

Symmetry of hind limb mechanics in orthopedically normal trotting Labrador Retrievers

G. Robert Colborne, PhD; Louise Good, BSc; Lucy E. Cozens, BSc; Lisa S. Kirk, BSc

Objective—To evaluate symmetry of the hind limbs in orthopedically normal trotting dogs.

Animals—19 orthopedically normal Labrador Retrievers with no history of lameness.

Procedures—Retroreflective markers were applied to the hind limb joints, and a 4-camera kinematic system captured positional data at 200 Hz in tandem with force platform data collection while the dogs trotted. Morphometric data were combined with kinematic and force data in an inverse dynamics method to calculate net joint moments and powers at the joints as well as total support moment for each limb. Dogs were identified as right or left dominant when their total support moment was > 10% asymmetric between sides.

Results—10 of the 19 dogs were mechanically dominant in the right hind limb as determined by their total support moments. One dog was left dominant, and the remaining 8 were symmetric. Right-dominant dogs had larger net joint moments at the right hip, tarsal, and metatarsophalangeal joints and a smaller moment at the right stifle joint, compared with values for the left hind limb. The 1 left-dominant dog had the exact opposite findings. Hip and stifle joint moments and powers varied between limbs of the right-dominant and left-dominant groups in the timing of their transition from negative to positive, and power amplitudes varied at the hip, tarsal, and metatarsophalangeal joints but not the stifle joint.

Conclusions and Clinical Relevance—Sound trotting dogs can have asymmetries in limb and joint mechanics. These natural mechanical asymmetries should be taken into account when considering models to evaluate stresses at joints and when considering surgery for cruciate ligament rupture. (*Am J Vet Res* 2011;72:336–344)

Motion symmetry is believed to be the hallmark of an orthopedically normal gait and forms the basis of clinical gait assessment in quadrupeds. It depends on the observation of limb, trunk, and head motions at a walk and trot, and there is often disagreement between clinicians' gait scores for any given clinical case,¹ particularly when lameness is mild. A study² on dogs recovering from surgery for elbow joint dysplasia revealed no correlation between objective gait measurements, clinical gait score, and owner assessments. Objective gait analysis is increasing in popularity as methods developed largely in human gait analysis are adapted for equine and canine analyses.^{3,4} Before lame gaits can be meaningfully assessed, there is a need to characterize an orthopedically normal gait for reference purposes. To this point, most of the clinical gait studies in the literature have involved kinematic analysis or force plate analysis alone and have largely been based on the presumption that trotting is a symmetric gait in which diagonal strides are similar when the dog is sound (orthopedically normal).

ABBREVIATIONS

LD	Mechanically dominant in the left hind limb
MTP	Metatarsophalangeal
RD	Mechanically dominant in the right hind limb
SYM	Mechanically symmetric in the hind limbs
TSM	Total support moment

Kinematic studies in sound trotting dogs have shown that any interlimb motion asymmetry is largely attributable to variation between trials,^{5–7} and researchers have concluded that such dogs are kinematically symmetric when trotting. Kinematic analyses of gait in horses have likewise shown that horses may have some natural motion asymmetry at a trot, but that there are overall insignificant differences in motion-time variables between limb pairs.⁸

In a study⁹ of horses walking over a force platform, ground reaction forces were approximately 90% symmetric between forelimb and hind limb pairs, and although there was some variation in this index among sound horses, repeated measurements within horses were consistent over a 3-year period. Vertical ground reaction force measurements in sound trotting horses is approximately 97% symmetric, and craniocaudal force symmetry is about 92%.¹⁰ At constant speed on an instrumented treadmill, sound trotting horses have small

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From the Centre for Comparative and Clinical Anatomy, Faculty of Medical and Veterinary Sciences, University of Bristol, Bristol, BS2 8EJ, England.

Address correspondence to Dr. Colborne (Bob.Colborne@Bristol.ac.uk).

and clinically unimportant degrees of asymmetry in force and timing variables.¹¹ Dogs trotting over multiple force platforms exert slightly higher peak vertical forces under their left forelimb and right hind limb than in the contralateral limbs.¹² On the other hand, peak vertical force symmetry averages 96.3% beneath the hind limbs of walking dogs and 97.6% in the same dogs at a trot.¹³

Ground reaction forces measured by use of a force platform represent the external interaction between a limb and the ground. They measure the overall effects on the ground of muscle contractions that resist flexion of the limb joints under the influence of gravity acting on the superincumbent segments and trunk or that generate extension of the joints to raise the trunk's mass against gravity. Ground reaction forces also quantify the longitudinal and transverse shear forces produced as the limb muscles act to decelerate or accelerate the horizontal motion of the body. Knowledge of the segmental morphometry and limb segment kinematics allows these external forces between the foot and ground to be decomposed into joint reaction forces at each joint, and these are combined with segment positional information to calculate the net moment at each joint by use of inverse dynamics.¹⁴

All of the net joint moments can be summed to yield a so-called TSM for the limb,^{15,16} which can then be compared between limbs as an indication of mechanical gait symmetry. Individual joint moments can also be evaluated for their discrete contributions to the limb TSM, thus delivering more information about mechanical limb symmetry than the ground reaction forces and kinematic patterns in isolation. In this way, the peak extensor moment at the stifle joint during late stance contributes more to the TSM in Labrador Retrievers than in Greyhounds, despite the absence of active extension of the stifle joint in the Labrador Retrievers during push-off.¹⁵ A pilot study¹⁷ of mechanical asymmetry in a sound Labrador Retriever showed that despite similar ground reaction force amplitudes, the TSM at midstance was 37% larger for the right hind limb than for the left hind limb. The purpose of the study reported here was to identify whether sound Labrador Retrievers were mechanically symmetric by evaluating moment and power patterns of right and left hind limb joints and their TSMs in each dog.

Materials and Methods

Dogs—Nineteen Labrador Retrievers from the local community with no history of lameness were enrolled. Thirteen were male, and 6 were female. Mean $\pm$ SD body mass was 28.6 ± 3.7 kg. Standard clinical veterinary assessment, consisting of observation of each dog's walking and trotting gait and manual manipulation of the limb joints, confirmed the dogs were sound and pain free at the time of testing. Because the methods involved no invasive measurements or stress to the dogs, the study protocol was approved by the local university's ethics committee.

