Are sound dogs mechanically symmetric at trot?

No, actually

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Introduction

Chances are you are right handed. It is well established that humans display a preference towards using a particular limb for motor tasks, and this is referred to as ‘handedness’ or ‘laterality’. Population studies indicate that about 90% of humans are right handed, with the remaining 10% preferring their left (1). Some evidence suggests that this lateral limb preference is associated with the small asymmetries typically observed in normal human gait (2) although other studies have shown that joint motions do not necessarily correlate with laterality. Maupas et al. (3) observed that 52% of adult humans demonstrated more than 5° of knee flexion-extension asymmetry during walking, and that this was not related to limb preference. Maupas et al. (4) likewise found that 62% of 40 subjects showed asymmetric measures of maximal knee flexion, but that there was no relationship with lateral preference.

Limb preference has also been observed in dogs (5) and horses (6, 7) and there appears to be a difference in preference between males and females. Wells (5) had 53 dogs perform three novel motor tasks involving the forelimbs, and found that male dogs had a preference for using the left paw while females preferred using their right paw. Murphy found that male horses had a significant preference for their left side in four motor behaviour tasks, while females preferred their right side (7). Wells also found that sea lions had a sex preference for direction of swimming (8). Males swam around their tanks in clockwise circles, while females swam counter-clockwise. Kinematic gait studies of trotting dogs, however, have shown that joint angular motions are symmetric (9, 10). Budsberg (11) demonstrated that variation in ground reaction forces had more to do with between-trial variation than L/R limb effects, and concluded that the ground reaction force patterns in trotting dogs were symmetric. Likewise, in a study of vertical forces and pressures under the paw pads in walking dogs (12) there were not any significant differences between right and left fore and hind limbs.

Sadeghi et al. (13) reviewed definitions of ‘laterality’ and ‘limb dominance’ in the bipedal gait literature and reported considerable inconsistency across studies relating functional gait symmetry or asymmetry to behavioural limb dominance, which was often determined by limb preference for certain motor tasks. Similar to the aforementioned studies by Wells (5), lower limb dominance might be inferred from such behavioural tasks as kicking a ball, picking something up with the toes, initiating gait or stepping up on a box, where subjects preferred to use one limb over the other. Robinson et al. (14) proposed a formulaic ‘symmetry index’ for ground reaction force variables and simpler Right/Left symmetry ratios have been reported in the clinical literature (15, 16). There does not appear to be a consistently used biomechanical definition for gait symmetry, and especially one that represents the whole function of each limb as a mechanical system.

Inverse dynamics analysis of gait uses the ground reaction forces in both the vertical and cranio-caudal directions, in addition to segmental morphometry and kinematics in order to calculate individual joint moments that can then be summed for all of the joints in a limb, yielding the total limb support moment. This is a more comprehensive indication of load within a limb than simple external vertical force or joint kinematics in isolation. Further, it has the ability to identify, even when total support moments are bi-
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Laterally similar, the concentration of forces at a particular joint within the limb. This is intuitive. In a multi-jointed, link segment system there are a number of mechanical degrees of freedom and a variety of ways to generate the total support moment. The distribution of these joint moments within a limb are scientifically interesting in their own right, but may also help to explain the unilateral incidence of some joint diseases despite indications in the literature that gait in sound dogs is symmetric. The purpose of this paper is to illustrate this asymmetric distribution of joint moments in a dog identified as ‘right hind limb dominant’ by comparison of its hind limb total support moments. Also, given that the stifle joint is a common location of joint pathology, including cranial cruciate ligament disease, its joint reaction forces were evaluated with respect to the sagittal plane orientation of the crus segment, in order to determine whether forces likely to be acting on the cruciate ligaments were asymmetric in their amplitude or orientation.

