Association between subjective lameness grade and kinetic gait parameters in horses with experimentally induced forelimb lameness

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Objective—To evaluate the association between subjective lameness grades and kinetic gait parameters and assess the variability in kinetic parameters in horses with experimentally induced forelimb lameness.

Animals—32 horses.

Procedures—Forelimb lameness was induced in each horse via injection of lipopolysaccharide into 1 metacarpophalangeal joint (40 experimental trials). Subjective lameness grading and 13 kinetic gait parameters (force plate analysis) were assessed before (baseline) and at 12, 18, and 24 hours after lipopolysaccharide injection. While horses were trotting, kinetic gait analysis was performed for 8 valid repetitions at each time point. Repeated-measures analyses were performed with 8 repetitions for each kinetic parameter as the outcome, and lameness grades, time points after lipopolysaccharide injection, and repetition order as explanatory variables. Sensitivity and specificity of kinetic parameters for classification of horses as sound or lame (in relation to subjective lameness scores) were calculated. Between- and within-horse variabilities of the 13 kinetic parameters were assessed by calculation of coefficients of variation.

Results—Subjective lameness grades were significantly associated with most of the kinetic parameters. Vertical force peak and impulse had the lowest between- and within-horse coefficients of variation and the highest correlations with subjective lameness grade. Vertical force peak had the highest sensitivity and specificity for lameness classification. Vertical force peak and impulse were significantly decreased even in horses with mild or unobservable lameness.

Conclusions and Clinical Relevance—Among the kinetic gait parameters, vertical force peak and impulse had the best potential to reflect lameness severity and identify subclinical forelimb gait abnormalities. (*Am J Vet Res* 2005;66:1805–1815)

Lameness is a major cause of waste and loss of athletic abilities in racing and performance horses.[1,2] To assess gait abnormality in horses, a clinical lameness grading system (based on an officially accepted numerical grading scale[3]) has been popular and extensively used in veterinary practice and research fields.[4-8] However, controversy exists regarding the reliability of subjective lameness assessment (specifically in horses with mild lameness), partly because of poor between-observer agreement.[9,10]

Kinetic gait analysis involving **ground reaction force (GRF)** measurements obtained by use of a force plate has been applied to equine forelimbs for quantification of normal gait[11-22] and lameness.[12,23-29] The application of this technique not only permits clinicians to more objectively assess the lameness status of horses but also provides potential for researchers to more accurately evaluate the effectiveness of new drugs, devices, shoeing procedures, and treatment methods in lame horses. Kinetic gait assessment has also been applied to quantification of lameness severity or gait improvement in dogs.[30-33] Despite its use for these purposes, we are not aware of studies to assess specific kinetic gait parameters or evaluate associations of those parameters with subjective lameness grades in horses with various lameness conditions. Results of previous studies indicate that there are significant differences in some kinetic gait parameters between sound horses and those with lameness as a result of conditions such as navicular disease[25,27,28] and superficial digital flexor tendinitis.[25,26] However, those studies[25-27] involved horses with mild to moderate lameness, but the magnitude of gait abnormality was not subjectively scored for statistical comparison with kinetic gait parameters.

An association between GRF and subjective lameness grade is intuitive but has not been analyzed to our knowledge. Lameness implies changes in locomotion symmetry caused by musculoskeletal pain; therefore, higher lameness scores probably represent a larger magnitude of disruption of normal limb forces. Consequently, kinetic gait parameters that reflect GRF may be expected to vary in their association with subjective observation of lameness. Certain kinetic parameters may be closely correlated with the degree of lameness (ranging from mild to severe) and perhaps be capable of detecting even slight changes in limb forces that cannot be subjectively identified.

The objective of the study reported here was to evaluate the association between subjective lameness grades and kinetic gait parameters and assess the variability in kinetic parameters in horses with experimentally induced forelimb lameness. The study involved clinically healthy horses in which lameness was experimentally induced via an intra-articular injection of **lipopolysaccharide (LPS)** by use of an established protocol,[34-38] and 13 routinely measured kinetic parameters

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were calculated. We hypothesized that a subset of kinetic parameters could be identified with low between- and within-horse variability and high association with subjective lameness grade.

Materials and Methods

Experimental design and terms—Forty experimental trials were performed involving 32 horses; 8 of these horses were used twice (each forelimb was used only once) at an interval of at least 3 months. For each trial, lameness was induced in 1 forelimb once by use of an intra-articular injection of LPS into the metacarpophalangeal joint. Each trial involved subjective and kinetic gait assessments, which were made at several time points as follows: 1 day prior to (baseline) and 12, 18, and 24 hours after LPS injection. The first 8 trials included only 3 time points (baseline and 12 and 24 hours after LPS injection), and 32 trials included 4 time points (baseline and 12, 18, and 24 hours after LPS injection). Eight repetitions of kinetic gait analysis were performed at each time point, and their order was recorded. For each of these repetitions, a computer system was used to 3-dimensionally analyze the GRF and provide 3 force-time curves corresponding to each force direction **(Figures 1 and 2)**. By use of these curves, 13 kinetic parameters were calculated for each repetition.

Horses—All horses were owned by The Ohio State University. The age range of the 32 horses was 2 to 19 years (median age, 8.5 years), and weight range was 428 to 640 kg (median weight, 539.5 kg); there were 19 mares, 2 stallions, and 11 geldings. Six breed groups were represented (13 Quarter Horses, 6 Thoroughbreds, 5 Appaloosas, 4 Standardbreds, 2 warmbloods, and 2 Arabians). For all horses, no abnormalities were detected during lameness examination or limb palpation or via radiography of the metacarpophalangeal joints. The horses were trained for 3 days to familiarize them with the force plate and establish calm trotting over the force plate. The hooves were trimmed by an experienced farrier in normal balance prior to the initiation of the trials. All experimental procedures were approved by the Institutional Laboratory Animal Care and Use Committee of The Ohio State University.

Lameness induction—Forelimb lameness was induced via an intra-articular injection of LPS; a subset of horses (30/40 trials; 26/32 horses) received oral administration of a variety of nonsteroidal anti-inflammatory drugs (experimental drugs in different dosages and phenylbutazone[a] [2 g]) 1 hour prior to the LPS injection to induce variable lameness severity that could not be predicted by the subjective or kinetic gait evaluator. To induce metacarpophalangeal joint synovitis, LPS (0.0005 ng/kg) was injected into a randomly chosen metacarpophalangeal joint after sedation of the horse and aseptic preparation of the joint. All horses were confined to a 3.66 × 3.66-m stall during the study period. Within the confines of the experimental design, blinding was optimized by performing the subjective and kinetic evaluations at a location separate from that at which other aspects of the study (eg, administration of injections and housing) were undertaken. The lameness evaluator (ALB) had no knowledge of the time that the LPS injection was administered, the limb that was treated, or whether nonsteroidal anti-inflammatory drugs had been administered. The change in lameness with time could not be predicted by the evaluator because it was unknown whether anti-inflammatory medication had been administered.

Subjective lameness evaluation—Prior to the kinetic gait analysis, subjective lameness grades were assigned to each horse by an experienced equine clinician (ALB) using the American Association of Equine Practitioners' lameness grading scale[3] (modified to include 0.5 increments). The evaluator performed a complete, direct-contact lameness examination before assigning a subjective lameness grade. This included visualization of each horse's gait from the front, side, and rear. The grade was assigned when the evaluator was confident the scores reflected the observed gait. Half grades were assigned when the evaluator decided that lameness severity should be allocated between 2 ordinal scores.