Gait analysis—Each hind limb was modeled as a linked-segment system of 5 segments. Small (8-mm) circular retroreflective markers were attached to the skin on the lateral aspect of the limb over the centers of

rotation of the right and left MTP, tarsal, stifle, and hip joints. Markers were also attached to the lateral distal aspect of the third phalanx of the paws and on the tuber coxae of each limb to measure the angular motion of the MTP and hip joints, respectively.

Four infrared cameras^a were positioned in a semi-circle to record the sagittal plane motions of the markers as each dog trotted back and forth along a runway and over a force platform.^b The calibrated volume of space was approximately 4 m in length, 1 m in width, and 1.5 m in height. The 3 orthogonal kinematic reference axes were aligned with the force platform coordinate system. Marker positional accuracy was within 2 mm of the actual value in the sagittal plane.

Each dog trotted back and forth along the runway and was led by a handler who did not interfere with the dog's speed or gait. The dogs were allowed to achieve a self-selected velocity during warm-up runs, and the handler then attempted to maintain this velocity in both directions during data collection. Only data from those runs in which the camera-side paw landed near the center of the force platform and the dog was moving at constant velocity were saved. Five of such trials were collected for each of the left and right sides. For each trial, velocity was recorded as stride length divided by stride duration.

Data analysis—Positional, ground reaction force, and morphometric data were imported into a custom computer program for calculation of segment and joint angular displacements, net joint moments, and net joint powers by means of inverse dynamics.¹⁴ Briefly, each limb segment was represented as a free body in the sagittal plane, with joint reaction forces computed from the segmental kinematics and instantaneous ground reaction forces in the vertical and craniocaudal directions and applied to the proximal and distal ends of the segment. Segment mass and center of mass location were estimated from a morphometric table for Labrador Retrievers,¹⁵ and the joint reaction forces were multiplied by their moment arms to the position of the mass center to calculate their respective moments around the segment center of mass. These were combined with the net joint moment calculated around the distal end of the segment to resolve the net moment around the proximal end. Joint power was calculated as the product of the net joint moment and the angular velocity of the joint.

The resultant sagittal plane stifle joint reaction force was computed from the vertical and horizontal stifle joint reaction forces by use of the Pythagorean theorem and was used with crus segment angle to compute the angle of the resultant stifle joint reaction force to the long axis of the crus on each side. Joint angles were calculated for the palmar or caudal aspect of the limb, and segment and resultant stifle joint reaction force angles were calculated for the palmar or caudal side of the limb in Cartesian coordinates from the horizontal. Net negative joint moments were palmar or caudal. Total stance phase support moment was calculated as the sum of the net joint moments contributing to extension or straightening of the limb during the stance phase.¹⁵ This involves reversing the moment at the stifle joint so it is negative on the cranial or dorsal aspect of the joint and adding that value to the net moment on the palmar or caudal side of the hip, tarsal, and MTP joints.

Dogs were grouped according to their TSM. Those with a peak TSM greater on their right side were designated as RD, and those with TSM greater on their left side were treated as LD. To be assigned to 1 of these 2 groups, the peak TSM on one side was required to be at least 10% greater than on the other side. When the degree of TSM asymmetry was < 10%, the dog was designated SYM. The 10% threshold was arbitrarily chosen on the basis that ground reaction force measurements in sound dogs and horses are 92% to 97% symmetric.^{9,13}

For each variable, data were normalized to stance duration (100%), averaged across the 5 right and left trials within dogs, and then averaged across the dogs within each group, yielding mean right and left joint moment and power curves per group.

Statistical analysis—Paired *t* tests were used to evaluate whether mean velocity varied between right and left trotting trials within each group. Likewise, mean joint moment and power curves were plotted per group, and discrete peaks in the TSM and joint moment and power curves were identified and labeled. Right-left differences for each variable were evaluated within groups by means of paired *t* tests of the individual dogs' right and left mean values.

Results

Of the 19 dogs evaluated, 10 were RD as determined by their peak TSM exceeding the 10% asymmetry threshold. One dog was LD, and 8 were classified as

SYM because their degree of asymmetry did not exceed 10% (Table 1). Of these symmetric dogs, 4 had a peak TSM slightly greater on the right side, 3 had a peak TSM slightly greater on the left side, and 1 was nearly identical on both sides. Mean TSM curves for the RD, LD, and SYM groups were created (Figure 1). Mean TSM was significantly ($P < 0.01$) greater on the right and left side in the RD and LD groups, respectively, and was not significantly greater on either side in the SYM group.

In the RD group, velocity was not significantly ($P > 0.05$) different between right and left trials (right, 2.02 ± 0.02 m/s; left, 1.98 ± 0.03 m/s). Given that only 1 dog was in the LD group, a *t* test for means of equal variance was used to compare the mean velocities from the 5 right and left trials (right, 1.93 ± 0.03 m/s; left, 1.81 ± 0.01 m/s; $P < 0.05$). No significant difference in velocity was evident between the right and left trials in the SYM group (right, 2.15 ± 0.21 m/s; left, 2.01 ± 0.09 m/s).

Metatarsophalangeal net joint moments and powers were graphically displayed (Figure 2). Net moments were palmar for the duration of the stance phase, indicating that the MTP flexors were the net active muscle group. Peak moments and powers were significantly larger on the right side than on the left side in the RD dogs. The peak moment occurred near midstance for the RD group, and there was no burst of positive power in early stance, indicating MTP joint angular velocity was quite small during this time. Peak MTP moment was earlier in the LD dog, which had a small burst of positive work from the MTP flexors in early stance as

Table 1—Mean (variance) joint moment and power peaks at right (R) and left (L) hind limb joints in trotting Labrador Retrievers judged as RD (n = 10), LD (1), and SYM (8).

