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Individual Variation in the Quarter Horse Gallop

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Summary

The individual transverse gallop stride characteristics of four Quarter Horse fillies were documented by means of high-speed cinematography. Horses were approximately thirty months of age and raised and trained similarly. Horses were filmed by two cameras simultaneously (243 frames/sec) while galloping under the standardized conditions of a specially constructed 1.5 m-wide track. Horses were all ridden by one person, using the same saddle and bridle. Limb contact variables determined for 62 strides included stride length and frequency, step lengths, and contact and non-contact durations for single limbs and combinations of limbs. In data analysis, velocity, day and lead effects were partitioned to enable the determination of persistent, individualized gallop stride patterns. Horses differed in average velocity and stride frequency but were not significantly different in stride length or the distance between any two successive hoof impacts. Subjects were found to differ in the duration of contact of the hind lead, fore trail and fore lead limbs; and the non-contact duration of the fore trail and fore lead limb. In the gallop stride cycle, horses differed in fore trail diagonal bipedal contact, fore trail unipedal contact and fore bipedal contact. Individual idiosyncracies of the gallop stride therefore appeared primarily in fore limb timing patterns. Methods utilized in this study may be useful for objective biomechanical gait evaluations of individual horses.

Index terms: Biomechanics; kinematics; gait; locomotion.

Introduction

Individual characteristics of motion are considered major contributors to successful competitive performance of equine athletes. Horses are currently selected for breeding and purchase primarily on the basis of subjective measures such as traditional conformation judging, visual appraisal of movement patterns and pedigree evaluation. High speed cinematography may be used in the future to augment these processes by providing objective measures of an individual horse's gait patterns (Leach and Crawford, 1983).

Motion patterns of the galloping horse were first objectively documented by Muy-

bridge (1899). There has been little additional objective information on the equine gallop until recently. The kinematic studies of Pratt and O'Connor (1978) and Leach and Sprigings (1979) provided measurements of certain gallop stride limb contact variables of Thoroughbred racehorses but employed only a limited number of observations on each horse.

Before it can be declared that individual horses differ in specific gallop stride characteristics, repeated measurements must be made and adjusted for the effects of velocity (Deuel and Lawrence, 1985a; Ratzlaff *et al.*, 1985) and bilateral asymmetry or "handedness" (Deuel and Lawrence, 1985b). Such studies must also account for genetic influences on gait and for environmental factors, such as training, rider effects, shoeing and track surface. The objective of this study was to identify gallop stride variables that differ between individuals within a group of Quarter Horse fillies of similar breeding and training.

Materials and Methods

Horses galloping with a rider were filmed on a specially designed track which confined the line of motion of the subjects to a single known plane. The track was a 115 m straightaway defined by parallel rails 1.5 m apart at a height of 1.2 m. The track surface was a level bed of finely cracked limestone, approximately 20 cm deep, maximum particle size approximately .2 cm³. The track surface was smoothed prior to each run to provide a consistent hoof impact surface for all trials. At one end of the track, large panel gates were set up as wings to direct the galloping horses into the track. All runs through the track were made heading north.

Two high speed motion picture cameras (Redlake Locam Model 51, Campbell, CA 95008; Eastman Ektachrome 16-mm Video News Film, High Speed 7250, Daylight ASA 250/25 DIN, Eastman Kodak Co., Rochester, NY 14650) were aimed at the track mid-point from both sides, 29.0 m perpendicular distance from the rail. The cameras' field of vision was a 12.6 m segment of track. The track rail in this section was 2 cm in diameter and did not substantially obstruct the view of the horses. Two cameras were used to enable independent replicate observations to be made on every gallop stride.

A one meter stick held horizontally within the plane of motion provided a conversion factor for film analysis of $4.63 \pm .03$ (mean \pm SE) projected cm/real meter for the right view of the subjects and $4.70 \pm .01$ projected cm/real meter for the left view. Camera frame rates were determined by simultaneous filming of a free-falling brick to be 243.3 ± 1.7 frames/sec (no significant difference between cameras by t-test). Camera shutters were open 1/9 of available time, creating an exposure time of 1/2190 sec/frame.