Kinetic gait analysis—An examination aisle (3 × 20 m) with an in-ground, stationary force plate[b] and computer analysis system[b] was used for data collection. The central force plate and aisle were covered by a mat to prevent horses from slipping and avoid recognition of the plate. The mat was cut around the force plate to prevent distracting forces. Data sampling rate was 500 Hz, and data were filtered by a stopband frequency of 80 Hz. Gait velocity was measured by use of 2 photoelectric switches[b] (spaced 5 m apart) that were connected to the computer analysis system. Following subjective lameness evaluation at each time point, 8 valid repetitions were recorded for the lame limb while the horse was trotting. One experienced handler trotted the horses at a consistent speed straight through the test aisle. A valid measurement was defined as a passage by the horse over the force plate during which the hoof of the limb of interest fully contacted the surface of the plate and the gait velocity was within the range of 2.5 to 3.5 m/s.

For each repetition, 3 force-time curves (vertical, craniocaudal, and lateromedial components of GRF) were calculated by the computer analysis system, in which accelerating force in the craniocaudal axis and lateral force in the lateromedial axis were assigned positive values (Figure 1). Thirteen kinetic gait parameters were calculated from the 3 force-time curves for each repetition. Specific kinetic gait parameters included vertical force peak and impulse (area under the force-time curve), craniocaudal peak force and impulse (divided into braking and propulsive components), lateral and medial force peaks, lateromedial force impulse, stance time, time of zero craniocaudal force at the transition between braking and propulsive forces, and 2 slopes of the vertical GRF-time curve. Slope 1 was measured between the first and second peaks in the craniocaudal force, and slope 2 was measured between the second and third peaks in the craniocaudal force-time curve (Figure 2). Vertical, braking, propulsive, and lateromedial force impulses were calculated by time integration of the force-time curves. Force peaks were normalized by horses' weight and expressed as Newtons per kilogram. Impulses were multiplied by time, normalized by weight, and expressed as Newton-seconds per kilogram (Ns/kg). Stance time was expressed as seconds, and the time of zero craniocaudal force was expressed as a percentile of the duration of stance time. Slopes of the vertical force-time curve were calculated as the vertical force (N), normalized by Newton body weight (N), divided by the duration of the slope portion (seconds), which resulted in dimensionless units.

Statistical methods—Data were analyzed by use of a commercial statistical computer program.[c] Horses that were subjectively sound (lameness grade 0) were subcategorized as follows: baseline (grade 0.0[B]), sound gait prior to the LPS injection; subclinical lameness (grade 0.0[S]), sound gait at all time points after LPS injection; and recovered lameness (grade 0.0[R]), sound gait following development of subjectively observable lameness. The associations between kinetic gait parameters and subjective lameness grades were assessed via multivariate repeated-measures analysis and calculation of the correlation coefficient, sensitivity, and specificity. Variability of each kinetic parameter was assessed by calculation of the **coefficient of variation (CV)** between and within horses.

To evaluate whether a kinetic parameter was significantly associated with the subjective lameness grade, repeated-measures analysis was performed. For each of the 13 kinetic parameters, 8 valid repetitions/time point and 3 or 4 time points/trial were used as the outcome variables. To account for the correlated data structure and the fact that 8 horses were each used in 2 experimental trials, different covariance structures, including variance components, first-order auto-regressive, compound symmetry, and unstructured, were tested[39,40] to evaluate which fit the data best. Possible explanatory variables considered in the modeling were subjective lameness grades, time points after LPS injection, order of the 8 repetitions, and sex, breed, age, and weight of the horse. First, univariate repeated-measures analyses were performed with the kinetic parameters as the outcome variables and each of the possible explanatory variables in the model, one at a time. If the explanatory variable was associated with at least one of the kinetic gait parameters (a value of $P < 0.2$ was considered significant), it was included in a multivariate model. Horse was treated as a random variable in the model, and the repeated measures were considered nested within time points and trials. Second, multivariate repeated-measures analyses were performed with kinetic parameter values as outcome variables and the subjective lameness grades, time points after LPS injection, and order of the 8 repetitions as explanatory variables. The program setting described above (random variable, nesting, and fit statistics) was used in this analysis. To adjust for inflated *P* values attributable to the simultaneous evaluation of 13 kinetic parameters, the overall significance level of multivariate repeated-measures analysis was set at $P < 0.005$.

To determine whether force plate analysis could detect subclinical lameness, data from trials in which horses had no subjectively observable lameness across all time points were extracted from the original data set. For this separate data set, multivariate repeated-measures analyses were performed as described with the time points after LPS injection and order of the 8 repetitions as explanatory variables.

To test whether kinetic parameters were significantly altered during the examination by the order of the 8 repetitions within each time point and whether this was dependent on the severity of lameness, the original data set was divided into 5 groups on the basis of lameness severity. These groups were as follows: baseline (grade 0.0[B]), no observable lameness (grades 0.0[S] and 0.0[R]), mild lameness (grades 0.5 and 1.0), moderate lameness (grades 1.5 to 2.5), and severe lameness (grades 3.0 to 4.0). For each of these 5 separate data sets, repeated-measures analysis was performed as described, with the order of the 8 repetitions as the explanatory variable.

Additionally, correlation between subjective lameness grades and kinetic gait parameters was evaluated by use of

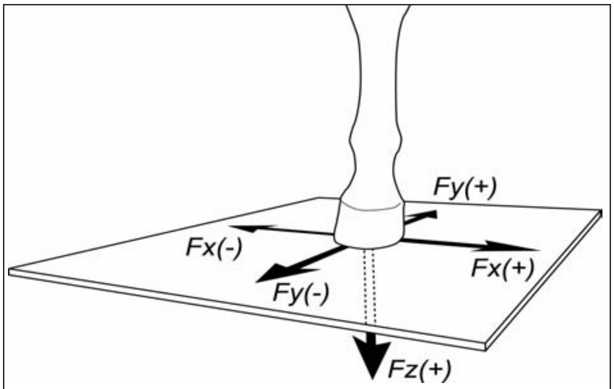

Figure 1—Three-dimensional image of ground reaction forces produced by the left front foot of a horse during contact with a force plate during assessment of kinetic gait parameters. Fx(-) = Medial force (negative x-axis force). Fx(+) = Lateral force (positive x-axis force). Fy(+) = Propulsive force (positive y-axis force). Fy(-) = Braking force (negative y-axis force). Fz(+) = Vertical force (positive z-axis force).