Variable	Side	RD	LD	SYM
TSM	R	-1.090 (0.049)*	-0.921 (0.005)	-1.225 (0.086)
	L	-0.895 (0.025)	-1.084 (0.001)*	-1.080 (0.138)
Hip joint				
Joint moment (Nm/kg)	R	-0.481 (0.022)†	-0.580 (0.003)†	-0.503 (0.020)
	L	-0.424 (0.010)	-0.524 (0.001)	-0.475 (0.013)
Power peak (W/kg)	R	1.525 (0.600)*	0.872 (0.047)	1.868 (0.817)
	L	0.916 (0.085)	1.612 (0.010)*	1.680 (0.366)
Stifle joint				
Early stance joint moment 1 (Nm/kg)	R	-0.215 (0.004)	-0.274 (0.001)	-0.238 (0.006)
	L	-0.188 (0.003)	-0.283 (0.001)	-0.237 (0.004)
Late stance joint moment 2 (Nm/kg)	R	0.085 (0.004)	0.169 (0.001)*	0.166 (0.005)
	L	0.134 (0.003)*	0.111 (0.001)	0.149 (0.002)
Power peak (W/kg)	R	1.285 (0.161)	1.890 (0.061)	1.300 (0.445)
	L	1.238 (0.350)	1.922 (0.030)	1.189 (0.202)
Tarsus				
Early stance joint moment (Nm/kg)	R	-0.536 (0.003)*	-0.565 (0.001)	-0.611 (0.010)
	L	-0.478 (0.003)	-0.644 (0.001)*	-0.612 (0.010)
Early stance power peak (W/kg)	R	-3.801 (1.17)*	-4.030 (0.259)	-3.905 (2.94)
	L	-3.049 (0.685)	-5.338 (0.134)*	-3.602 (1.50)
Late stance power peak (W/kg)	R	2.125 (0.191)*	1.594 (0.007)	2.188 (0.349)
	L	1.718 (0.172)	2.299 (0.080)*	2.235 (0.285)
MTP				
Joint moment (Nm/kg)	R	-0.254 (0.002)*	-0.241 (0.001)	-0.296 (0.012)
	L	-0.176 (0.001)	-0.252 (0.001)	-0.289 (0.016)
Midstance power peak (W/kg)	R	-1.184 (0.128)*	-0.755 (0.002)	-1.121 (0.080)
	L	-0.803 (0.041)	-0.891 (0.012)†	-0.984 (0.097)
Late stance power peak (W/kg)	R	0.251 (0.024)†	0.083 (0.002)	0.230 (0.014)
	L	0.162 (0.008)	0.085 (0.001)	0.224 (0.043)

*Value is significantly ($P < 0.01$) different between right and left hind limbs. †Value is significantly ($P < 0.05$) different between right and left hind limbs.

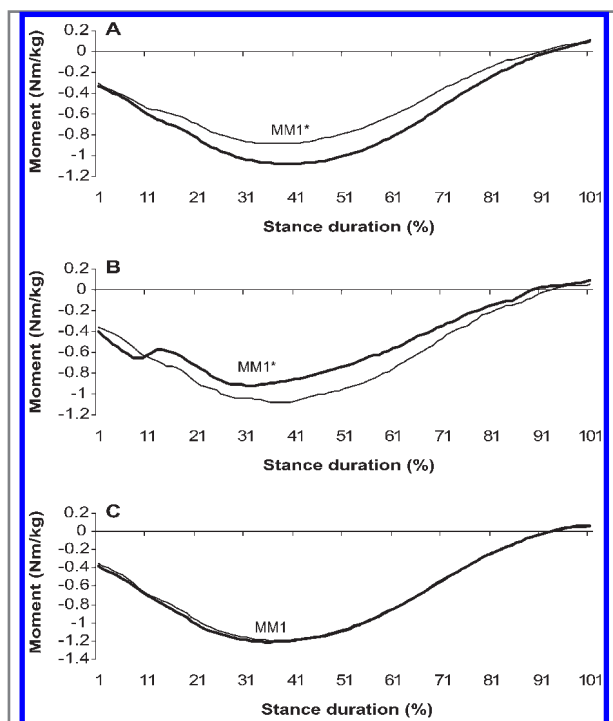


Figure 1—Total support moments for right (thick line) and left (thin line) hind limbs in trotting Labrador Retrievers judged as RD (A; $n = 10$), LD (B; 1), and SYM (C; 8). *Value is significantly ($P < 0.01$) different between right and left limbs. MM1 = Early stance local mean peak moment for all dogs.

the MTP joint flexed against the flexor moment during the immediate period after contact. The LD dog's negative power peak at midstance was significantly greater on the left side than on the right. The SYM dogs had MTP moment and power profiles similar to the RD group, with no positive power in the period after contact and a small burst of positive work at the end of stance, but the right and left curves were not grossly asymmetric or significantly different.

The net tarsal joint moment was significantly larger on the dominant versus nondominant side (Figure 3; Table 1). Power profiles indicated that the dominant-side tarsal flexors did significantly more negative work in early stance as the tarsal flexors lengthened and more positive work in late stance in the RD and LD dogs. The SYM dogs' tarsal joint profiles were nearly identical on both sides.

The stifle joint moment amplitudes as well as their timings were grossly different between groups, but these differences were only apparent after the weight-acceptance phase in early stance (Figure 4; Table 1). In the RD group, the net stifle joint moment changed from negative (net flexor effect) to positive (net extensor effect) before midstance on the left side, whereas it remains flexor until approximately midstance on the right. The amplitude of the subsequent extensor moment was then significantly larger on the left versus right side in the second half of the stance phase. This profile was reversed in the LD dog in that the stifle joint moment on the right became positive early on that side

