Therefore, at higher velocities, they do not attempt to mimic a wheel with their limb placement pattern..."

The "wheel" is the low overlap, high extension pattern. In fact, extension does generally rise with velocity, and P2 and P3 often go to the extreme double or even triple-airborne style at top racing speeds (Seder JA, Vickery CE. Double and Triple Fully Airborne Phases in the Gaits of Racing Speed Thoroughbreds. AESM Proceedings, 1993), which is exactly the "spokes of the wheel style." Figures 12 and 13 show how extension between all but the rear legs approaches zero overlap at higher velocities for two-year-olds and race-age Thoroughbred racehorses.

However, the authors observed in this study that horses with low ability sometimes needed to resort to high frequencies to achieve high velocities, and would therefore have high overlap—the opposite of the "spokes of the wheel." Also, horses accelerating sharply often used high-frequency gaits, with the same resulting high overlap, "non-wheel" gait pattern.

Appendix F

EXPLANATION OF *t* TEST TABLES (TABLES 5-10 AND TABLES 21-24)

Definitions: High earners had earnings through their three-year-old year ≥$50,000; low earners had earnings through their three-year-old year ≤$30,000 and earnings per start ≤$1000.

t tests compared groups of horses within 3-foot per second velocity groups of: 45 to 48 (ie, velocity ≥45 and <48), 48 to 51, 51 to 54, 54 to 57, 57 to 60, 60 to 63, and 63+.

These *t* tests compared the following variables: velocity (VEL), count, total money earned through three-year-old year (TMONEY), earnings per start (EPS), total stride time (TSTRIDE), total stance time per stride (TSTANCE), total swing time per stride (TSWING), total air time per stride (TAIR), total ground time per stride (TGND), total percent overlap per stride (PCTXLAP), length of stride (LSTRIDE), stride frequency per second (FREQ), extension between rear legs (P1), extension rear to front (P2), extension between front legs (P3), average stance time (AVGSTN), inspiration time per stride (INSP), and expiration time per stride (EXP). The number of horses in each group is also given (N).

The numbers in the tables represent the probability that differences seen in the means are really not significant. If a *P* value shows = .0001, the confidence of the significance of that difference is at the 99.99% level. If a *P* value shows = .8500, then the confidence level of the significance of the difference between means = 15%.

These tables provide all *P* values, regardless of significance level, to show possible trends in the data. For example, if a gait variable for 1 group of horses has a consistently lower mean across velocities than for the comparison group, the trend can be indicated despite its weak significance.

A positive *P* value indicates that the first group listed in the table's title had a mean that was higher than the mean for the second group listed in the title. A negative *P* value indicates that the first group listed in the table's title had a mean that was lower than the mean for the second group listed in the title.

Appendix G

ECLIPSE AWARD-WINNING THOROUGHBREDS INCLUDED IN THIS STUDY

Award category	Year	Horse
Two-year-old colt or gelding		
	1983	Devil's Bag
	1984	Chief's Crown
	1985	Tasso
	1986	Capote
	1987	Forty Niner
	1988	Easy Goer
	1989	Rhythm
	1990	Fly So Free
Two-year-old filly		
	1984	Outstandingly
	1985	Family Style
	1986	Brave Raj
	1987	Epitome
	1988	Open Mind
	1989	Go For Wand
	1990	Meadow Star
Three-year-old colt or gelding		
	1982	Conquistador Cielo
	1983	Slew O' Gold
	1985	Spend a Buck
	1986	Snow Chief
	1987	Alysheba
	1988	Risen Star
	1989	Sunday Silence
	1990	Unbridled
Three-year-old filly		
	1984	Life's Magic
	1987	Sacahuista
	1988	Winning Colors
	1989	Open Mind
	1990	Go For Wand
Older colt or gelding		
	1984	Slew O' Gold
	1985	Vanlandingham
	1986	Turkoman
	1987	Ferdinand
	1988	Alysheba
	1989	Blushing John
	1990	Criminal Type
Older filly or mare		
	1985	Life's Magic
	1986	Lady's Secret
	1988	Personal Ensign
	1989	Bayakoa
	1990	Queena
Grass horse		
	1985	Cozzene (M)
		Pebbles (F)
	1986	Manila (M)
		Estrapade (F)
	1987	Theatrical (M)
		Miesque (F)
	1988	Sunshine Forever (M)
		Miesque (F)
	1989	Steinlen (M)
		Brown Bess (F)
	1990	Itsallgreektome (M)
		Laugh and Be Merry (F)
Sprinter		
	1984	Eillo
	1985	Precisionist
	1986	Smile
	1987	Groovy
	1988	Gulch
	1989	Safely Kept
	1990	Housebuster
Horse of the Year		
	1982	Conquistador Cielo
	1985	Spend a Buck
	1986	Lady's Secret
	1987	Ferdinand
	1988	Alysheba
	1989	Sunday Silence
	1990	Criminal Type

EPILOGUE

This epilogue records personal thoughts and subjective philosophical comments of its author, Jeffrey Seder, regarding EQB's gait analysis scientific papers.

Dear Reader,

It should probably be noted that in the last 2 years, before the presentation of this paper, pieces of this work and our cardiac study work have been presented to the owners, trainers, and managers of various major racehorse stables by EQB's staff. Not one of those persons chose to take advantage of this knowledge in any sustained, organized way, even at modest consulting fee rates (except one huge stable's veterinarian who took[m] data and technology from us and made a very private business of his own from it with billionaire clients).