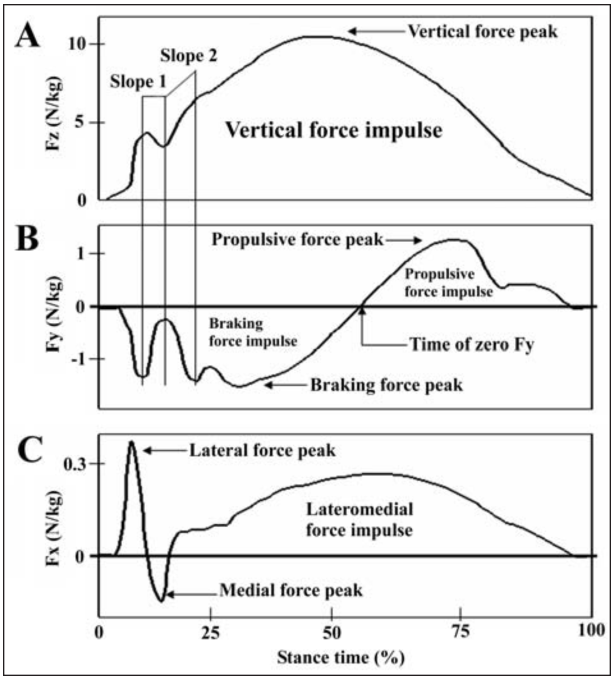

Figure 2—Computer-generated ground reaction force-time curves typical of those obtained during assessment of 13 kinetic gait parameters in horses. A—Vertical axis force (Fz). B—Craniocaudal axis force (Fy). C—Lateromedial axis force (Fx). Slope 1 was measured between the first and second peaks in the craniocaudal force-time curve, and slope 2 was measured between the second and third peaks in the craniocaudal force-time curve. Time of zero Fy = Time of zero craniocaudal force at the transition between braking and propulsive forces.

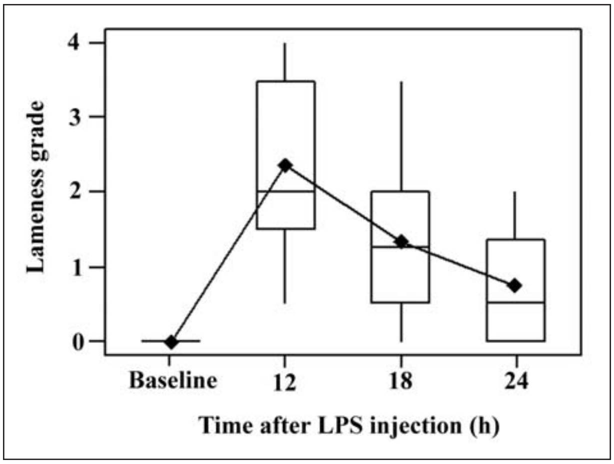

Figure 3—Box-and-whisker plots of the mean subjective lameness grades assessed during 32 trials in 26 horses in which lameness was induced experimentally via intra-articular injection of lipopolysaccharide (LPS). Lameness assessments were made at baseline (1 day prior to LPS injection) and 12, 18, and 24 hours after LPS injection. In each box plot, the diamond indicates the mean value, the box outline includes the middle 50% of the data, the central horizontal line indicates the median, and the whiskers indicate the maximum and minimum datum points. No potential outliers were identified.

the Spearman nonparametric method. For these analyses, the mean of the 8 repetitions was calculated at each time point and matched with a subjective lameness grade at that time point. For the 8 horses that were used for 2 trials, the second trials were eliminated from this analysis. Spearman correlation coefficients were calculated between lameness grades and the mean values of kinetic parameters for the data in each of 3 time points (12, 18, and 24 hours after LPS injection). The data at baseline were not used because lameness grade was zero for each horse; thus, there was no variability. The calculations were made separately for each of the 13 kinetic parameters, and a value of $P < 0.005$ was considered significant.

For each of the kinetic parameters that was significantly associated with lameness, sensitivity and specificity were calculated by use of different cutoff values for the

Table 1—Crude mean ± SE kinetic gait analysis parameters assessed during 40 experimental trials by use of a force plate in 32 healthy adult horses with various levels of forelimb lameness induced via intra-articular injection of lipopolysaccharide (LPS). Kinetic gait analysis was performed at a trot for 8 valid repetitions at various time points, and 13 kinetic parameters were calculated; 8 of the 32 horses were used twice (each forelimb was used only once) at an interval of at least 3 months. The *P* values indicate the overall significance level in the association of each kinetic parameter with the lameness grade or the repetition order obtained from the multivariate repeated-measures analysis. Slope 1 was measured between the first and second peaks in the craniocaudal force-time curve, and slope 2 was measured between the second and third peaks in the craniocaudal force-time curve.

Explanatory variables	Gait velocity (m/s)	Vertical force peak (N/kg)	Vertical force impulse (Ns/kg)	Braking force peak (N/kg)	Braking force impulse (Ns/kg)	Propulsive force peak (N/kg)	Propulsive force impulse (Ns/kg)
Lameness grade	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$
Grade 0.0(B)	3.04 ± 0.01	9.79 ± 0.05	1.99 ± 0.01	–1.11 ± 0.02	–0.118 ± 0.003	0.71 ± 0.01	0.065 ± 0.001
Grade 0.0(S)	3.02 ± 0.01	9.98 ± 0.06	1.97 ± 0.01	–1.11 ± 0.03	–0.115 ± 0.003	0.67 ± 0.02	0.059 ± 0.002
Grade 0.0(R)	3.05 ± 0.01	9.31 ± 0.07*	1.97 ± 0.01	–1.10 ± 0.03	–0.117 ± 0.003	0.71 ± 0.01	0.068 ± 0.002
Grade 0.5	3.03 ± 0.01	9.06 ± 0.06†	1.92 ± 0.01	–1.01 ± 0.02	–0.111 ± 0.003	0.69 ± 0.02	0.069 ± 0.002
Grade 1.0	3.05 ± 0.01	8.19 ± 0.11†	1.76 ± 0.02‡	–0.99 ± 0.03	–0.096 ± 0.003	0.66 ± 0.01	0.065 ± 0.002
Grade 1.5	3.02 ± 0.01	7.94 ± 0.14†	1.74 ± 0.03†	–0.90 ± 0.02‡	–0.096 ± 0.004	0.61 ± 0.02	0.063 ± 0.002
Grade 2.0	3.04 ± 0.01	7.87 ± 0.09†	1.63 ± 0.02†	–0.94 ± 0.02‡	–0.086 ± 0.002*	0.62 ± 0.01	0.059 ± 0.002
Grade 2.5	2.96 ± 0.03	6.30 ± 0.15†	1.41 ± 0.02†	–0.76 ± 0.03‡	–0.073 ± 0.003‡	0.47 ± 0.03*	0.044 ± 0.003*
Grade 3.0	3.00 ± 0.02	6.26 ± 0.11†	1.40 ± 0.03†	–0.72 ± 0.02†	–0.066 ± 0.003†	0.51 ± 0.01*	0.055 ± 0.002
Grade 3.5	3.03 ± 0.02	4.97 ± 0.12†	1.06 ± 0.04†	–0.66 ± 0.03†	–0.039 ± 0.003†	0.44 ± 0.01†	0.045 ± 0.003*
Grade 4.0	2.88 ± 0.06†	4.15 ± 0.26†	0.98 ± 0.05†	–0.64 ± 0.05†	–0.038 ± 0.003†	0.42 ± 0.03†	0.035 ± 0.004†
Repetition order	$P = 0.211$	$P < 0.001$	$P < 0.0001$	$P = 0.855$	$P = 0.640$	$P = 0.356$	$P = 0.292$
1st repetition	3.03 ± 0.01	8.52 ± 0.15	1.78 ± 0.03	–1.01 ± 0.03	–0.104 ± 0.004	0.63 ± 0.02	0.059 ± 0.002
2nd repetition	3.03 ± 0.01	8.60 ± 0.15	1.79 ± 0.03	–0.99 ± 0.02	–0.100 ± 0.004	0.65 ± 0.02	0.062 ± 0.002
3rd repetition	3.04 ± 0.01	8.62 ± 0.14§	1.79 ± 0.03	–0.99 ± 0.02	–0.100 ± 0.004	0.65 ± 0.01	0.061 ± 0.002
4th repetition	3.03 ± 0.01	8.59 ± 0.14	1.80 ± 0.03	–1.02 ± 0.03	–0.105 ± 0.004	0.64 ± 0.02	0.060 ± 0.002
5th repetition	3.01 ± 0.01	8.71 ± 0.14||	1.80 ± 0.03	–1.00 ± 0.03	–0.100 ± 0.003	0.65 ± 0.02	0.061 ± 0.002
6th repetition	3.03 ± 0.01	8.74 ± 0.14||	1.81 ± 0.03¶	–1.01 ± 0.02	–0.099 ± 0.003	0.67 ± 0.01	0.064 ± 0.002
7th repetition	3.00 ± 0.01	8.74 ± 0.13||	1.82 ± 0.03¶	–0.99 ± 0.02	–0.102 ± 0.003	0.65 ± 0.02	0.062 ± 0.002
8th repetition	3.04 ± 0.01	8.82 ± 0.14||	1.83 ± 0.02¶	–1.01 ± 0.03	–0.103 ± 0.003	0.66 ± 0.02	0.062 ± 0.002