Method

The subject was a two-year-old neutered male Labrador Retriever, one of a cohort of 19 dogs in an ongoing study of mechanical laterality. It had a body mass of 24 kg. The dog did not have a history of lameness. Standard clinical veterinary assessment, consisting of observation of the dog’s walking and trotting gait and manual manipulation of the limb joints confirmed the dog to be sound and pain-free at the time of testing. Each hind limb was modelled as a linked-segment system of five segments. Small (8 mm) circular retroreflective markers were attached to the skin on the lateral aspect of the limb to disk. Five ‘good’ trials were collected for each of the left and right sides, from a total of 56 trials. Trotting velocity was calculated using Pythagorean theorem. Joint angles were calculated on the palmar/caudal aspect of the limb, and segment and resultant stifle joint reaction force angles were calculated with respect to the sagittal plane, with joint reaction forces computed from the instantaneous ground reaction forces in the vertical and cranio-caudal directions and applied to the proximal and distal ends of the segment. Segment mass and centre of mass location was estimated from a morphometric table for labrador Retrievers (17) and the joint reaction forces were multiplied by their moment arms to the position of the mass centre in order to calculate their respective moments around the segment centre of mass. These were combined with the moment calculated around the distal end of the segment to resolve the net joint moment around the proximal end. Joint power was calculated as the product of the net joint moment and angular velocity of the joint.

The resultant sagittal plane stifle joint reaction force was computed from the vertical and cranio-caudal joint reaction forces using Pythagorean theorem. Joint angles were calculated on the palmar/caudal aspect of the limb, and segment and resultant stifle joint reaction force angles were calculated
on the palmar/caudal side of the limb in Cartesian coordinates from horizontal. Net negative joint moments were palmar/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 stance (17). This involves reversing the moment at the stifle so it is negative on the cranial/dorsal aspect of the joint, and adding that to the net moment on the palmar/caudal side of the hip, tarsal and MTP joints.

Results

There were small but insignificant differences between mean (sd) trotting velocities for the five trials collected for each hind limb (Right: 2.50(.12)m/s; Left: 2.46(.10)m/s). The right hind limb landed 18(13) mm medial to the landing position of the right forelimb, and 64 (16) mm cranially. The left hind limb landed 44(23) mm lateral to the landing position of the left forelimb, and 61(24) mm cranially indicating a slight left lateral body inclination along the long axis of the runway. Mean ground reaction force traces are illustrated in Fig. 1. Stance time was slightly less for the right trials (.185s) compared to the left trials (.195s), which is in agreement with the slightly greater observed velocity. Mean peak vertical force was larger under the right limb, and this is also likely to be related to the slightly greater trotting velocity during those trials. Peak braking force was not different, although braking impulse was larger under the left limb, as the braking force was applied over a longer duration. Fig. 2 shows that the left limb was more protracted at initial contact with the stifle joint more extended and the crus segment was angled caudal to vertical. Peak propulsive force was slightly greater under the left limb.

Fig. 3 shows that the right hip was more flexed by about 10° at limb contact, and for the duration of stance. The net extensor moment at the hip was larger on the right, and peak power generation was delayed and larger on the right. Likewise, the right stifle was...
more flexed by about 5° (Fig. 4) and the peak flexor moment and power was delayed on the right, although the amplitudes of each curve were similar. Fig. 5 shows that the tarsus was more flexed on the left by about 3°, and that the net moment in mid-stance was larger on the right. More energy was absorbed by the tarsal plantarflexors in early stance and generated in late stance on the right. The MTP was more extended on the right until late stance, and the moment was larger on the right (Fig. 6). More energy was absorbed in early and late stance on the right, as the limb dorsiflexed over the stationary paw, but minimal additional work was performed on that side in push-off at the end of stance.

Total support moment was larger on the right side (Fig. 7), leading to the designation of this dog as ‘right handed’.

There were very small differences in caudally directed force on the tibial plateau during braking in early stance and during propulsion in late stance (Fig. 8), with larger horizontal forces measured on the left. However, the vertical and resultant joint reaction forces were larger on the right side. The angle of the resultant joint reaction force from horizontal was more cranially inclined on the right side (Fig. 9A) and the right crus segment was more vertically oriented at foot contact, remaining 3–4° more cranially inclined than the left crus until near the end of stance (Fig. 9B). As a consequence, the angle between the resultant stifle joint reaction force and the long axis of the crus segment was nearly identical on each side through midstance (Fig. 9C).

**Discussion**

This dog was determined to be ‘right hind limb dominant’ by comparison of its right and left total hind limb support moments. The net moments and powers at the hip, tarsal and MTP joints were all larger on the right side. The stifle moments and powers were approximately equal in amplitude, but their peaks occurred earlier in the stance phase on the left side.