Furthermore, EQB has been turned down by the managements of major racetracks, like Calder, to whom we have offered the knowledge to help evaluate the safety and the effects of changes to racing surfaces, by providing them baseline locomotion data on expected averages of gait variables on their own tracks and under different conditions from their own racetracks.

We even offered The New Bolton Center the data bank itself, together with the use of EQB's research office, our racehorse training center, and our full-time technical staff to operate our equipment, computer, and copies of all our studies, and all at no cost to them. They declined to pursue our offer. Their Dean was enthusiastic, but the follow-up faded.

Finally, this paper was rejected from the Locomotion Group's (SIWAL) part of the 1993 AESM/SIWAL conference (combined meeting of The Association of Equine

m. The company I was a partner in through EQB is now suing that individual as a result.

Sportsmedicine Practitioners and the Society of International World Animal Locomotion), perhaps because of the format of the abstract presented by us. Only 1 member of SIWAL expressed an interest in seeing the data or in talking to us. I must thank Hillary Clayton for singlehandedly saving the opportunity for us to present it to the AESM. When I requested an extra 2 minutes (in addition to the allotted 15 minutes) to present my data at the conference, the AESM turned me down. (We were very grateful, regardless, that the AESM gave us such an extensive forum. They also offered to include this paper in their proceedings, but we chose to distribute it independently.)

We realize we are not familiar with many university policies and customs, but all of the above led us to feel quite rejected. This was an academic rejection of massive data in their field. We did not even presume to try to be heard on what we thought were extensive, important understandings we gained from the data over the 15 years of working with it.

It is understandable that there was resistance and skepticism to our work given the way we presented it and the way we presented ourselves. For example, I am not a veterinarian, nor do I have a current university affiliation. Probably our refusal to publish on this topic before was a big problem. Perhaps I have some flaw in my personality or my personal communication style. Certainly our perceived status as "commercial" was not helpful. Perhaps we were perceived as threatening traditions and/or traditional managers' expertise, and traditional managers, existing commercial network of overt (and covert) commissions. But does all that merit what appeared to us to be such a blanket of disinterest?

My own background includes advanced degrees in the social sciences with honors from Harvard, together with extensive experience managing several businesses, including a sports medicine research team. I have also been a racehorse owner and responsible for the management of a racehorse training center and the training of racehorses. This "commercialism" added practical industry experience to our knowledge.

My studies were "commercially" funded by leading racing stables who put publish delays onto the results from their expenditures. Various patents and copyrights still apply to some of this work.

I chose this means of commercial research support because no other funding was available to me that was even close to the scope of what was required to do my work's agenda. Our research cost hundreds of thousands per year, totaling millions of dollars.

However, although EQB and our racing stable partners hoped to make money, and create value in a consulting business, EQB was not a profit-making organization, and the key researchers, like myself, were never paid. This meant I had to work other jobs to afford the privilege of doing this research. In fact, I spent a very great deal of my own money to continue the research and at one point I even borrowed money to continue the research. I was primarily motivated by the desire to know, and to use that knowledge in horse racing, as a demonstration of the validity of the knowledge,[n] and to help the horses and their owners. I believe that same motivation existed for most of the EQB staff.

Some of us worked full time at collecting and analyzing the data. Some, like me, put in more than 40 hours a week at this as a second job.

Finally, as I said, I am not a veterinarian or a university professor. Regardless, I have presented this material as best I can and hope you find it useful. It may not have always been in the format to which you are accustomed. Please forgive me, and please be patient with me the next few years as EQB continues to try and share its data and what we think we have learned from it.

The pursuit of this study and work with horses have been passions and labors of love for me. I have made a sincere effort at great personal cost for many years to learn and now to share. I hope that whatever our mistakes and/or sins may have been, this data will be useful to the readers and will be reviewed by them in the spirit of the desire to learn, and to have that learning used in horse racing.

Sincerely,

Jeffrey A. Seder

This paper is the first of a series EQB will publish on its last 16 years of full-time research on Thoroughbred racehorse locomotion. EQB's research was done under the direction of Jeffrey A. Seder by a multidisciplinary team that over the years has included veterinarians, MDs, engineers, biomechanists, and statisticians from major universities and from private practice. This research team also included practitioners in the field that included jockeys, racetrack officials, racehorse breeders and racehorse trainers. EQB extends thanks to all these colleagues for their extensive help.

We especially want to thank Patti Miller, who has put in enormous quantities of energetic time on this research for 15 years, and the Association for the Advancement of Sports Potential (AASP), a non-profit research foundation. We also want to acknowledge: Dr George W. Pratt, Jr, Dr David Barlow, Clint Clark, Carl Freeman, Dr John R. S. Fisher, Dr Jonathan Foreman, Dr Fred Fregin, Paul Hellhake, Dr Scott Palmer, Dr Douglas Rabin, Dr Norm Rantanen, Billy and Barbara Turner, Dr Richard Trout, Dick Winn, the US Olympic Committee, The New York Racing Association, NBC Sports, The Breeders' Cup, and all the dedicated, hard-working employees of EQB, Inc, over the years.

n. In fact, among the last several horses that fit our "profile," that we recommended as unraced two-year-olds for clients, almost all became at least stakes placed at major racetracks. These Thoroughbreds include Crazy Canuck, Murmuration, Conga Tempo, Tusculum Road, Venom, and Tusculum Dancer. Tusculum Dancer now holds the track record at Monmouth Park for 1 1/8 miles on the turf (a record he broke by more than a full second). Murmuration had a severe case of "epistaxis" (a "bleeder").