Explanatory variables	Lateral force peak (N/kg)	Medial force peak (N/kg)	Lateromedial force impulse (Ns/kg)	Slope 1 (N/N/s)	Slope 2 (N/N/s)	Stance time (s)	Time of zero y-axis force (% stance)
Lameness grade	$P = 0.0234$	$P = 0.031$	$P = 0.154$	$P = 0.010$	$P = 0.002$	$P = 0.334$	$P = 0.017$
Grade 0.0(B)	0.31 ± 0.01	–0.27 ± 0.01	0.015 ± 0.003	2.28 ± 0.28	12.83 ± 0.17	0.330 ± 0.002	54.3 ± 0.4
Grade 0.0(S)	0.32 ± 0.01	–0.27 ± 0.01	0.024 ± 0.003	1.85 ± 0.38	13.41 ± 0.25	0.324 ± 0.002	54.3 ± 0.5
Grade 0.0(R)	0.29 ± 0.02	–0.26 ± 0.02	0.011 ± 0.004	2.91 ± 0.41	11.62 ± 0.29	0.348 ± 0.002	52.5 ± 0.4
Grade 0.5	0.23 ± 0.01*	–0.23 ± 0.01	0.010 ± 0.004	2.17 ± 0.38	11.81 ± 0.28	0.343 ± 0.002	53.1 ± 0.4
Grade 1.0	0.28 ± 0.02	–0.20 ± 0.01*	0.032 ± 0.004	3.09 ± 0.37	11.08 ± 0.28*	0.336 ± 0.003	52.0 ± 0.6
Grade 1.5	0.26 ± 0.01	–0.21 ± 0.01	0.017 ± 0.004	2.03 ± 0.54	11.35 ± 0.35*	0.351 ± 0.004	51.7 ± 0.9
Grade 2.0	0.22 ± 0.02‡	–0.23 ± 0.01	0.011 ± 0.003	2.84 ± 0.31	10.32 ± 0.26*	0.326 ± 0.002	52.9 ± 0.5
Grade 2.5	0.22 ± 0.03	–0.20 ± 0.02	0.015 ± 0.004	1.65 ± 0.58	9.24 ± 0.48‡	0.332 ± 0.004	53.8 ± 1.0
Grade 3.0	0.21 ± 0.01*	–0.16 ± 0.01‡	0.010 ± 0.003	1.40 ± 0.30	9.16 ± 0.29†	0.352 ± 0.005	49.9 ± 0.5*
Grade 3.5	0.19 ± 0.02‡	–0.19 ± 0.02*	0.016 ± 0.003	0.16 ± 0.39‡	8.09 ± 0.32†	0.317 ± 0.007	48.4 ± 1.3*
Grade 4.0	0.16 ± 0.02‡	0.22 ± 0.02	0.018 ± 0.004	0.47 ± 0.39*	6.84 ± 0.58†	0.349 ± 0.013	56.1 ± 2.3
Repetition order	$P = 0.269$	$P = 0.687$	$P = 0.581$	$P = 0.163$	$P = 0.082$	$P = 0.333$	$P = 0.482$
1st repetition	0.29 ± 0.01	–0.25 ± 0.01	0.014 ± 0.003	2.10 ± 0.40	11.94 ± 0.30	0.334 ± 0.003	53.6 ± 0.7
2nd repetition	0.29 ± 0.01	–0.23 ± 0.01	0.021 ± 0.004	2.18 ± 0.37	11.81 ± 0.30	0.332 ± 0.003	53.0 ± 0.6
3rd repetition	0.27 ± 0.01	–0.23 ± 0.01	0.017 ± 0.004	2.08 ± 0.36	11.26 ± 0.27	0.334 ± 0.003	53.3 ± 0.5
4th repetition	0.26 ± 0.01	–0.24 ± 0.01	0.017 ± 0.003	1.98 ± 0.37	11.21 ± 0.26	0.337 ± 0.003	53.5 ± 0.6
5th repetition	0.28 ± 0.02	–0.24 ± 0.01	0.017 ± 0.003	2.27 ± 0.32	11.66 ± 0.27	0.334 ± 0.002	52.8 ± 0.5
6th repetition	0.27 ± 0.01	–0.26 ± 0.01	0.014 ± 0.004	1.61 ± 0.37	11.56 ± 0.26	0.335 ± 0.003	52.7 ± 0.5
7th repetition	0.26 ± 0.01	–0.24 ± 0.01	0.015 ± 0.003	2.12 ± 0.35	11.73 ± 0.26	0.336 ± 0.003	52.7 ± 0.5
8th repetition	0.27 ± 0.01	–0.23 ± 0.01	0.017 ± 0.003	2.18 ± 0.34	11.70 ± 0.28	0.336 ± 0.003	53.3 ± 0.6

*Value significantly ($P < 0.05$) different from the grade 0.0(B) value for this kinetic gait parameter. †Value significantly ($P < 0.001$) different from the grade 0.0(B) value for this kinetic gait parameter. ‡Value significantly ($P < 0.01$) different from the grade 0.0(B) value for this kinetic parameter. §Value significantly ($P < 0.05$) different from the first repetition value for this kinetic gait parameter. ||Value significantly ($P < 0.001$) different from the first repetition value for this kinetic gait parameter. ¶Value significantly ($P < 0.01$) different from the first repetition value for this kinetic gait parameter.

Time of zero y-axis force = Time of zero craniocaudal force at the transition between braking and propulsive forces. Grade 0.0(B) lameness = Baseline (sound gait 1 day prior to the LPS injection). Grade 0.0(S) lameness = Subclinical lameness (sound gait at all time points after LPS injection). Grade 0.0(R) lameness = Recovered lameness (sound gait following development of subjectively observable lameness). Grade 0.5 to 4.0 lameness = Lameness grades assigned according to the American Association of Equine Practitioners' lameness grading scale[3] (modified to include 0.5 increments).

parameters to classify a horse as either sound or lame. Subjective lameness grade was used as the gold standard to separate data into either sound (lameness grades 0, 0.0[B], 0.0[S], and 0.0[R]) or lame (lameness grades 0.5 to 4.0) gaits. Sensitivity of each kinetic parameter represented the probability of obtaining a positive test result in lame horses. Specificity represented the probability of obtaining a negative test result in sound horses. Receiver operating characteristic curves were then created, and the cutoff value that maximized the sensitivity and specificity for classification of a horse as either sound or lame was determined for each kinetic gait parameter.