The subjects of the study were 4 two-year-old Quarter Horse fillies of similar breeding and background, group-fed and housed together. Horses were shod similarly with steel shoes (mean wt 187 g) on all hooves trimmed in accordance with their individual pastern angles, with .3 cm thick neoprene pads (mean wt 80 g) on the fore hooves.

Efforts were made to minimize the effects of training on gait and to standardize training procedures. In a 12-week preparatory period, horses were trained to sprint at a gallop down the track several times per day. Prior to training for this study the horses had only nominal experience being ridden. Throughout the training and testing procedures, a single handler rode the horses with an English forward seat saddle and snaffle

bit bridle (total weight with rider 76 kg). The amount and type of exercise were equalized for all horses.

Filming took place between 1100 and 1430 hours on a Monday, Wednesday and the following Monday. Weights, segmental lengths and withers height measurements were taken on days between filmings. The morphometric measurement techniques used have been defined (Deuel, 1985). Common equestrian terms, when available and appropriate, were used to denote line segments between body markers to emphasize the distinction between the theoretical mechanical links and the actual skeletal structures. Hooves were brightly painted for high visibility during film analysis. Order of filming horses was random each day. For each trial the rider signaled the horse with leg and rein pressure for the desired lead and directed it at a gallop into the south end of the track. The rider exerted no force on the reins and stood balanced in the stirrups in a crouched position until the end of the track was reached, attempting to maintain similar body positions for all trials. Mistrials were designated if there were apparent inconsistencies in velocity along the track or if the horse was not centered between the rails. Rotary gallop strides and lead changes were also filmed but were omitted from this analysis. No more than 9 trials were filmed for each horse per day to prevent excessive fatigue.

Horses were visible in the film image of a 10.1 m segment of the track on every day of filming, within which all kinematic variables were measured. To ascertain that the horses were traveling at a relatively constant velocity while being filmed, horses were hand-timed for every run through a 77-m segment of track centered on the filming segment. There was excellent agreement between hand-timed velocities and velocities measured by film analysis (correlation coefficient = .92, $P < .0001$). Therefore the subjects were considered to be galloping at constant velocities.

Sixty-two transverse gallop strides were documented, including 41 left lead and 21 right lead strides. One film technician collected all data. Only the center-most stride within the film frame was used to minimize possible influences of camera lens distortion and perspective error at the film frame periphery. Temporal data for limb contact variables were obtained via frame counts on a single-frame advance projector (Motion analyzer, Model M-16; Vanguard Instrument Corp., Melville, NY 11746). Cartesian coordinates of toe locations at impact were obtained from the projection system in conjunction with a manual digitizer (Electronic Digitizer, Model 1224, Numonics Corp., resolution .25 mm, absolute accuracy $\pm .50$ mm., Lansdale, PA 19446). The digitizer coordinate system was zeroed on a fixed marker in each frame to minimize possible effects of inconsistent frame alignment.

All linear and temporal measurements reported herein were demarcated by the impact or lift-off of the hooves, thus are classified as limb contact variables. In film analysis, the hoof impact frame was defined as the first frame following partial obscuring of the view of the distal edge of the shoe and preceding rapid extension of the fetlock joint. The lift-off frame was defined as the first frame at the end of the limb contact period in which the fetlock joint palmar or plantar angle was less than 180 degrees.

Stride lengths were calculated as the mean horizontal toe displacement between successive impacts, averaged for 4 hooves. The hind-step length was determined by the linear distance measured between impacts of the hind limbs; mid-step between impacts of the hind leading limb and fore trailing limb; fore-step between impacts of the fore limbs and airborne step between successive impacts of the fore leading limb and hind trailing limb.