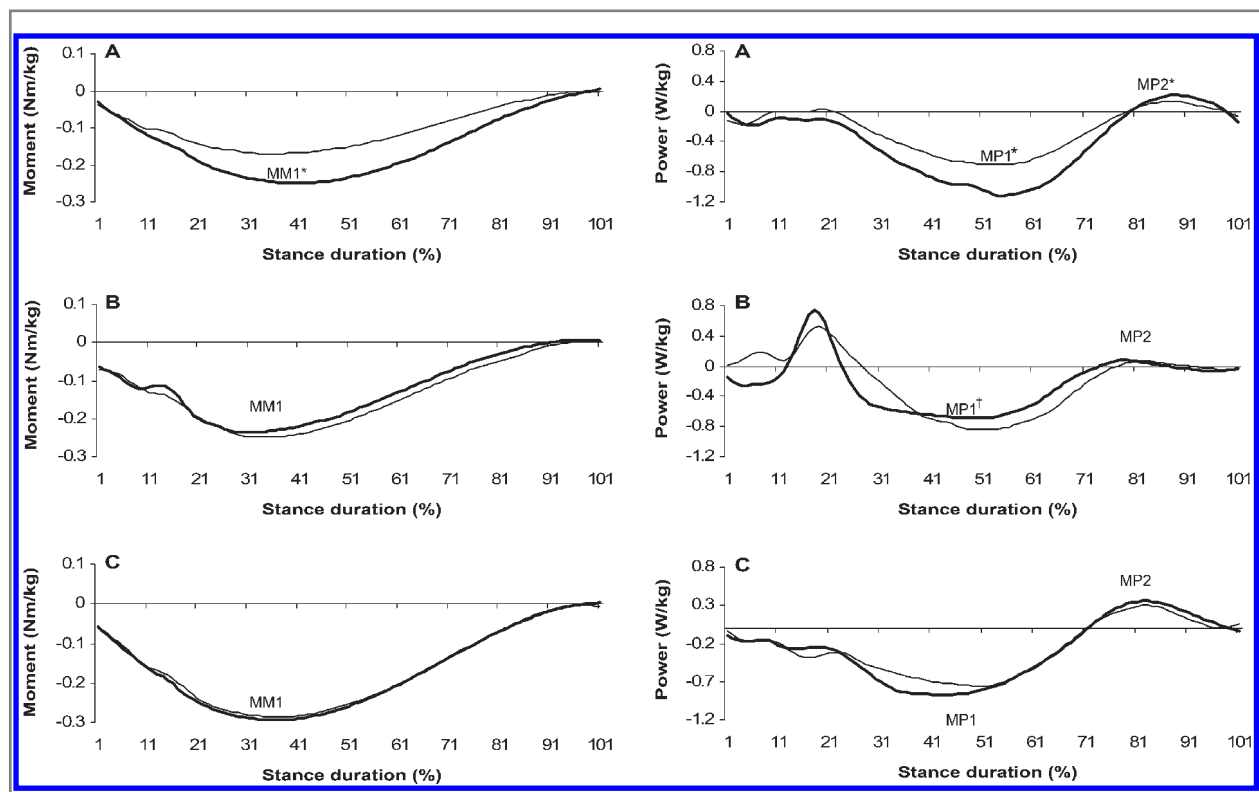


Figure 2—Metatarsophalangeal joint moments (left column) and powers (right column) for the right (thick line) and left (thin line) hind limbs in trotting Labrador Retrievers judged as RD (A; $n = 10$), LD (B; 1), and SYM (C; 8). †Value is significantly ($P < 0.05$) different between right and left limbs. MP1 = Early stance local mean power for all dogs. MP2 = Late stance local mean power for all dogs. See Figure 1 for remainder of key.

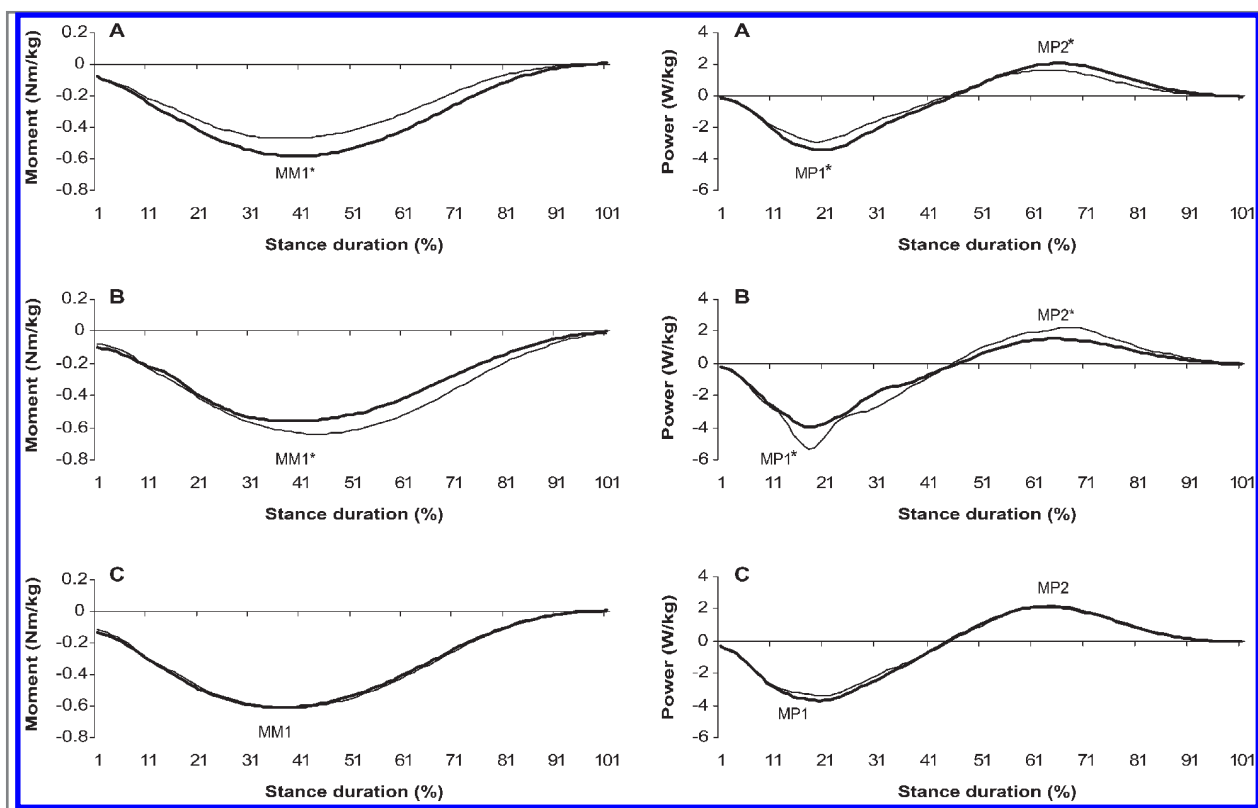


Figure 3—Tarsal joint moments (left column) and powers (right column) for the right (thick line) and left (thin line) hind limbs in trotting Labrador Retrievers judged as RD (A; n = 10), LD (B; 1), and SYM (C; 8). See Figures 1 and 2 for remainder of key.