For each lameness grade, between- and within-horse variabilities were evaluated by calculation of CVs. First, all data points of each kinetic parameter were separated by lameness grade categories, such as grade 0.0(B), grade 0.0(S), grade 0.0(R), and grades 0.5 through 4.0 (ie, 11 lameness groups). Applying each of these data sets individually, between-horse CV was determined as follows: the 8 repetitions were averaged for each horse, the mean and SD of those means were calculated by lameness grade, and between-horse CV was calculated as that SD value divided by the mean value. Thus, a single CV value was determined for each lameness grade. The CV values were calculated for each kinetic parameter. Applying each of the 11 data sets separately, within-horse CV was determined as follows: the mean and SD were calculated for the 8 repetitions for each horse and within-horse CV was calculated as that SD value divided by the mean value; for each lameness grade group, all of these within-horse CV values were averaged as the estimation of overall within-horse CV. These calculations were made separately for each kinetic parameter.

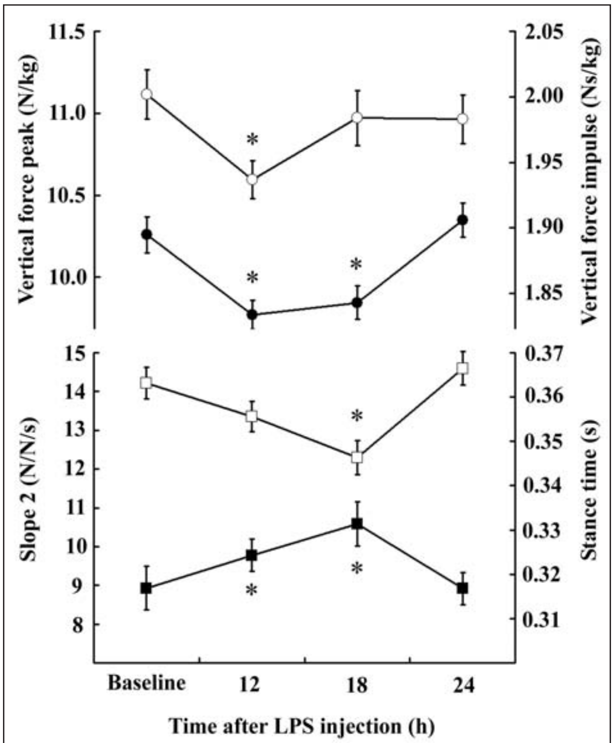

Figure 4—Mean ± SE vertical force peak (closed circle), vertical force impulse (open circle), slope 2 (open square), and stance time (closed square) obtained from 8 experimental trials involving 8 horses that had no subjectively observable lameness (ie, subclinical lameness; grade 0.0[S]) before (baseline) and at 12, 18, and 24 hours after intra-articular injection of LPS. *Value significantly ($P < 0.005$) different from the baseline value of that parameter.

Results

Lameness conditions—In 8 of 40 trials (involving 8 horses), lameness was not observed by the experienced clinician at any time point after the LPS injection. For 32 trials (involving 26 horses) during which horses were graded as lame, severity of lameness peaked at 12 hours following the intra-articular administration of LPS and subsequently decreased **(Figure 3)**. For 2 horses, data were not available for one of the time points. The distribution of subjective lameness grades was as follows: grade 0.0(B), 40 time points; grade 0.0(S), 22 time points; grade 0.0(R), 14 time points; grade 0.5, 15 time points; grade 1.0, 13 time points; grade 1.5, 11 time points; grade 2.0, 16 time points; grade 2.5, 3 time points; grade 3.0, 6 time points; grade 3.5, 6 time points; and grade 4.0, 4 time points.

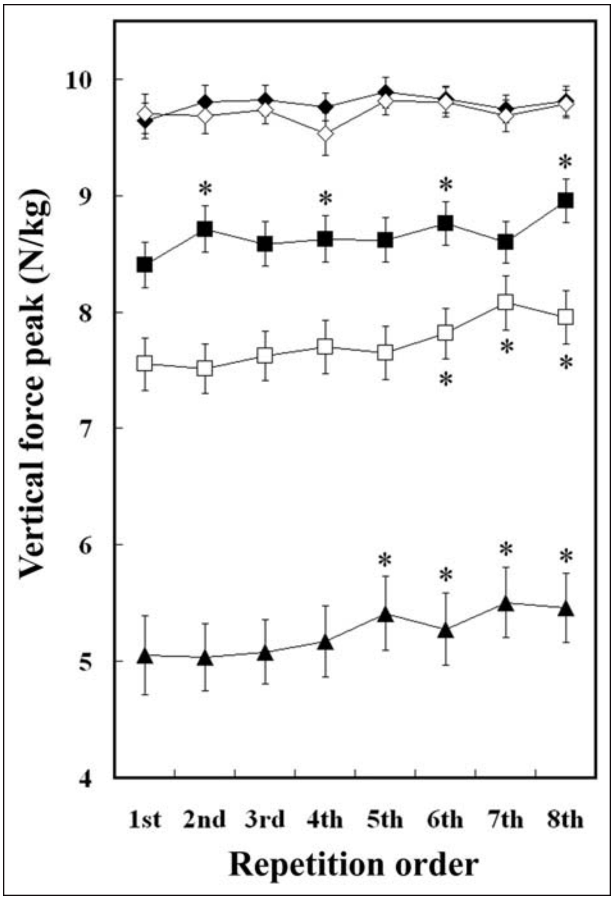

Figure 5—Mean ± SE vertical force peak values for each repetition order in horses with various levels of experimentally induced forelimb lameness. Data presented were obtained at baseline (1 day prior to intra-articular injection of LPS; closed diamond) and for horses that were sound (grades 0.0[S] and 0.0[R] {recovered lameness or sound gait following development of subjectively observable lameness}; open diamond), mildly lame (grades 0.5 and 1.0; closed square), moderately lame (grades 1.5, 2.0, and 2.5; open square), or severely lame (grades 3.0, 3.5, and 4.0; closed triangle) after LPS injection. The distribution of data in each group was as follows: baseline, 40 time points; sound, 36 time points; mildly lame, 28 time points; moderately lame, 30 time points; and severely lame, 16 time points. Grades were assigned according to the American Association of Equine Practitioners' lameness grading scale[3] (modified to allow 0.5 increments). The data indicate that lame horses had less lameness as trotting progressed, but the gaits of sound horses were constant during force plate analysis. *Value significantly ($P < 0.005$) different from that of the first repetition of that lameness group. *See* Figure 4 for remainder of key.

Table 2—Spearman correlation coefficients between forelimb lameness grade and kinetic gait parameters at 12, 18, and 24 hours after intra-articular injection of LPS in 32 horses. Forty experimental trials were performed; 8 of the 32 horses were used twice (each forelimb was used only once) at an interval of at least 3 months. The first 8 trials included only 3 time points (baseline and 12 and 24 hours after LPS injection), and 32 trials included 4 time points (baseline and 12, 18, and 24 hours after LPS injection). The baseline lameness grade values were not used in this analysis because there was no variability in lameness grade.