Calculations were made of the duration of the entire gallop stride, stride frequency being the reciprocal of that value. Also calculated were limb contact durations, limb non-contact durations and durations of each successive gallop stride temporal phase created by a different combination of limbs (or no limbs) in contact with the ground. Successive gallop stride temporal phases were termed hind trail unipedal contact, hind bipedal contact, hind lead unipedal contact, fore trail diagonal bipedal contact, fore trail unipedal contact, fore bipedal contact, fore lead unipedal contact and the airborne phase. The sum of durations of the unipedal contact phases and the sum of durations of the bipedal contact phases ("total overlap time"; Pratt and O'Connor, 1978) were also calculated for each stride.

Statistical analysis on gallop stride data were performed with commercially available software (SAS, 1982). Values from each camera were considered replicate observations. The independent, categorical, class variables considered in the model as determining the kinematic properties of gallop strides included individual horse, day and lead effects. Continuous covariables included sequence of trials for each horse each day, stride length and stride frequency. Gallop stride limb contact kinematic variables, considered dependent variables, were fitted to a single multiple linear regression/homogeneity of slopes model that included main class effects; all two-factor interactions of class effects; covariables; and heterogeneity of slope effects of class variables with covariables. Effects with type III sums of squares probabilities of $P < .05$ were considered significant. The effects of velocity (Deuel and Lawrence, 1985a) and lead (Deuel and Lawrence, 1985b) on gallop stride limb contact variables have been presented elsewhere.

It should be noted that once stride frequency and stride length effects are partitioned out in the statistical analysis, results are similar whether variables are expressed as absolute durations (sec), absolute distances (m), or as a proportion of the entire stride duration or stride length (%). Absolute values are emphasized in these Results

Results

Body weights, withers heights and segmental lengths characterizing the 4 subjects are given in Table 1. Horses differed ($P < .05$) in shoulder length, forearm length, femur length, tibia length, hind cannon length, withers height and body weight. Horses were not significantly different ($P > .10$) in neck length, arm length, fore cannon length, fore pastern length, pelvis length and hind pastern length.

Table 2 presents the effect of the individual horse on gallop stride variables. Horses differed in average velocity ($P < .001$), which was associated primarily with differences in gallop stride frequency ($P = .05$). Stride length was not significantly different between horses. All other variables were analyzed on the basis of a constant (average) stride frequency and constant (average) stride length.

There were no significant differences between horses in total stride length or in the linear distance between any two successive hoof impacts. Of the temporal gallop stride variables, inter-individual differences were present ($P < .05$) in both the contact and non-contact durations for the fore leading limb and the fore trailing limb. Horses also differed ($P < .05$) in the hind leading limb contact duration and the sum of bipedal contact phases. Of the component stride temporal phases, individual differences ($P < .05$) were present in fore trail diagonal bipedal contact, fore trail unipedal contact and fore bipedal contact.

TABLE 1. Body measurements of horses.

Measurement	Horse*				SD†	Probability horse effect‡
	A	B	C	D		
Neck (cm)	62.8	65.8	60.8	64.8	2.9	.160
Shoulder (cm)	37.5	38.0	34.2	36.0	1.1	.007
Arm (cm)	25.2	26.5	25.5	26.0	2.2	.857
Forearm (cm)	45.5	45.8	41.8	42.2	1.0	.001
Fore cannon (cm)	25.5	25.2	24.8	26.8	1.0	.110
Fore pastern (cm)	7.8	7.2	7.0	6.8	.6	.246
Pelvis (cm)	26.8	27.2	25.5	26.2	1.1	.226
Femur (cm)	30.2	32.0	34.5	32.0	1.3	.019
Tibia (cm)	50.0	51.0	44.5	48.8	1.1	.001
Hind cannon (cm)	39.5	38.8	37.5	38.0	.6	.015
Hind pastern (cm)	7.5	7.5	6.8	7.0	.6	.336
Withers ht (cm)	152.2	154.9	149.0	152.7	1.3	.004
Body wt (kg)	523	523	488	500	2	.001

*Values represent means of measurements on 2 days on right and left sides of the body for segment lengths ($n = 4$); means of a single weighing on 2 days for body wt ($n = 2$) and means of 4 measurements on 1 day for withers ht ($n = 4$). Methods have been detailed by Deuel (1985).

