Temporal-spatial gait analysis by use of a portable walkway system in healthy Labrador Retrievers at a walk

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Objective—To establish a protocol to collect temporal-spatial gait analysis variables by use of a portable walkway system in Labrador Retrievers at a walk and to determine reference values.

Animals—56 healthy Labrador Retrievers.

Procedures—6 passes across the walkway (3 passes in each direction) were recorded. Inclusion criteria for a pass were that the dog was at a walk (velocity, 60.0 to 90.0 cm/s) and had minimal head turning. The first 3 passes that met the inclusion criteria were analyzed for each dog.

Results—Mean stride length was 88.4 cm. Mean stance time (ST) of forelimbs and hind limbs was 0.62 and 0.56 seconds, respectively. Mean stance time percentage (ST%; proportion of stance time to total gait cycle time) for forelimbs and hind limbs was 55.6% and 50.2%, respectively. Mean total pressure index (TPI) of forelimbs and hind limbs was 27.1 and 17.4, respectively. Mean number of sensors (NS) activated by each paw strike of forelimbs and hind limbs was 17 and 13, respectively. Mean forelimb-to-hind limb symmetry ratios were 1.11 (ST), 1.10 (ST%), 1.62 (TPI), and 1.37 (NS). Symmetry ratios for left limbs to right limbs, left forelimb to right forelimb, and left hind limb to right hind limb were 1.00.

Conclusions and Clinical Relevance—A protocol for collection of temporal-spatial gait analysis variables with a portable walkway system in Labrador Retrievers at a walk was developed, and reference values for variables and symmetry ratios were reported. Further research will determine the extent to which symmetry ratios differ in dogs with orthopedic disorders. (*Am J Vet Res* 2010;71:997–1002)

Gait analysis systems that provide quantitative assessment of lameness beyond subjective analysis have improved the ability of clinicians and researchers to diagnosis lameness.[1–4] Two-dimensional and 3-D motion analysis systems provide various measurement options for the detection of subtle gait abnormalities in dogs.[5,6] Advancements in the medical field, including portable walkway systems, have improved the ability to collect data during sequential footfalls.[7–9]

A portable pressure walkway system has been validated in the human medical field[9–11] and for use in Beagles.[a] The walkway system records temporal-spatial variables, which include SrL, SrT, ST, ST%, TPI applied by each limb, and NS.[b] The purpose of the study reported here was to establish a protocol for the collection of temporal-spatial gait analysis variables by use of a portable walkway system in healthy Labrador Retrievers at a walk and determine reference values for variables and symmetry ratios.

Abbreviations

LF	Left forelimb
LH	Left hind limb
MPI	Mean pressure index
NS	Number of sensors activated by each paw strike
RF	Right forelimb
RH	Right hind limb
SrL	Stride length
SrT	Stride time
ST	Stance time
ST%	Stance time percentage
TPI	Total pressure index

Materials and Methods

Animals—Fifty-six Labrador Retrievers between 1 and 11 years of age (mean, 3.3 years old) and weighing between 17.7 and 35.5 kg (mean, 27.9 kg) were enrolled

Received March 10, 2009.
Accepted August 4, 2009.

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This manuscript represents a portion of a dissertation submitted by Ms. Light to the College of Veterinary Medicine, Auburn University, Auburn, Ala.

Supported by the Department of Homeland Security (Science and Technology Directorate) and CIR Systems Incorporated.

The authors thank Carrie Ouellette and Jennifer Sanders for technical assistance.

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in the study. There were 8 spayed and 20 sexually intact female dogs and 13 castrated and 15 sexually intact male dogs. Forty-four of 56 dogs were being trained at an institute[c] as detector dogs, and 12 were being trained for use in competitive field trials. No dog had a history of orthopedic disorders. All dogs were examined by a veterinarian and judged orthopedically sound. The study was approved by the Auburn University Institutional Animal Care and Use Committee.