	Time (h) after LPS injection (subjective lameness grade range)		
Kinetic gait parameter	**12 (0–4.0)**	**18 (0–3.5)**	**24 (0–2.0)**
Vertical force peak	–0.882*	–0.784*	–0.644*
Vertical force impulse	–0.849*	–0.746*	–0.549*
Braking force peak	0.679*	0.569*	0.479*
Braking force impulse	0.805*	0.552*	0.398
Propulsive force peak	–0.601*	–0.317	0.180
Propulsive force impulse	–0.331	–0.164	–0.024
Lateral force peak	–0.412	–0.255	–0.178
Medial force peak	0.311	0.156	0.280
Lateromedial force impulse	–0.065	–0.051	0.088
Slope 1	–0.264	0.018	–0.084
Slope 2	–0.651*	–0.457*	–0.319
Stance time	0.054	–0.022	–0.072
Time of zero y-axis force	–0.229	–0.163	–0.147

*Significant ($P < 0.005$) correlation between lameness grade and kinetic gait parameter.
See Table 1 for remainder of key.

Table 3—Sensitivity and specificity for classification of horses as either sound or lame calculated for each of the kinetic parameters that were significantly associated with lameness in a study of 32 horses with experimentally induced forelimb lameness (40 experimental trials). Subjective lameness grade was used as the gold standard to separate data into either sound (lameness grades 0, 0.0[B], 0.0[S], and 0.0[R]) or lame (lameness grades 0.5 to 4.0) gaits. The cutoff values were selected to maximize sensitivity and specificity. Vertical force peak most accurately reflected lameness scores (ie, had the highest simultaneous sensitivity and specificity values).

Kinetic gait parameter	Cutoff value	Sensitivity	Specificity
Vertical force peak (N/kg)	9.1	0.813	0.813
Vertical force impulse (Ns/kg)	1.88	0.767	0.773
Braking force peak (N/kg)	–0.93	0.606	0.720
Braking force impulse (Ns/kg)	–0.095	0.623	0.701
Propulsive force peak (N/kg)	0.63	0.633	0.658
Propulsive force impulse (Ns/kg)	0.057	0.457	0.628
Slope 2 (N/N/s)	10.6	0.594	0.745

See Table 1 for key.

Repeated-measures analyses—Unstructured covariance structure fit the data best and was therefore used in all analyses to account for the correlated data. When each of the potential explanatory variables was used individually in the model, 3 major factors (lameness grade, time point after LPS injection, and order of the 8 repetitions) were significantly associated with at least 1 of the 13 kinetic gait parameters (results not shown); therefore, those were included in the multivariate repeated-measures analysis model as the next step. Other variables including sex, breed, age, and weight were not associated ($P > 0.2$) with any kinetic gait parameter. In the multivariate repeated-measures analysis, subjective lameness grades were significantly associated with most of the kinetic parameters including vertical force peak and impulse, braking force peak and impulse, propulsive force peak and impulse, and slope 2 (**Table 1**). Of those parameters, vertical force peak values were significantly different between baseline and grade 0.5 (mild) lameness or higher grades of lameness. The values of vertical force peak in horses with recovered lameness (grade 0.0[R]) were also significantly lower than the baseline value. The values of vertical force peak and impulse, slope 2, and stance time in the subclinical lameness group (grade 0.0[S]) at the 12- and 18-hour time points were significantly different from their baseline values (**Figure 4**).

Vertical force peak and impulse values were significantly increased after the fourth and fifth repetition, respectively, compared with the first repetition, when the horses were repeatedly trotted over the force plate to obtain the 8 valid measurements (Table 1). However, when the data for the 5 lameness severity groups (baseline; no observable lameness; and mild, moderate, and severe lameness) were analyzed separately, that change was only observed in the mild, moderate, and severe lameness groups but not in the groups of sound horses (baseline and no observable lameness; **Figure 5**). The repeated trotting did not significantly change any of the other kinetic parameters.

The time points after LPS injection were not significantly associated with any of the kinetic parameters when the subjective lameness grades and repetition order were controlled in the model (results not shown). Because of the effort to restrict the trotting speed of the horses within a narrow range, only grade 4.0 lameness data had significantly lower gait velocity, compared with baseline values, but were still within our inclusion range (Table 1).

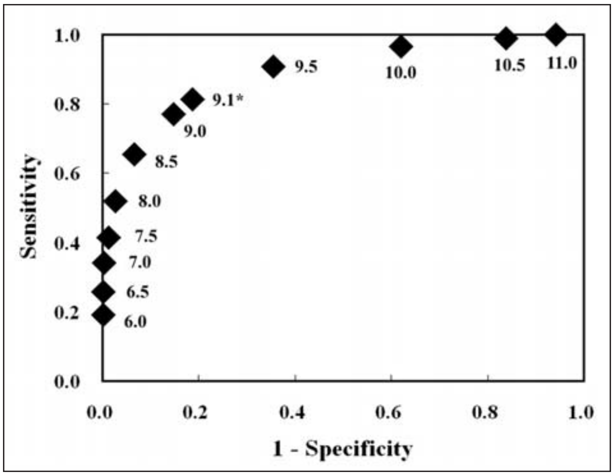

Figure 6—Receiver operating characteristic curve for vertical force peak calculated from 40 kinetic gait trials in 32 horses with forelimb lameness induced via intra-articular injection of LPS. At each datum point, the cutoff value of vertical force peak (N/kg) is indicated. *The cutoff value of 9.1 N/kg simultaneously maximized sensitivity and specificity of this parameter for classification of horses as either sound or lame. Sensitivity represents the probability of lame horses obtaining a vertical force peak value smaller than the cutoff value. Specificity represents the probability of sound horses obtaining a vertical force peak value larger than the cutoff value.

Correlation between subjective lameness grades and kinetic gait analysis parameters—Vertical force peak and impulse and braking force peak were significantly correlated with subjective lameness grades at all 3 time points (**Table 2**). At earlier time points that were associated with a greater range of lameness, subjective lameness grades had a higher correlation with most of the kinetic parameters. The range of lameness grades for 12, 18, and 24 hours after LPS injection was 0 to 4.0, 0 to 3.5, and 0 to 2.0, respectively.

Relative sensitivity and specificity of kinetic gait parameters for classification of lameness—For kinetic gait parameters that had significant association with lameness, the cutoff values that maximized sensitivity and specificity for classification of lameness were determined with subjective lameness grade as the gold standard (**Table 3**). A cutoff value at 9.1 N/kg for vertical force peak appeared to best differentiate between sound and lame horses because of the higher simultaneous sensitivity (0.813) and specificity (0.813), compared with the other kinetic parameters (Table 3; **Figure 6**).

Between- and within-horse variability—Only 4 kinetic parameters (vertical force peak and impulse, stance time, and time of zero craniocaudal force) had

Table 4—Between-horse coefficient of variation (%) across subjective lameness grades for each of 13 kinetic gait parameters assessed during 40 experimental trials by use of a force plate in 32 healthy adult horses with various levels of forelimb lameness induced via intra-articular injection of LPS.