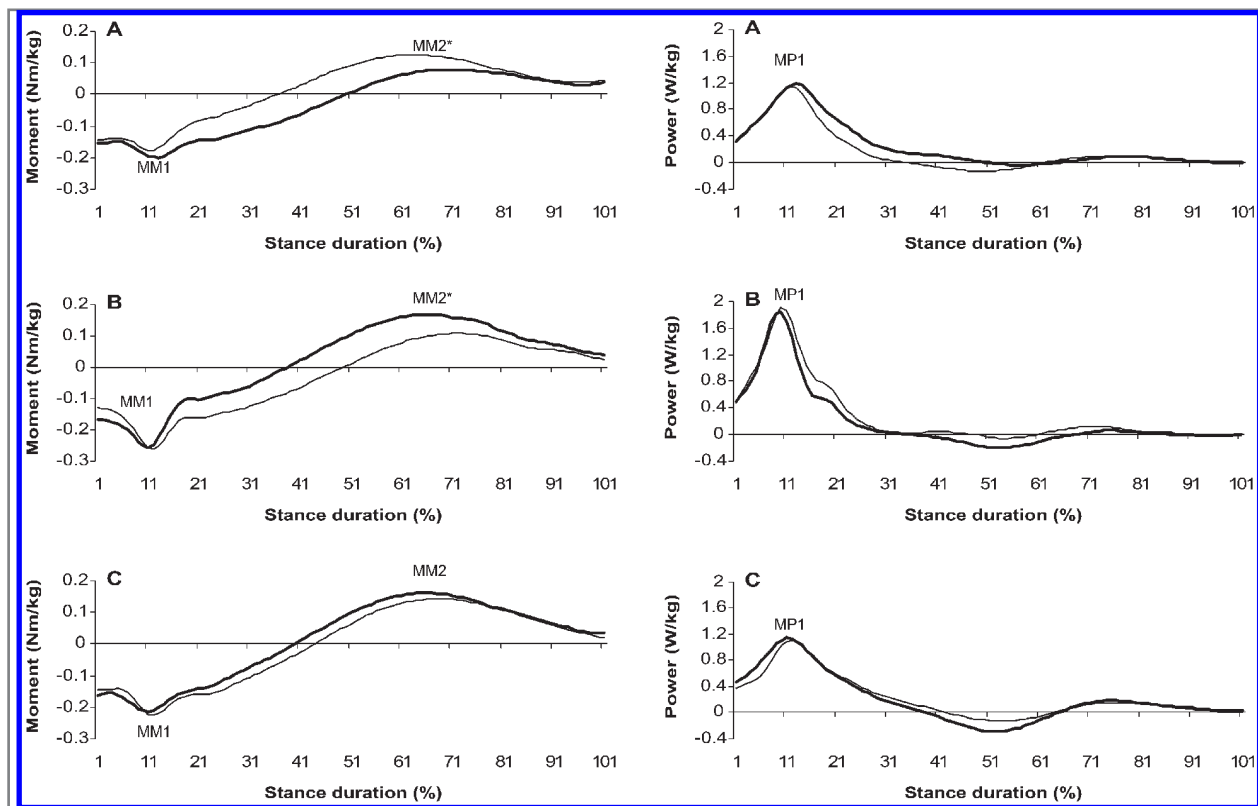


Figure 4—Stifle joint moments (left column) and powers (right column) for the right (thick line) and left (thin line) hind limbs in trotting Labrador Retrievers judged as RD (A; n = 10), LD (B; 1), and SYM (C; 8). MM2 = Late stance local mean peak moment for all dogs. See Figures 1 and 2 for remainder of key.

and had significantly greater amplitude than on the left side. These moment differences notwithstanding, the power curves indicated insignificant right-left differences, suggesting the stifle joint angular velocities were minimal after 30% stance. In the SYM dogs, the stifle joint moments had smaller right-left differences in timing and the amplitudes were similar. The power profiles likewise reflected no functional differences in work output between right and left stifle muscle groups.

The hip joint curves were similarly affected (Figure 5). After approximately 10% of the stance phase, the hip extensor moments predominated on the dominant side in the RD and LD groups but were largely symmetric in the SYM group. The transient local peak occurring at 10% stance was significantly larger on the right versus left side in both the RD and LD groups. Power ampli-

tude from the hip extensor muscles was significantly greater on the dominant versus nondominant side in the RD and LD groups but was largely symmetric in the SYM group. Positive power was greatest in the first half of stance as the hip extensor muscles forcefully extended the hip and then was minimal in the last third of stance and negative as the hip flexor muscles restrained further extension.

Despite small differences in horizontal and vertical joint reaction forces (Table 2), the angle between the resultant stifle joint reaction force vector and the long axis of the crus segment was the same between right and left limbs in all 3 groups (Figures 6–8). In the RD and SYM groups, this angle was approximately constant at 154° for most of the stance phase but slowly increased from 147° to 177° through stance in the LD