Equipment—The walkway system[d] used in the study was equipped with a 5.5 × 0.85-m portable mat that had 18,432 encapsulated sensors. The active dimensions of the mat were 4.88 × 0.61 m. A 1.25 × 0.85-m section of inactive mat was placed at each end of the walkway system to provide a transition surface when entering and exiting the system. The mat was calibrated by the manufacturer before purchase. Sensors were batch tested with an air-actuated plunger that applied a force of 0 to 7 kg to the mat. The walkway system interfaced with a computer and software program[e] for processing and storage of raw data recorded from quadruped gait analysis. The software program interpreted a change in pressure on the sensor and recorded it as a switching level. Additionally, the sensors of the mat had 8 equal switching levels. Accuracy of the switching level of the sensors, spatial resolution, and temporal accuracy at the sampling rate of 180 Hz were ± 0.15 switching level, ± 1.27 cm, and ± 5.55 ms/sample, respectively. Two cameras[f,g] were positioned at a height of 50 cm at opposite ends of the walkway system to simultaneously record movement in both directions. Digital video files of each pass across the walkway system were automatically linked to the data files for footfall verification.

Experimental design—The active and inactive mats were placed on a flat concrete or tile floor. Dogs were walked on the mat until they appeared relaxed and acclimated (approx 4 to 6 passes/dog) to the portable walkway system and their surroundings. Dogs were walked across the portable walkway system by the same handler; the handler attempted to maintain a constant velocity on a loose leash. A pass was defined as a dog walking the length of the portable walkway system in 1 direction. Each pass consisted of 4 to 5 gait cycles. Two passes were completed across the portable walkway system by walking a dog across the mats, turning the dog beyond the end of the inactive mat, and walking the dog across the mats again. At least 6 passes across the portable walkway system (3 passes in each direction) were recorded with a total recording time of approximately 3 min/dog. Inclusion criteria for a pass in the data analysis were a relaxed steady walk without the dog pulling on the leash, a velocity between 60.0 and 90.0 cm/s, and no overt turning of the head from midline. The first 3 passes that met the inclusion criteria were analyzed for each dog.

Data processing and analysis—Videos of each pass were reviewed to ensure inclusion criteria were met. The software program[e] was used to distinguish the paw print of each footfall. Paw prints were identified manually as LF, RF, LH, or RH during the first gait cycle; thereafter, the software program automatically replicated the gait pattern on the basis of the manually identified prints. Analysis of each pass by the software program provided a mean velocity, which was calculated by dividing the distance traveled (in centimeters) by ambulation time (in seconds). Additionally, the velocity of individual gait cycles was compared to verify that variation within each pass did not exceed > 10%.

Data analysis included mean ± SD values for ST, ST%, SrT, SrL, NS, TPI, and MPI. The ST (ie, stance phase) was the duration of time the paw was in contact with the ground during 1 gait cycle. An ST% (ie, duty factor) was defined as the proportion of ST to total gait cycle time. The SrT was the amount of time required for a paw to complete a gait cycle, and SrL was defined as the distance between 2 successive strikes of the same paw. An NS was the number of sensors activated by each paw. The TPI was defined as the sum of peak pressure values recorded from each activated sensor by a paw during mat contact, represented by the switching levels and reported as a scaled pressure from 0 to 7 for each sensor. Mean pressure index was defined as the sum of pressure values recorded from each activated sensor during ST divided by NS.

The mean ± SD symmetry ratios of forelimbs to hind limbs, left limbs to right limbs, LF to RF, and LH to RH were calculated for each pass. The software program allowed for a summary of data in a printout after 1 pass or exportation of data for each dog to a spreadsheet[h] for calculation of additional symmetry ratios for each side (ie, LF to LH and RF to RH) and diagonal limbs (ie, LF to RH and RF to LH).

Statistical analysis—A mixed model for a repeated-measures ANOVA was used to analyze differences among passes and the mean values of each variable of each dog for limb (ie, forelimb and hind limb [forelimbs to hind limbs, LF to RF, LH to RH, LF to RH, and RF to LH]), side (ie, left and right), and the interaction between limb and side (fixed effects). Comparisons of results were made between individual limbs, left and right sides, and forelimbs and hind limbs for each variable. To measure repeatability, dog and walk were evaluated as random factors in the model. The sum of the covariance parameter estimates and the residual error (as a percentage of the grand means) was used as an indicator of intraobserver repeatability and measurement error for each of the temporal-spatial gait analysis variables and symmetry ratios. A repeatability index was calculated by subtraction of the measurement error percentage (error divided by the grand mean) from 100%. Values of $P \le 0.05$ were considered significant.