	Subjective lameness grade										
Kinetic gait parameter	**0.0(B)**	**0.0(S)**	**0.0(R)**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Vertical force peak	7.5	6.8	6.3	6.5	13.0	15.9	13.0	13.4	11.6	17.3	39.3
Vertical force impulse	5.9	5.9	3.8	6.5	9.1	13.5	12.0	4.6	14.0	25.9	30.0
Braking force peak	16.4	21.5	17.9	9.9	24.9	19.4	25.2	11.5	13.3	21.1	38.6
Braking force impulse	24.7	24.6	7.4	14.2	24.8	30.7	20.8	16.3	27.8	45.6	34.6
Propulsive force peak	19.5	24.2	12.6	19.8	17.9	21.5	22.3	24.2	15.0	15.7	34.8
Propulsive force impulse	25.8	28.1	16.6	22.5	22.1	25.8	29.8	23.0	21.5	51.0	61.8
Lateral force peak	39.9	42.1	44.3	51.6	47.7	26.6	56.5	15.6	30.6	32.1	38.9
Medial force peak	35.9	38.6	43.7	36.1	47.9	32.4	39.4	38.3	31.0	46.9	17.4
Lateromedial force impulse	>100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100
Slope 1	>100	> 100	96.8	> 100	59.2	> 100	72.5	60.1	> 100	> 100	> 100
Slope 2	16.2	18.2	23.0	20.6	20.9	24.7	22.8	20.0	16.1	14.3	49.2
Stance time	7.3	7.9	5.4	5.8	5.3	8.8	5.4	3.1	9.1	13.6	19.7
Time of zero y-axis force	9.0	6.3	3.9	5.7	8.8	12.8	8.3	2.6	5.0	13.9	23.9

See Table 1 for key.

Table 5—Within-horse coefficient of variation (%) across subjective lameness grades for each of 13 kinetic gait parameters assessed during 40 experimental trials by use of a force plate in 32 healthy adult horses with various levels of forelimb lameness induced via intra-articular injection of LPS.

	Subjective lameness grade										
Kinetic gait parameter	**0.0(B)**	**0.0(S)**	**0.0(R)**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Vertical force peak	4.2	4.0	4.6	4.1	5.2	5.4	4.4	4.8	5.3	7.4	8.0
Vertical force impulse	3.9	3.9	4.8	4.0	5.1	5.0	4.6	4.6	7.1	12.3	11.9
Braking force peak	21.0	21.1	17.0	17.3	19.9	16.5	14.8	16.0	15.4	21.8	24.7
Braking force impulse	30.3	29.7	21.9	22.6	25.0	25.1	19.0	18.4	14.5	27.9	33.0
Propulsive force peak	20.2	23.3	16.9	16.7	15.9	17.0	11.7	18.6	9.8	15.1	23.2
Propulsive force impulse	27.0	29.0	20.5	21.4	22.5	23.5	17.2	28.7	15.6	26.2	25.8
Lateral force peak	51.8	49.0	46.8	52.4	40.9	38.3	53.4	69.1	33.2	45.7	44.3
Medial force peak	49.2	51.4	50.8	53.2	67.1	45.4	59.0	37.5	36.3	62.8	62.9
Lateromedial force impulse	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100
Slope 1	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100
Slope 2	15.3	17.5	14.7	16.5	16.6	19.7	16.1	19.5	17.4	24.3	22.0
Stance time	5.5	5.8	4.8	4.7	6.6	5.7	4.7	5.1	5.9	9.5	9.5
Time of zero y-axis force	8.8	8.9	6.5	6.7	7.5	9.0	5.6	9.2	4.9	11.3	9.0

See Table 1 for key.

relatively small (< 10%) between-horse CVs at the baseline values (**Table 4**). These 4 parameters also had relatively small (< 10%) within-horse CVs at the baseline values (**Table 5**). For all 13 kinetic parameters, between- and within-horse CV values were generally larger for the more severe lameness grades. The within-horse CV remained < 10% across all lameness grades for vertical force peak and stance time, although it increased as lameness grades increased.

Discussion

Kinetic gait analysis can be used to objectively evaluate forelimb lameness in horses, and the results of our study have indicated that certain kinetic parameters are associated with subjective lameness grade. In agreement with findings of previous studies,[25-28] our data also indicated that vertical force peak and impulse significantly decreased with mild forelimb lameness in horses, compared with baseline values. However, other kinetic parameters that were evaluated changed significantly only between the sound gait and moderate to severe lameness grades. The present study also revealed significant changes from baseline in vertical force peak and impulse when no lameness was detected subjectively, suggesting a role for kinetic gait analysis in detection of subclinical lameness. Additional studies are warranted to evaluate which kinetic gait parameters are useful for assessment of types of forelimb lameness other than LPS-induced metacarpophalangeal joint synovitis. Equine locomotion studies have been used to assess various lameness models including collagenase-induced superficial digital flexor tendinitis,[25,26] LPS-induced arthritis,[41-43] foot lameness with toe or heel pain induced by sole-screw shoes,[12,44,45] and spontaneous lameness.[25,27,28,46-48] Moreover, research involving computer-assisted kinematic gait analysis has revealed that some kinematic gait parameters changed significantly in association with specific musculoskeletal abnormalities.[26,38,44,45,47-50] Therefore, such kinematic characteristics may possibly result in changes in specific kinetic parameters depending on the cause of lameness, even though kinetic gait analysis via force plate is unable to analyze the locomotion changes of the limb in space. The results of the present study are not intended to suggest that simultaneous evaluation of kinetic parameters and kinematic assessment of gait may not be additionally valuable.

Of the 7 kinetic parameters that had a significant association with lameness grade, smaller variability between and within horses was found in vertical force peak and impulse at the baseline values, compared with other kinetic gait parameters. The baseline values were most relevant because they were obtained in subjectively sound, noninjected horses and estimated reference values. Our data suggest that reliable quantification of sound gait status can be performed with few repetitions (< 5) and may be applicable for routine clinical evaluation of sound horses. In the LPS-induced metacarpophalangeal joint synovitis model of lameness in horses that was used in the present study, quantification of lame gait (even mild lameness) can be reliably performed by assessment of vertical force peak values with < 5 repetitions. Consideration of this repetition effect should be assessed for all lameness models as well as naturally occurring lameness.

For the parameters other than vertical force peak, the between- and within-horse CV values were generally larger than the percentage change between values for baseline and mild lameness. For example, braking force peak and impulse values in horses with grade 1.0 lameness were decreased from baseline by < 10%, but between- and within-horse CV for grade 1.0 lameness was > 20%. Therefore, these parameters with greater CVs will be less useful in distinguishing lameness. The craniocaudal and lateromedial forces had larger CVs than the vertical force, which is in agreement with findings in studies of humans[51] and dogs.[52] Between- and within-horse CVs in most of the kinetic parameters increased in horses with more severe lameness, and the capability of these parameters to reliably quantify a lameness gait will be less than their capability to quantify sound gait. However, large variability of kinetic parameters in moderate to severe, distinctly observable, lameness gait is less important because the lameness can be diagnosed by a clinician without the need for objective gait assessment.

Results of the present study indicated that sound and lame horses may be objectively distinguished with reasonable accuracy by use of a vertical force peak cutoff value that provided the highest sensitivity and specificity. This finding further supports the contention that vertical force peak values reflect lameness status as determined by subjective observation. However, in our study, the sound and lame gait data were collected from the same horses before and after experimental induction of lameness, which reduced variability in kinetic parameters between sound and lame groups. A random sampling from a population of horses with and without naturally occurring lameness may lower sensitivity and specificity of vertical force peak. Regardless, among the kinetic parameters evaluated, vertical force peak provided the most accurate association with subjective lameness grade (ie, the highest simultaneous sensitivity and specificity for classification of sound and lame horses). Data obtained in the present study were insufficient to provide cutoff values or complete reference ranges for clinically sound horses, such as may be used in prepurchase examinations of horses, but we suggest that vertical force peak may be the best candidate parameter for such a test.