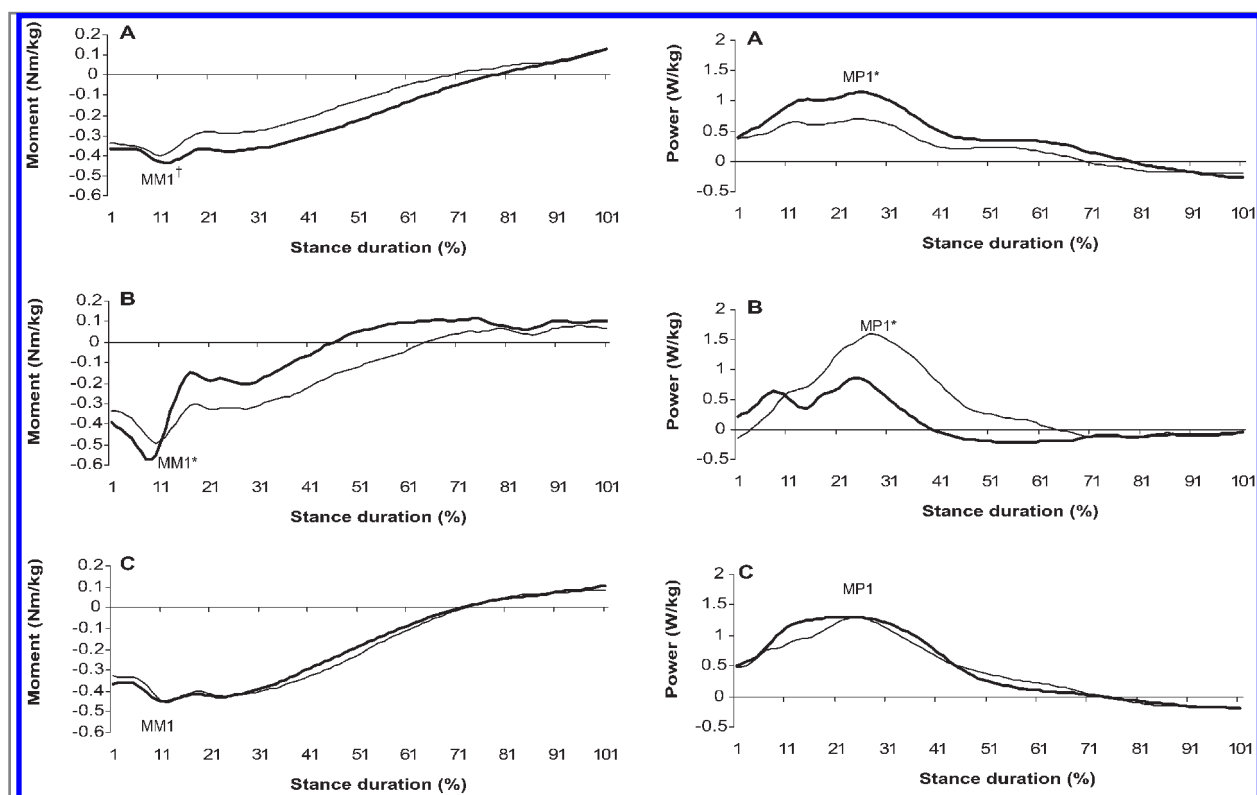


Figure 5—Hip joint moments (left column) and powers (right column) for the right (thick line) and left (thin line) hind limbs in trotting Labrador Retrievers judged as RD (A; n = 10), LD (B; 1), and SYM (C; 8). See Figures 1 and 2 for remainder of key.

Table 2—Mean (variance) stifle joint reaction forces at right (R) and left (L) stifle joints in trotting Labrador Retrievers judged as RD (n = 10), LD (1), and SYM (8).

Force (N/kg)	Side	RD	LD	SYM
Early stance horizontal	R	0.624 (0.043)	1.348 (0.019)	0.990 (0.185)
	L	0.798 (0.050)*	1.527 (0.047)†	0.980 (0.143)
Late stance horizontal	R	−0.854 (0.108)†	−1.672 (0.009)*	−1.200 (0.228)
	L	−0.752 (0.081)	−1.403 (0.017)	−1.122 (0.129)
Vertical	R	−6.191 (0.426)	−5.193 (0.020)	−6.235 (0.953)
	L	−6.149 (0.412)	−5.390 (0.001)†	−6.275 (1.162)
Resultant	R	−6.205 (0.432)	−5.411 (0.002)†	−6.243 (0.939)
	L	−6.081 (0.501)	−5.208 (0.024)	−6.295 (1.153)

See Table 1 for key.

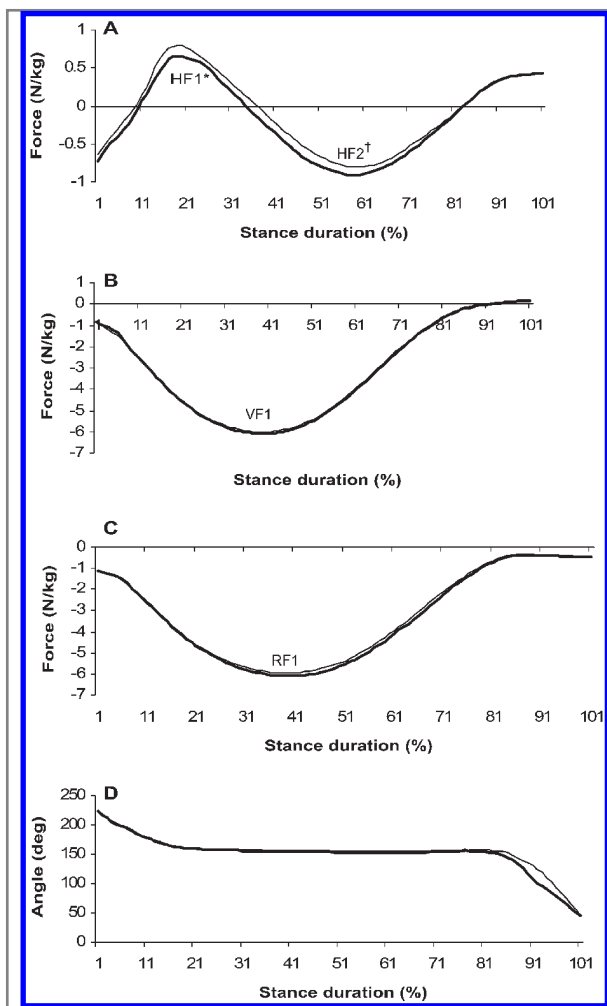


Figure 6—Mean horizontal (A), vertical (B), and resultant (C) joint reaction forces and sagittal angle between the resultant joint reaction force and crus segment (D) for right (thick line) and left (thin line) hind limbs in 10 Labrador Retrievers judged as RD. deg = Degrees. HF1 and HF2 = Local mean peak horizontal force. RF1 = Local mean peak resultant force. VF1 = Local mean peak vertical force. See Figure 2 for remainder of key.

dog before decreasing rapidly at the end of stance as the stifle joint collapsed into swing. In both the RD and LD groups, the horizontal stifle joint reaction force was significantly larger on the left side during the braking support phase of early stance, but significantly larger on the right side in the second part of the stance phase. Only the LD dog had significant right-left differences in its vertical and resultant joint reaction forces.