†Standard deviation.

‡Probability of no difference between horses.

Across all gallop strides observed the hind trail contact duration was longer ($P < .05$) than that of any other limb, but there was no significant difference between contact durations of hind lead, fore trail and fore lead limbs when data from left and right leads (Deuel and Lawrence, 1985b) were pooled. Each horse of this study followed this general trend. However, slightly different patterns of limb contact durations were present for each individual. Horse A had a relatively long hind lead contact duration, with intermediate values for other limbs. Horse B had a longer ($P < .05$) hind trail contact than any other horse, but tended to have shorter fore limb contact durations than other horses. Horse C had a relatively long fore trail contact duration, but tended to have short hind limb contact durations. Horse D had a long fore lead contact duration, with intermediate values for other limbs.

Figure 1 is a diagram of a representative gallop stride (Deuel and Lawrence, 1984), derived from the average of all 62 gallop strides of this study. Figure 2 similarly diagrams the individual gallop stride temporal patterns for the four subjects, adjusted for velocity and lead effects.

Discussion

The individual gallop gait characteristics of a group of 4 Quarter Horse fillies were documented in this study. Although measurable differences were present in some morphometric variables, as would be expected in repeated measurements made on individuals within any group of animals, the interindividual differences were small in absolute value. Since the group of horses used in this study were of similar breeding and had

TABLE 2 Effect of individual horse on gallop stride variables.

Item	Horse*				SD†	Probability Horse Effect‡
	A	B	C	D		
<i>Number of strides</i>	17	12	16	17		
Velocity (m/sec)	12.15	12.93	13.24	12.05	.02	.001
Stride frequency (sec ⁻¹)	2.42	2.59	2.67	2.42	.10	.051
Stride length (m)	5.06	5.11	4.99	5.05	.10	.117
<i>Step Lengths (m)</i>						
Hind step	.84	.92	.71	.89	.08	.372
Mid-step	2.09	1.88	2.30	1.83	.11	.235
Fore-step	.99	1.05	1.09	1.04	.03	.365
Airborne step	1.19	1.28	1.04	1.42	.10	.209
<i>Limb contact phases (sec)</i>						
Hind trail	.109	.115	.107	.109	.004	.621
Hind lead	.105	.099	.098	.103	.004	.029
Fore trail	.098	.093	.102	.099	.004	.001
Fore lead	.100	.093	.098	.101	.004	.001
<i>Limb non-contact phases (sec)</i>						
Hind trail	.270	.264	.270	.271	.004	.346
Hind lead	.274	.280	.279	.277	.004	.148
Fore trail	.281	.285	.275	.281	.004	.001
Fore lead	.279	.285	.279	.279	.004	.001
<i>Sequential gallop stride phases (sec)</i>						
Hind trail unipedal	.060	.072	.053	.065	.005	.082
Hind bipedal	.039	.032	.043	.035	.005	.137
Hind lead unipedal	.043	.031	.048	.029	.009	.242
Fore trail diagonal bipedal	.023	.034	.004	.039	.009	.040
Fore trail unipedal	.039	.030	.066	.024	.007	.015
Fore bipedal	.027	.020	.021	.027	.003	.001
Fore lead unipedal	.071	.072	.075	.073	.004	.084
Airborne step	.075	.085	.063	.086	.007	.830
<i>Sums of contact phases (sec)</i>						
Total unipedal	.203	.195	.233	.181	.015	.059
Total bipedal	.088	.085	.069	.100	.011	.001

*Least square means from total of $n = 122$ observations.

†Standard deviation estimated by root mean square error.

‡Probability of no difference between horses.

been raised, trained, ridden and shod similarly, they were considered to be quite homogeneous. Even so, distinctive individualized gallop kinematic patterns were characterized for each of the four horses.