Results

Mean ± SD values for temporal-spatial gait analysis variables and symmetry ratios were summarized **(Tables 1 and 2).** No significant differences were detected among passes for temporal-spatial gait analysis variables. No significant differences were detected among all symmetry ratios for SrT and SrL. No significant differences were detected among symmetry ratios for LF to RF, LH to RH, and left side to right side. Significant differences were detected among symmetry ratios for forelimbs to hind limbs, LF to LH, RF to RH, LF to RH, and RF to LH when comparisons were made for

Table 1—Mean ± SD values for temporal-spatial gait analysis variables* obtained by use of a portable walkway system in 56 healthy Labrador Retrievers at a walk.

Variable	LF	RF	LH	RH	Repeatability index (%)†
ST (s)	0.62 ± 0.08	0.62 ± 0.08	0.56 ± 0.08	0.56 ± 0.08	77
ST% (%)	55.7 ± 3.0	55.4 ± 3.2	50.2 ± 4.0	50.3 ± 4.0	89
SrT (s)	1.11 ± 0.13	1.11 ± 0.12	1.10 ± 0.13	1.10 ± 0.13	83
SrL (cm)	88.36 ± 7.20	88.39 ± 7.18	88.63 ± 7.56	88.65 ± 7.69	87
MPI	2.11 ± 0.30	2.10 ± 0.32	1.79 ± 0.26	1.80 ± 0.25	77
TPI	27.4 ± 4.2	26.8 ± 4.2	16.7 ± 3.3	17.1 ± 3.5	67
NS (No.)	13 ± 2	13 ± 2	9 ± 2	10 ± 2	73

*Variables were derived from 3 passes of each dog walking at a velocity between 60 and 90 cm/s across a portable walkway system.[d] †Within a variable, the value is representative of all limbs.

Table 2—Mean ± SD values for symmetry ratios*† obtained by use of a portable walkway system in 56 healthy Labrador Retrievers at a walk.

Variable	Forelimbs: hind limbs	Left limbs: right limbs	LF:RF	LH:RH	LF:LH	RF:RH	LF:RH	RF:LH
ST (s)	1.11 ± 0.07‡§	1.00 ± 0.03‖	1.00 ± 0.03‖	1.00 ± 0.05‖	1.11 ± 0.08‡	1.10 ± 0.07‡§	1.11 ± 0.08‡§	1.11 ± 0.07‡§
ST% (%)	1.10 ± 0.06‡§	1.00 ± 0.03‖	1.00 ± 0.03‖	1.00 ± 0.04‖	1.10 ± 0.07‡§	1.10 ± 0.06‡§	1.10 ± 0.08‡§	1.10 ± 0.06‡§
SrT (s)	1.00 ± 0.02‖	1.00 ± 0.01‖	1.00 ± 0.01‖	1.00 ± 0.01‖	1.00 ± 0.02‖	1.00 ± 0.02‖	1.00 ± 0.02‖	1.00 ± 0.02‖
SrL (cm)	1.00 ± 0.01‖	1.00 ± 0.01‖	1.00 ± 0.01‖	1.00 ± 0.01‖	1.00 ± 0.01‖	1.00 ± 0.02‖	1.00 ± 0.02‖	1.00 ± 0.01‖
MPI	1.17 ± 0.09‡§	1.00 ± 0.05§	1.00 ± 0.07§	1.00 ± 0.07§	1.18 ± 0.10‡§	1.17 ± 0.12‡§	1.18 ± 0.11‡§	1.18 ± 0.11‡§
TPI	1.62 ± 0.23‡	1.01 ± 0.07§	1.03 ± 0.09§	0.99 ± 0.12	1.66 ± 0.25‡	1.60 ± 0.28‡	1.63 ± 0.27‡	1.63 ± 0.25‡
NS (No.)	1.37 ± 0.12‡	1.00 ± 0.05§	1.01 ± 0.06§	0.99 ± 0.08§	1.38 ± 0.16‡	1.36 ± 0.14‡	1.37 ± 0.16‡	1.38 ± 0.14‡

†A symmetry ratio of 1.0 results when the recorded value of the numerator equals the recorded value of the denominator. ‡Within a variable, values for forelimbs are significantly ($P < 0.001$) different, compared with values for hind limbs. §Repeatability index was > 80%. ‖Repeatability index was > 90%.

See Table 1 for remainder of key.

TPI, MPI, NS, ST, and ST%. Repeatability indices were > 80% for ST%, SrT, and SrL in all limbs. The repeatability indices for MPI ratios were between 80% and 89%. Repeatability indices were > 90% for SrT and SrL in all ratios.