It would be easy to suggest that this subject was sub-clinically lame, and that the exhibited bilateral differences in joint mechanics and the overall support moment were a consequence of this. However, this dog was one of a cohort of 19 young, sound dogs enrolled to date in an ongoing survey study of
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If their peak total support moments varied by 10% or more, they were classified as ‘right handed’ or ‘left handed’, and classified as bilaterally symmetric if the discrepancy between sides was less than 10%. Using this discriminator to separate groups, 10 dogs of the 19 have been classified as right dominant, eight have been classified as symmetric (notwithstanding their <10% asymmetry) and only one dog has been classified as left handed. If classified with a 95% criterion, then 15 would be right handed, three symmetric, and the remaining one left handed. In other words, most of the dogs demonstrate this pattern of hip, tarsal and MTP moments contributing to a larger total support moment on the right, with the right stifle joint contributing relatively less.

The fact that these asymmetries exist in total support moment, despite indications in the literature that joint angular motions and ground reaction forces are symmetric, may relate to the limb segmental angles. Some joint angular excursions may well be symmetric in the presence of asymmetries in their constituent segment angles caused by differences in limb placement. Net joint moments are calculated using joint reaction forces and their moment arms to the centre of mass of the segment. If the segment is more horizontally inclined, the large vertical joint reaction forces are multiplied by larger moment arms, thus increasing the turning moment around the mass centre. This might also be compounded by small and statistically insignificant, but functionally significant differences in the ground reaction force variables decomposed to local joint reaction forces.

One must also accept the possibility that the skin mounted markers could have been asymmetrically placed, which would contribute to the discrepancy between the angular displacements measured at the hip and stifle. The proximal markers are certainly more prone to skin movement over their supposed joint centres of rotation, and their accurate placement is often hindered by soft tissue covering the bony landmarks used to estimate the joint centres. This is less of an issue for markers on the distal limb, where palpable landmarks are easy to identify, and where skin motion is restricted. The MTP joint excursions are marked by a large asymmetry in early stance due to the more protracted placement of the left limb, and this likely accounts for some of the observed side differences at the stifle joint. On the right side, the hip and stifle joints were more flexed all the way through stance, whereas the tarsal joint was more extended. The MTP was more flexed in early stance, and the combination of these joint positions is concomitant with the observed differences in limb posture; the right limb was less protracted and was therefore more vertical especially in early stance. If the stifle joint markers were asymmetrically positioned, such that joint angular positions were discrepant between sides then this should be matched in the tarsal joint, but in fact, the tarsal angle discrepancy is in the opposite direction.

Fig. 7
Mean total support moments. The stance phase was time normalised to 101 data points. For line legends, see Fig. 1.

Fig. 8
Stifle joint reaction forces in the (A) horizontal direction, (B) vertical direction and (C) resultant vector. For line legends, see Fig. 1.
Asymmetric skeletal conformation is another confounding possibility. Small variations in bilateral segment lengths could contribute to differences in moment arms of the joint reaction forces acting around the centre of mass of a segment, and thus account for some variation between sides. However, these potential small variations are unlikely to be separable from the small errors in joint centre locations and the inherent variability between trials caused by variations in limb placement and velocity.

The stifle joint horizontal reaction forces were larger on the left, but this difference is dwarfed in comparison to the magnitude of the vertical joint reaction forces, which were larger on the right. The overall effect was that the resultant stifle joint reaction force on the right side. Couple this with reduced horizontal joint reaction force on the right, and there may be a mechanism whereby the cranial cruciate ligament is stress shielded in the stifle joint on the dominant side. Whether this mitigates for or against eventual injury to this important ligament remains to be determined, but it may help to explain the unilateral incidence of ‘idiopathic’ cruciate ligament injury in dogs (19).

A drawback of the inverse dynamics approach is the inability to quantify co-contraction of muscles on opposite sides of a joint. It is quite likely that the flexed position of the hip and stifle joints on the right side during stance comes with a mechanical energy cost. It is also likely that the quadriceps drive the femoral condyles caudally during stance as a result of this flexed posture and that may well mitigate against any stress shielding of the ligaments resulting from the segment angle against the vertical joint reaction force. Further research into limb conformation and handedness and their respective effects on the forces experienced during gait will, perhaps, provide more insight. In the meantime, happy 80th birthday, Geoff!

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