Horses that were not as morphologically and genetically similar as this relatively homogeneous group and that had been subjected to a greater variety of environmental and training influences would also be likely to differ in additional temporal and linear

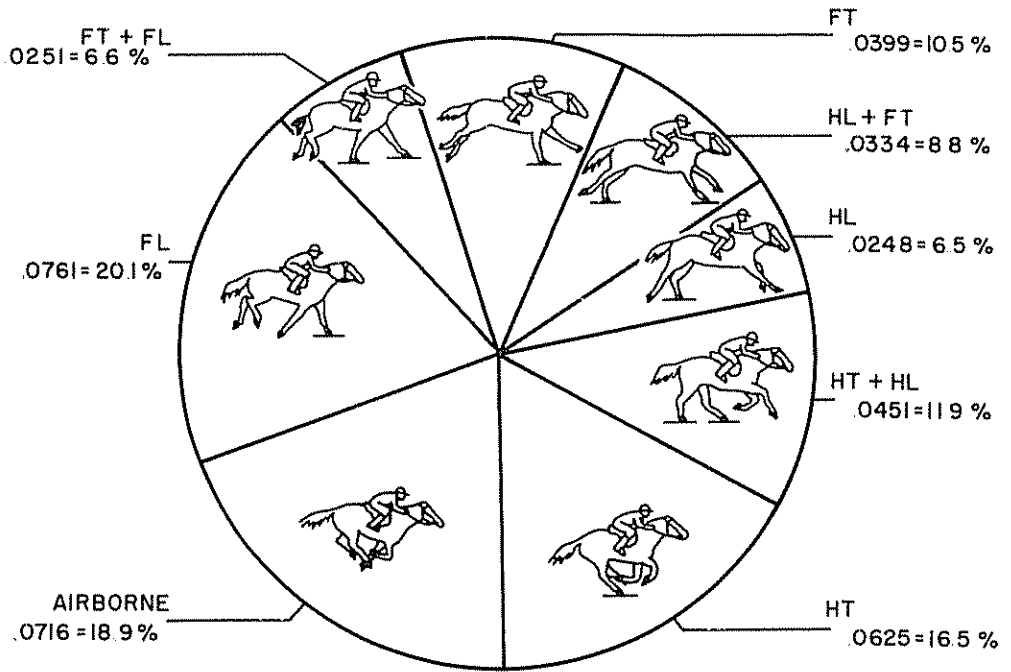


FIGURE 1 Pie gait diagram of sequential ground contact intervals of fore (F) and hind (H), leading (L) and trailing (T) limbs of an average of 62 gallop strides, velocity 13.4 m/sec. Label values indicate duration of each phase (sec) and proportion of the total stride (%).

gallop stride variables that were not found to differ among the horses of this study. A more heterogeneous group of horses would also be expected to show larger differences in the variables that differed between horses of this study.

Velocities of this study compared favorably to the mean velocity of 15 m/sec measured by Leach and Sprigings (1979) for Thoroughbreds at the start of a race. Not surprisingly, they were less than reported by Pratt and O'Connor (1978) for elite Thoroughbred racehorses Secretariat and Riva Ridge. Stride lengths of the Quarter Horses of this study tended to be 1 to 2 meters shorter than those of Thoroughbred racehorses (Pratt and O'Connor, 1978; Leach and Sprigings, 1979; Ratzlaff *et al.*, 1985). Stride frequencies of this study were greater than reported previously for the horse (Rooney, 1984; Ratzlaff *et al.*, 1985). Breed differences probably influenced reported gallop stride variables. Quarter Horses have been selectively bred for their agility and sprinting ability (at distances between 400 and 600 m), while Thoroughbred horses may be likened to middle-distance or cross-country runners (excelling at distances between 1200 and 6500 m). The relatively shorter strides and higher stride frequencies of Quarter Horses may contribute to maneuverability and rapid acceleration, while the longer strides and lower stride frequency of Thoroughbreds may contribute to endurance at longer distances.