Discussion

Most of the literature suggests that there is some degree of natural asymmetry in bipedal and quadrupedal gait.^{18–20} This could be due to neuromuscular handedness or laterality, or it could be due to small bilateral discrepancies in segment or limb lengths. A smaller threshold of 5% TSM asymmetry could have been selected for grouping the dogs, and this would have resulted in 4 of the SYM dogs being placed in the RD group and an additional 3 in the LD group. Only 1 dog was nearly perfectly symmetric in its TSM calculation.

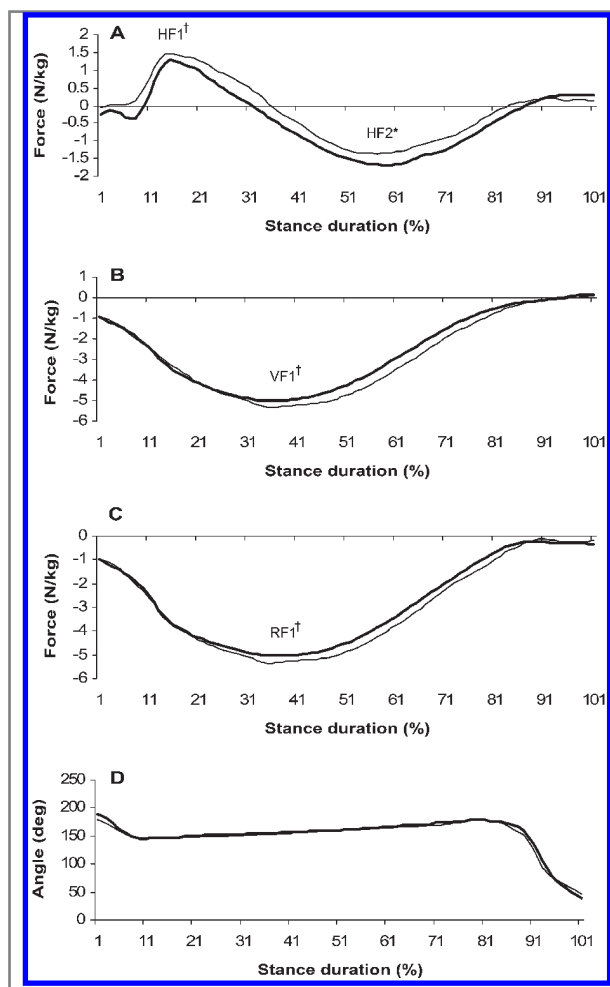


Figure 7—Horizontal (A), vertical (B), and resultant (C) joint reaction forces and crus segment (D) for right (thick line) and left (thin line) hind limbs in 1 Labrador Retriever judged as LD. See Figures 2 and 6 for remainder of key.

As it happened with the 10% asymmetry threshold, only 1 dog was included in the LD group. However, this 1 dog had larger amplitude stance phase moments on the left side at the MTP, tarsal, and hip joints and a larger flexor moment at the right stifle joint, in the exact opposite pattern of the RD dogs. Importantly, the timing of the transition between flexor to extensor moment at the stifle joint and extensor to flexor moment at the hip joint likewise varied between the RD dogs and the LD dog, indicating that both amplitudes and timing of the moment patterns were affected. The LD dog generated a larger and longer extensor moment and more power from the left hip extensors than from the right and generated an associated larger and longer flexor moment across the left stifle joint. Then, the extensor moment in the second half of the stance phase was greater at the right stifle joint as the stifle extensors stabilized the joint in the absence of a burst of positive work during push-off in terminal stance. The RD dogs had the exact opposite pattern, agreeing with earlier findings¹² that the right hind limb generates larger forces.

Other investigators^{5–7} have concluded that small asymmetries in joint angular motions may be due to

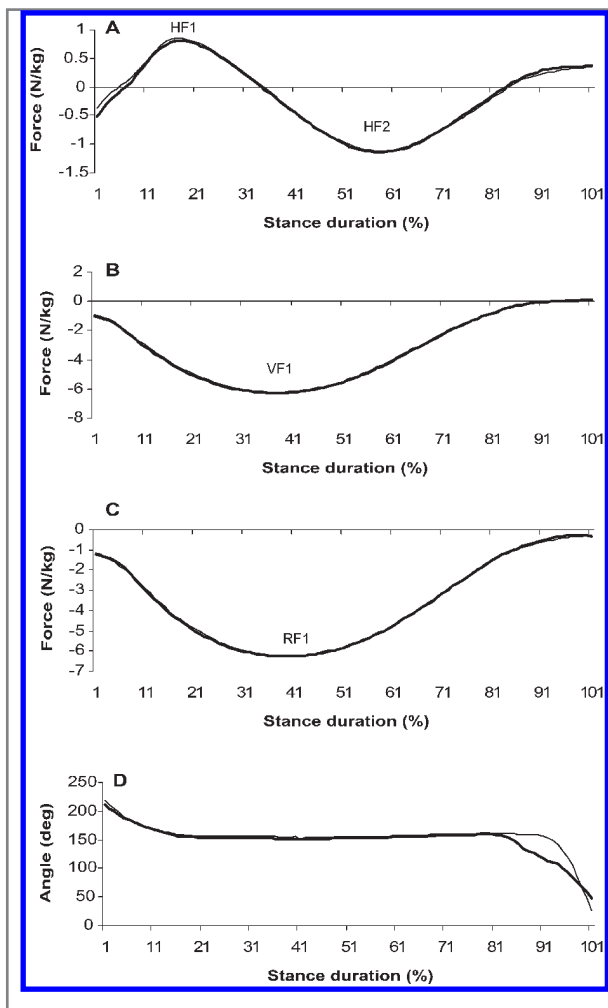


Figure 8—Mean horizontal (A), vertical (B), and resultant (C) joint reaction forces and sagittal angle (D) between the resultant joint reaction force and crus segment (D) for right (thick line) and left (thin line) hind limbs in 8 Labrador Retrievers judged as SYM. See Figure 6 for remainder of key.

small variations in trotting velocity between trials. One study²¹ showed that variations in trotting velocity yielded differences in joint moment and power amplitudes but that the profiles of the moment and power curves persisted. The results reported here do not implicate velocity as a factor in the differences, given that the profiles varied grossly among groups in both their amplitudes and timings. The recorded velocities were not significantly different between right and left trials in the RD and SYM groups but paradoxically were greater in the right trials for the LD dog. This was counterintuitive in that TSM was larger on the left side, for the lower velocities, when it might have been expected to be larger for the higher velocities. This observation helps to confirm that the LD dog's left limb behaved in a mechanically dominant manner independent of velocity. The greatest mean velocity was recorded for the right-sided trials in the SYM group, but this was influenced by a single dog with the fastest trotting speed.