The results of our study suggest that kinetic gait analysis may have the potential to identify a subclinical gait abnormality in horses. Some horses included in the study returned to a subjectively sound gait following the previous episode of lameness; therefore, those horses were determined to have recovered from metacarpophalangeal joint synovitis. Nevertheless, the values of vertical force peak in those horses that were assumed to be recovered from lameness were significantly decreased from baseline values for those horses. It may be speculated that some discomfort associated with LPS-induced synovitis still remained in those horses, and kinetic gait analysis was capable of detecting the slight gait abnormalities. Moreover, some horses in the present study had no subjectively observable lameness at any time point during the study period.

This is due to the fact that a subset of the horses in the study received oral administration of nonsteroidal anti-inflammatory drugs 1 hour prior to the LPS injection to induce variable severity of lameness and clearly this goal was obtained. Yet, the values of vertical force peak and impulse, slope 2, and stance time at 12 or 18 hours after LPS injection were significantly different, compared with baseline values. Those time points corresponded approximately to the peak of lameness severity in horses that developed lameness. Previous studies[34,35,37,38] have revealed that synovial fluid samples from joints with LPS-induced synovitis had a peak increase in leukocyte count and specific gravity 10 to 12 hours after administration of LPS, compared with baseline values. The findings in our study support the supposition that horses with no subjectively observable lameness may have mild discomfort or hesitancy to fully load the LPS-treated limb. A similar association has been suggested by the identification of a subclinical tendon injury prior to clinical signs of lameness by use of slope 1 and slope 2 parameters; the increase in slope 1 and decrease in slope 2 values were attributed to a reduced loading rate in lame limbs.[23,26] In the present study, the slope 1 parameter had larger between- and within-horse variability than did slope 2, and this may be the reason why significant differences in the value were not detected. Reportedly,[25,26] others have also identified large variations for slope 1 and slope 2 parameters attributable to the fact that braking force peaks may not be exactly matched with the true slope portions of the vertical force-time curve.

To the authors' knowledge, this is the first report of differences in lateromedial GRF between sound and lame horses. The lateral and medial force peaks in sound horses in the present study were at approximately 3% of body weight, which is similar to the force in normally gaited dogs[52] but smaller than that in normally gaited humans[53] and chickens.[54] An acceleration of the center of gravity to the opposite side of the body primarily contributes to the occurrence of lateral force during a step,[54,55] and the results of our study support the finding that the lateromedial GRF of a symmetric trot gait in quadruped species is relatively smaller than that in biped species. Typical GRF-time curves revealed that the lateral force peak in horses occurs slightly earlier in the stance time than medial force peak, and this may indicate that the lateral hoof wall of a normally balanced equine foot usually contacts land first. As the degree of lameness increased, lateral force peak decreased and medial force peak increased; thus, both values were closer to zero in horses with more severe lameness. It has been shown that the position of the body center of mass in horses with forelimb lameness shifts significantly toward the sound limb,[56,57] and this may explain the smaller lateromedial force on the lame limb in more severe lameness conditions. The lateromedial force impulse was a slightly positive value, indicating that total lateromedial force usually occurs toward the lateral side. Regardless, large between- and within-horse variability may limit the use of these parameters as indicators of equine forelimb lameness. Because the characteristics of foot path or limb conformation were not recorded in the present study, it is unclear whether an abnormal sideway swing of the limb (eg, paddling or winging) or faults in conformation (eg, valgus or varus deformity of the carpus, base-wide or base-narrow stance, or toe-in or toe-out stance) influence the lateromedial force.

In the present study, kinetic parameters such as vertical force peak and impulse significantly increased in the later order of the 8 repetitions, indicating that the lameness improved as the horses were trotting, at least in this metacarpophalangeal joint synovitis model of lameness. Findings of studies[58-60] in rabbits with arthritis suggest that continuous passive motion exerts an anti-inflammatory action on inflamed joints. Perhaps the change in lameness severity detected in the horses of our study is not an uncommon phenomenon during clinical lameness examinations; however, to our knowledge, this is the first study to demonstrate it by use of an objective gait assessment method. On the basis of our data, collection of 4 valid force plate repetitions may be sufficient to appropriately evaluate GRF in this LPS-induced forelimb lameness model in horses. At present, kinetic gait evaluations have been performed by measuring 4,[26] 5,[42] or 6[23,25,28] valid data points with a force plate, but these studies did not evaluate the influence of repeated trotting over the force plate on the kinetic parameters. These same concerns are present for any lameness evaluation, including naturally occurring lameness. Standardization of a protocol for clinical or experimental lameness studies is paramount to help control for this effect on kinetic gait parameters.

In the analyses of the study data, subjective lameness gradings assigned by 1 evaluator were used. In a previous kinematic study,[9] subjective lameness scores were assigned after videotape evaluation by multiple investigators; there was variability in scores among inexperienced and experienced evaluators and relatively low agreement between simultaneous kinematic measurements and subjective visual assessment of limb movement. We elected to use lameness grade data obtained from an experienced clinician who performed a complete, direct-contact lameness examination of each horse before assigning a subjective lameness grade. This included visualization of the gait from the front, side, and rear. The grade was assigned when the evaluator was confident the scores reflected the observed gait. This method was chosen to achieve the highest confidence that the subjective score should represent the true lameness status. Subjective evaluation by use of a videotaping method can permit scrambling video sequences in random order, but a relatively poor correlation has been detected between subjective scores and kinematic variables by use of this method.[9] In contrast, a higher correlation between subjective grades and kinetic variables was determined in the present study. This may reveal differences in kinematic versus kinetic assessments or may be related to use of a video segment as the method to apply a subjective score. It is intuitive that these quantitative and subjective values should be correlated. Video assessment limits viewing angle and viewing duration, which may not sufficiently represent the true gait. This may be especially important in cases of mild lameness. Importantly, it was not a goal of our study to assess variability among clinicians in assigning lameness grades, which has already been reported[9,10] for kinematic assessments. Our study was designed to assess the correlation of kinetic gait analysis parameters with a subjective grade assigned by the same experienced clinician, as may occur in typical clinical examinations. The correlations reflected repeated assessments over a range of lameness grades. The use of the force plate in the evaluation of horses for changes in lameness in a clinical setting or in experimental trials may often follow a similar protocol because of practical considerations.

The gait velocity in horses with grade 4.0 lameness was significantly less than the velocity in baseline gaits, although the difference was numerically small (approx 5% change from baseline velocity). Despite the effort to keep the horses' trot speed within a narrow range, the more severely lame horses did not maintain the same gait velocity as the sound or mildly lame horses. Although a significant positive correlation between trot velocity and vertical force has been reported,[14] it should be emphasized that the gait velocity in horses with grade 4.0 lameness was still within a narrow range in our study. The slightly slower trotting speed of those horses may have decreased the vertical force and overestimated the lameness. However, use of an objective parameter to compare severe lameness is less critical because the condition is obvious to the observer.

a. Phenylzone, Schering-Plough Animal Health, Union, NJ.
b. Kistler Instrument Corp, Amherst, NY.
c. SAS, version 8.2, SAS Institute Inc, Cary, NC.

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