Temporal measures of the gallop stride comprised the main source of variability among the gait patterns of the Quarter Horse fillies in this study. The individual idiosyncracies of the gallop stride appeared principally in fore limb timing patterns. It would therefore

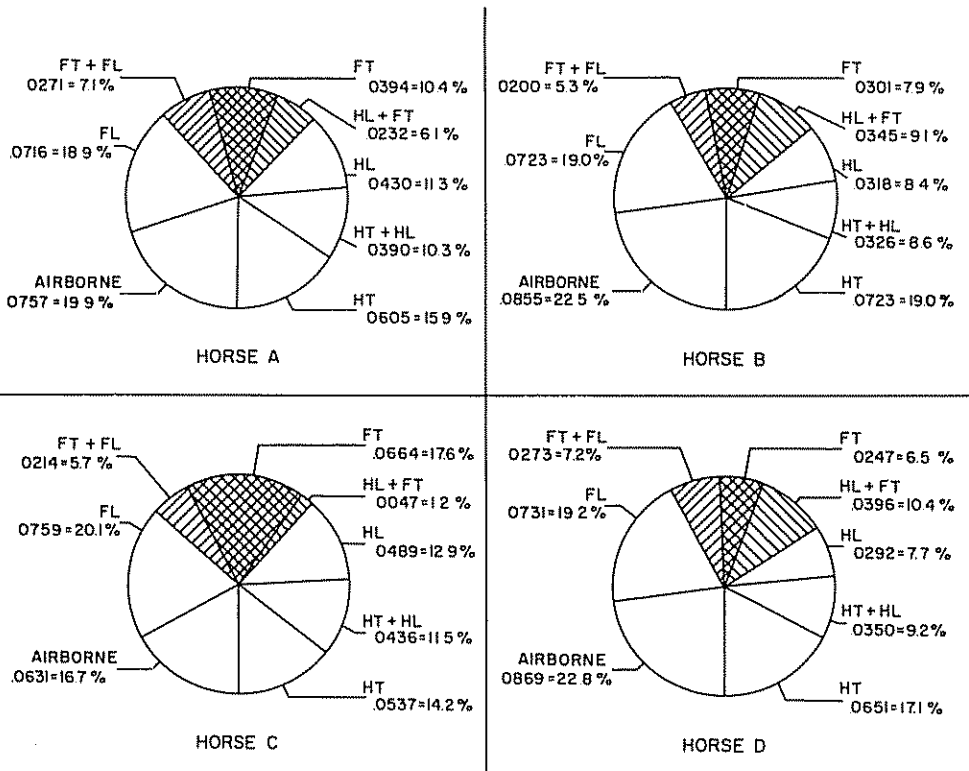


FIGURE 2 Pie gait diagrams of sequential ground contact intervals of fore (F) and hind (H), leading (L) and trailing (T) limbs of four Quarter Horse fillies, standardized to velocity 1.34 m/sec, stride length 5.1 m, stride frequency 2.64 sec⁻¹. Label values indicate duration of each phase (sec) and proportion of the total stride (%). Shaded segments represent gallop stride phases that differ ($P < .05$) between individual horses

seem that timings of fore limb motions comprised the primary feature of individuality of gallop stride motions within this group of similar horses. These characteristics are persistent beyond the level of individual gallop stride frequency differences. Unfortunately, the relatively small number of subjects makes it difficult to associate these gallop stride characteristics with any specific physical attributes or athletic performance capabilities of individual horses. It is important to consider that some limb contact variables shown to differ between horses may also be influenced by velocity (Deuel and Lawrence, 1985a) and by lead (Deuel and Lawrence, 1985b), so these factors must be accounted for in statistical designs.