The variations in moment amplitudes among groups generally appeared to manifest after the weight acceptance phase of early stance; in the first 10% of the

stance phase, the moment amplitudes were similar between right and left sides but then varied most through midstance. The moment curves were primarily affected by 2 variables: the ground reaction force amplitudes and the moment arm distances between the points of application of the forces on the segment ends and the center of mass of the segments. The lack of difference between moment values in the first 10% of the stance phase probably stemmed from the absorptive nature of this phase of the gait cycle. The distal limb joints appear to absorb energy during this phase, while the proximal muscle groups begin to initiate concentric contractions. Small differences in limb placement positions might make a limb slightly more or less vertical, mitigating against small bilateral differences in ground reaction forces for an overall similar joint moment. Judging from the hip joint power profiles, concentric muscle activations that generate hip joint extension appear to occur after this early weight acceptance phase and peak between 25% to 30% of the stance phase. Likewise, stifle flexor power rapidly increased during weight acceptance, and peak stifle joint power occurred at about the end of this period. This indicated that the weight acceptance period immediately following contact of the limb with the ground was less affected by voluntary limb motor variables and more by discrete placement and reflex muscle activations to prevent collapse of the limb.

Any study involving skin-mounted markers to identify the sagittal plane motions of limb segments around joint centers can be hampered by inaccurate placement of those markers. These markers are fairly easy to place on the distal limb joints, where bony landmarks are easy to palpate. The stifle and hip joint landmarks are less easy to locate, however, because of large muscle masses covering them, and the potential to misplace markers some distance from the anatomic joint center can result in errors in joint moment calculations due to the moment arm inaccuracies. In the present study, 1 individual (GRC) placed all of the markers, which in theory should reduce variations caused by placement error. Care was taken to compare marker positions, particularly over the right and left stifle and hip joints, to ensure that placement was correct and symmetric. Preliminary research indicated that intentional bilateral errors of approximately 4 cm in stifle joint marker placements could produce the right-left discrepancies detected. Labrador Retriever-specific morphometric measurements were used in the inverse dynamics equations, but this did not preclude the possibility that small bilateral variations in segment lengths or conformation could occur within dogs and be responsible for the right-left differences detected. However, the potential for small cumulative errors in proximal marker placement and local anatomic variations in segment morphometry notwithstanding, the MTP and tarsal moments and powers were calculated from markers placed on easily palpated landmarks, and even the associated curves indicated substantial differences in MTP and tarsal joint mechanics in the RD and LD dogs. We propose that small errors in marker placement in this study would be random and would not result in a systemic error in joint moments per group.

The present study was limited to evaluating joint kinetics in the sagittal plane; therefore, TSM was calculated entirely from the sagittal plane moments. It should be emphasized that frontal plane moments generated from, for example, the hip abductor muscles also contribute to the forces acting across local joints, so any asymmetry of moments in the frontal or horizontal planes may well equalize the overall force profile at any 1 joint or against the ground and even the energetic input to gait. The study was also limited to investigation of moments and powers during the stance phase, but substantial negative power is invested at the end of the swing phase, mainly by the stifle flexor and hip extensor muscles as they slow the protraction of the limb and reverse it for placement.²¹ This mechanism transfers energy from the swinging leg to the trunk, giving it forward momentum, and there is likewise potential for this burst of work to be asymmetric, although the similarity of the moments and powers observed at the beginning of the stance phase makes this unlikely.

The stifle joint reaction force angle against the long axis of the crus segment increased through the stance phase in the LD dog, whereas, on average, it remained the same in the RD and SYM dogs as the crus rotated forward in the stance phase (Figures 6–8). This change of angle indicates a more caudally directed stifle joint reaction force in late stance of the LD dog. Further examination of the RD dogs showed that 2 of the 10 had this same characteristic, whereas the angle remained constant at approximately 154° in the remaining 8 dogs. Whether this variable, local effect at the stifle joint, had any bearing on cranial cruciate ligament stress in individual dogs is something worth considering. Approximately 8% of Labrador Retrievers eventually sustain a cranial cruciate ligament injury.²² Something else worth considering is that, notwithstanding their outwardly normal gait, a few of the dogs in our study may have been affected by subtle, preclinical lameness that contributed to the measured asymmetries or to the observed differences in stifle joint reaction force direction that may have been a compensation for a subtle lameness.

Finally, the dogs trotted back and forth on the runway as their gait was recorded by cameras on 1 side. This required the handler to lead from the left going one way and from the right going the other way. Although it is usual to handle horses from the left side, it would be unusual for domestic dogs to be consistently led from 1 side; therefore, it is proposed that this did not affect the gait measurements in any systemic way.

The study reported here identified that sound trotting dogs can have bilateral differences in their joint moment and power profiles at all hind limb joints. Most dogs appeared to be RD in their hind limbs. The variations between sides in our study were in timing as well as amplitude variables and indicated that thought needs to be given to these naturally occurring asymmetries when considering causes of conditions such as cranial cruciate ligament disease. In addition, corrective surgery for cruciate ligament rupture may need to

account for the variable forces imposed across the right and left hip and stifle joints.

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- a. ProReflex, Qualisys AB, Gothenburg, Sweden.
 - b. Model 9287, Kistler Instrumente AG, Winterthur, Switzerland.
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