Discussion

The use of visual gait analysis alone has been insufficient for gait evaluation in humans.[12] In a study[13] of experimentally induced lameness in dogs, subjective evaluation of gait differed between evaluators and correlated poorly to objective measures of limb function. There are several methods available for obtaining data from objective gait analysis for use by researchers and clinicians. However, each method has limitations. Researchers have used electrogoniometry to measure joint angles in dogs, but the method was cumbersome and failed to provide kinetic data.[14] The use of force plates has become a key advancement in kinetic analysis.[15] Additionally, researchers have evaluated[16] ground reaction forces in healthy dogs with different conformations. Furthermore, that study[16] was followed by studies of abnormal gait in dogs associated with cranial cruciate ligament rupture[6,17–19] or hip dysplasia[20,21] and in response to pain management.[22,23]

Although the use of force plates has become the standard method for measurement of contact time, braking, impulsion, and ground reaction force of each paw independently, several disadvantages have been recognized.[24] For example, the force plate must be located on a level surface and may require the designation of an area dedicated for force plate use and construction of a platform. A single force plate recording supplies data for 1 footfall at a time and does not measure successive footfalls or force distribution from all 4 paws during a single pass[25]; therefore, multiple passes are necessary to collect data for each limb and to obtain proper positioning of the paw on the force plate.[24] At a walk, dogs have 1 or more paws in contact with the ground at a time,[24] and overlap of paw prints on the force plate causes an inability to distinguish among limbs.[26] This is problematic in smaller breeds because of their typically shorter stride lengths.[24,26] Multiple passes across the plate increase the time required for data collection and also lead to variability associated with repetition.[27]

Investigators found that dogs with undiagnosed cranial cruciate ligament rupture could not be distinguished from clinically normal dogs on the basis of peak vertical force alone through the evaluation of force plate data.[19,28] Thus, a multivariate approach to lameness evaluation was suggested to enhance the accuracy of detection of cranial cruciate ligament rupture.[19,28] In another study,[24] investigators compared ground reaction force values from a force plate and a pressure-sensitive walkway in dogs. Findings of that study[24] indicated the use of a multivariate approach was possible with a pressure walkway system that collected sequential footfalls and multiple variables. This method[24] decreased the number of recordings required and reduced the variability of results.[26,27]

The portable walkway system[d] used in the study reported here has been validated in the human medical field[9,11,29] and has been used to quantify temporal-spatial gait analysis variables[30,31] for the study of humans with gait abnormalities,[7,32] Parkinson disease,[33,34] and Huntington disease.[35] Similar to reports[7,9,11,29–35] from other investigators, the authors of the study reported here determined that this walkway system provided a portable and noninvasive method for the collection of data from sequential footfalls without the need for a dedicated area or construction of a platform for use with the system.

The protocol included in the present study allowed for the collection of data from sequential footfalls at a walk. The walk was evaluated because it is a symmetric gait,[36] the forces generated in dogs with unilateral lameness are strongly correlated with forces at a trot,[4,37] and there are lower braking and impulsion forces during a walk, which might cause discomfort in dogs with severe lameness and result in failure to use the limb during a trotting gait.[4,37] A consistent velocity is necessary to reduce the within-pass variability that could occur in the temporal (ie, ST) or spatial (ie, SrL) gait analysis variables because of a change in walking velocity.[38] Velocity also must be maintained within a consistent range for the comparison of variables among dogs.[38,39] Four gait cycles are required for the calculation of 3 SrLs and SrTs. Error resulting from external influences in the study reported here was minimized by the use of inclusion criteria.

Analysis of results of the present study indicated that symmetry ratios for healthy Labrador Retrievers were 1.0 when comparing LF to RF, LH to RH, and left limbs to right limbs. No significant differences were detected when a comparison was made between the left and right limbs and between forelimbs and hind limbs. Mean symmetry ratio values (ie, ST, ST%, TPI, MPI, and NS) were significantly different when a comparison was made between forelimbs and hind limbs; differences in these variables may have been caused by differences in the distribution of weight on the paws of the forelimbs versus the hind limbs during a walk.[16,40] The greatest repeatability index value in the present study was reported for the symmetry ratios. Repeatability indices for all SrT and SrL symmetry ratios were > 90%.