On the basis of 4 means of gallop limb contact variables, differences in individual performance potential, soundness, "extension" and gallop velocity have been attributed to differences in the sum of gallop stride bipedal contact durations ("total overlap time," Pratt and O'Connor, 1978). However, this study shows individual differences in total bipedal contact duration resulting primarily from differences in fore trail diagonal bipedal contact duration and fore bipedal contact duration, but not from differences in

hind bipedal contact duration. There is a trend for a decrease in the durations of fore trail diagonal bipedal contact and fore bipedal contact, but not hind bipedal contact, with an increase in galloping velocity (Deuel and Lawrence, 1985a). Quarter Horses of this study, merely average athletes, had total bipedal contact durations in the same range as elite Thoroughbred racehorses galloping at higher velocities (Pratt and O'Connor, 1978), both in absolute and relative terms. Total bipedal contact durations measured in this study ranged from .056–.162 sec, or 16.2–37.5% of the total stride, while those measured in 3 observations of Secretariat and Riva Ridge (Pratt and O'Connor, 1978) ranged from .081–.115 sec, or 18.6–27.1%.

This study shows that individual characteristics of gallop stride motion may be documented readily by multiple observations utilizing the cinematographic technique. It also provides reference gallop limb contact variables for normal, sound 2-year-old Quarter Horse fillies with documented physical characteristics. In the future, limb contact variable determination for individual horses may be useful as a selection tool. Further research is needed to determine whether specific kinematic variables that differ between horses are associated with different conformational attributes, different performance levels in athletic competitions or with different incidences of lamenesses.

More research is also needed on the variation in gallop stride characteristics over extended time periods during the productive life of the horse as well as between male and females, different breeds and different strains within a breed. Since velocity (Deuel and Lawrence, 1985a) and bilateral asymmetry (Deuel and Lawrence, 1985b) both influence gallop limb contact variables, it is important to statistically account for these factors in future investigations. These studies would provide a foundation for the use of gallop kinematic variables in selection indices for the purpose of choosing horses suitable for athletic training investments or for breeding successive generations of equine athletes.

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Locomotor Forces of Galloping Horses

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Summary

Vertical forces exerted by galloping horses were measured using instrumented shoes nailed to each hoof. Each shoe consisted of an aluminum racing plate, aluminum transducer mount, and piezoelectric force transducer. The transducers were positioned over the center of the frog of each foot. Simultaneous recordings of the vertical forces exerted by all four feet were obtained from consecutive strides of each horse as it galloped through the straightaways and turns of a one-half mile (0.8 km) research track. The temporal patterns and force-time curves of each limb were repetitive for successive strides. On the straightaways, the greatest forces were exerted by the lead forelimb followed by the lead rear, non-lead fore, and non-lead rear limbs. The mean peak forces and ranges, expressed as a percentage of the total force exerted on the transducers from the four feet, were 29.3 (24.6–33.4), 26.4 (16.2–32.4), 23.3 (18.4–30.4), and 21.0 (17.0–29.3) for the lead front, lead rear, non-lead front, and non-lead rear limbs, respectively. On the turns the greatest forces were exerted by the lead forelimb followed by the non-lead fore, lead rear, and non-lead rear limbs. The mean peak forces and ranges, expressed as a percentage of the total vertical force, were 30.1 (26.3–35.1), 26.3 (23.8–31.5), 23.0 (17.2–25.3), and 20.7 (17.6–25.0) for the lead fore, non-lead fore, lead rear, and non-lead rear limbs, respectively. The greater vertical forces exerted by the front legs of horses galloping through the turns may help explain the propensity for forelimb injuries in racing Thoroughbred horses.

Index terms: Biokinetics; locomotion.

Introduction

Force plates have been used to measure the ground reaction forces exerted by horses moving at various gaits (Goodship *et al.*, 1983; Pratt and O'Connor, 1976; Quddus *et al.*, 1978; Kingsbury *et al.*, 1978; Schryver *et al.*, 1978; Steiss *et al.*, 1982) and under a variety of conditions (Auer *et al.*, 1980; Cheney *et al.*, 1973; Ratzlaff *et al.*, 1985a). The primary advantages of using a force plate to measure locomotor forces are the ease of operation and ability to measure the horizontal force components as well as the vertical component. The disadvantages of the force plate include the inability to measure forces exerted in repetitive strides, difficulty in recording forces exerted by horses