Symmetry ratios for ST and ST% in the present study were 1.11 and 1.10, respectively, when a comparison was made between forelimbs and hind limbs. These symmetry ratios were not similar to the findings of another study[41] in which investigators reported that contact time for forelimbs and hind limbs in dogs at a walk was the same. Furthermore, these symmetry ratios do not support the findings of another study[42] that revealed STs for forelimbs could be 1.5 times as great as those of the corresponding hind limbs. However, the conclusions of both of those studies[41,42] could be accurate when considering the larger inverse correlation of ST with velocity on the forelimbs when a comparison is made with that of the hind limbs.[39] However, the symmetry ratios for ST and ST% in the present study were similar to those in another study[43] in which investigators reported that the difference in duty factor (ie, ST%) between the forelimbs and hind limbs is less as the body size of the quadruped increases. An ST% of 1.07 was reported in that study[43] for dogs at a walk.

Researchers in another study[40] reported that the mean force on the forelimbs and hind limbs during a walk is 1.1 and 0.8 times that of the weight of the dog, respectively, when the velocity ranges from 91 to 152 cm/s. The calculated forelimb-to-hind limb force ratio of that study[40] was 1.4 and corresponded to a weight distribution ratio of 58:42 between the forelimbs and hind limbs, respectively; this was similar to weight distribution ratios reported in another study.[b] In the present study, the forelimb-to-hind limb symmetry ratio for TPI was 1.62, and this corresponded to a weight distribution ratio of 62:38 between the forelimbs and hind limbs, respectively, when the velocity ranged from 60 to 90 cm/s. This ratio is similar to the established[40] forelimbs-to-hind limbs symmetry ratio of 60:40 whereby 60% of a dog's weight is distributed over the forelimbs when at rest or at a walk.[40] The difference in reported values for this ratio may be because of differences in velocity, in breed of dog, or between the measurement of peak vertical force on the force plate versus TPI on the portable walkway system. Symmetry ratios of both the LF to RH and RF and LH were 1.63 and not significantly different from that of the forelimbs-to-hind limbs symmetry ratio of 1.62. Additionally, the LF:LH and RF:RH symmetry ratios were 1.66 and 1.60, respectively, but were not significantly different from that of the forelimbs-to-hind limbs symmetry ratio. Further studies are required to determine whether these symmetry ratios can be used to determine the pattern of pressure redistribution for individual limbs during sequential gait cycles.

The forelimbs-to-hind limbs symmetry ratio for NS was 1.37. Therefore, the paws of the forelimbs support more of the dog's weight but also have a greater ground contact area than do the paws of the hind limbs. An explanation for the difference in ground contact area could be that only a portion of the paws of the hind limbs are in contact with the ground at a walk.

Researchers have used ground reaction forces of nonconsecutive footfalls to obtain symmetry ratios.[27] In that study,[27] small deviations (attributable to variation among passes) in results were not considered abnormal when limb symmetry was used to establish a reference value. Furthermore, dogs that were within 2 SDs for measured temporal-spatial gait analysis variables and symmetry ratios were considered to have a normal gait. In the present study, consecutive footfalls were used and thereby reduced the number of passes and variation among successive passes. The SDs of the symmetry ratios for TPI and NS were greater than the SD for the other symmetry ratios. The larger SDs for these measurements could have been related to the body weight or conformation of the dog. A dog with a heavier body weight or larger conformation would be expected to have larger paws, activate more sensors, and exert a greater TPI than would a dog with a lighter body weight. Furthermore, dogs with heavily muscled forelimbs would be expected to exert a greater TPI on the paws of the forelimbs than that of the paws of the hind limbs. Both the body weight and the extent of muscling of the forelimb would contribute to an increase in the SD of the measured values of the variables and the related symmetry ratios. Further studies are needed to establish whether symmetry ratios for TPI and NS can be applied to other breeds of dog.

In summary, a protocol for the collection of temporal-spatial gait analysis variables by use of a portable walkway system in healthy Labrador Retrievers at a walk was developed, and reference values for variables and symmetry ratios were reported. It is uncertain whether the results determined for these variables or symmetry ratios are similar to those in other dog breeds. However, this protocol can be used to establish databases for other dog breeds. Kinetic data can vary among and within dog breeds.[44] However, a symmetric gait would be expected to yield similar symmetry ratios in healthy dogs regardless of breed. Therefore, these ranges could prove to be a reliable resource, and the portable walkway system could be considered a useful tool for gait analysis. Further research is needed to determine the extent to which symmetry ratios will change in dogs with orthopedic disorders.

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