AJVR

# Pelvic limb joint motion increases with treadmill walking speed in healthy Beagles

Kazuyuki Yoshikawa, PT, PhD[1–3*]; Takio Kitazawa, DVM, PhD[4]; Tadashi Sano, DVM, PhD[5]; Atsushi Yamazaki, DVM, PhD[3]; Kazuya Edamura, DVM, PhD[3]

[1]Japan Small Animal Medical Center, Tokorozawa, Japan
[2]Department of Veterinary Medicine, Graduate School of Veterinary Medicine, Rakuno Gakuen University, Ebetsu, Japan
[3]Laboratory of Veterinary Surgery, Department of Veterinary Medicine, College of Bioresource Sciences, Nihon University, Fujisawa, Japan
[4]Department of Veterinary Sciences, School of Veterinary Medicine, Rakuno Gakuen University, Ebetsu, Japan
[5]Department of Veterinary Medicine, School of Cooperative Veterinary Medicine, Obihiro University of Agriculture and Veterinary Medicine, Obihiro, Japan

*Corresponding author: Dr. Yoshikawa (k.yoshikawa@jsamc.or.jp)

**Objective**
To determine the effects of 4 fixed treadmill walking speeds on sagittal-plane pelvic limb joint motion in healthy Beagles and to provide speed-stratified descriptive kinematic values for interpreting treadmill-based canine gait assessments.

**Methods**
8 healthy Beagles underwent 3-D motion analysis during treadmill walking at 1.1 km/h (0.31 m/s), 1.8 km/h (0.50 m/s), 2.5 km/h (0.69 m/s), and 3.2 km/h (0.89 m/s). For each dog at each speed, 10 gait cycles were time normalized and averaged to generate representative waveforms. Peak extension angle, peak flexion angle, and range of motion (ROM) were calculated for the hip, stifle, and tarsus. Linear mixed-effects models were used to assess speed-related changes. Only walk trials were analyzed; for 1 dog, the 3.2 km/h (0.89 m/s) trial was excluded after gait classification identified trot.

**Results**
ROM increased with speed in all 3 joints. For every 1-km/h (0.28 m/s) increase in speed, ROM increased by 6.11° (95% CI, 5.37 to 6.86) at the hip, 5.37° (95% CI, 4.17 to 6.56) at the stifle, and 3.66° (95% CI, 2.41 to 4.90) at the tarsus. At the hip and stifle, the increase in ROM reflected increased peak extension and decreased peak flexion, whereas at the tarsus, it was associated mainly with a decrease in peak flexion angle.

**Conclusions**
Faster treadmill walking was associated with greater pelvic limb ROM in healthy Beagles, with joint-specific patterns of change.

**Clinical Relevance**
Walking speed should be standardized or accounted for when interpreting treadmill-derived ROM in canine gait analysis or rehabilitation follow-up.

**Keywords:** walking speed, treadmill walking, canine gait analysis, kinematics, range of motion

In canine gait analysis, which is commonly used in veterinary orthopedic research, rehabilitation, and repeated functional assessment, joint range of motion (ROM) is one of the most practical kinematic-summary variables.[1] Range of motion is attractive as it can be derived directly from sagittal-plane joint angle waveforms and is expressed in clinically accessible units. However, ROM is not a fixed biological property but is influenced by the locomotor conditions under which it is measured. In human gait analysis, walking speed is known to affect lower-extremity joint kinematics.[2] Accordingly, differences in canine ROM may reflect not only biological changes but also differences in gait, treadmill conditions, and walking speed.

Studies[3,4] of sagittal-plane hind limb kinematics during canine walking have revealed that treadmill-based gait analysis can generate reproducible waveforms under controlled conditions.

Received March 28, 2026
Accepted May 17, 2026
Published online May 26, 2026

doi.org/10.2460/ajvr.26.03.0139

Treadmill assessment is particularly useful because it allows locomotion at fixed speeds as well as collection of multiple consecutive strides. Interpretation of treadmill-derived kinematic data requires attention to methodological influences. In healthy dogs, habituation status can affect locomotor variables during treadmill walking,[5] and treadmill-derived ROM exhibits day-to-day variability.[6] Therefore, joint motion should be interpreted in relation to the conditions under which the data were obtained.

Canine hind limb kinematics vary across locomotor tasks. Hind limb ROM differs between swimming and walking,[7] and treadmill inclination and exercise regimens can alter joint motion.[8,9] Normative kinematic data are available for certain breeds and study settings.[3,10,11] However, most of these studies were designed to compare locomotor tasks, describe breed- or setting-specific kinematics, or evaluate habituation and repeatability rather than to isolate walking speed as the primary explanatory variable within the walking gait. Thus, although walking speed is one of the most controllable variables during treadmill-based assessment and rehabilitation, speed-specific reference data for hind limb ROM during walking remain limited.

This knowledge gap is particularly relevant at the lower end of the speed spectrum. In postoperative, geriatric, or neurologically impaired dogs, treadmill exercise is often initiated at a walk rather than a trot, and relatively slow walking speeds are commonly used in clinical settings. Under these circumstances, interpretation of hind limb ROM requires an understanding of the physiological variation expected across walking speeds. Therefore, the objective of this study was to determine the effects of 4 fixed treadmill walking speeds on the sagittal-plane kinematics of the hip, stifle, and tarsal joints in healthy Beagles. We hypothesized that ROM would increase with walking speed and that the contributions of peak extension and peak flexion to this change would differ among joints.

## Methods

### *Study design*

This prospective, within-subject, repeated-measures kinematic study was designed to evaluate the effects of treadmill walking speed on hind limb joint motion in healthy dogs.

### *Animals*

The study protocol was approved by the Animal Experiment Committee of Rakuno Gakuen University (approval No. VH17B7). Eight university-owned adult Beagles, judged to be clinically healthy, were studied. Before data collection, each dog underwent orthopedic and neurological examinations to confirm the absence of abnormalities that could affect gait. Body condition score was assessed using a 9-point scale. The baseline characteristics of the dogs are summarized in **Table 1**.

### *Treadmill protocol*

The trials were performed on a motorized treadmill (AF1900; ALINCO), with belt dimensions of 117 X 35.5 cm. Before formal data collection, the dogs were habituated to treadmill walking in 20-minute sessions twice daily for 3 consecutive days, consistent with previous laboratory protocols for Beagles.[12] After habituation, the kinematic data were collected at 4 preset treadmill speeds: 1.1 km/h (0.31 m/s), 1.8 km/h (0.50 m/s), 2.5 km/h (0.69 m/s), and 3.2 km/h (0.89 m/s). The speeds were tested in ascending order from slowest to fastest. At each speed, data collection began after the dog had settled into a consistent walking pattern on the treadmill, and 10 analyzable gait cycles were recorded.[12] During treadmill walking, each dog wore a collar attached to a leash. The handler stood in front of the dog in the direction of treadmill progression and encouraged walking verbally. Although a leash was attached for safety, the dog was not pulled or physically guided by the leash, and the handler attempted to avoid intentionally correcting or interfering with the dog's natural walking pattern.

The gait cycle was defined as the interval from the initial contact of the left hind limb to the subsequent initial contact of the same limb.[12] Only trials in which walking was confirmed were included in the primary analysis because the objective of the study was to characterize speed effects within the walking gait. Gait type was determined from a video review based on footfall pattern; walking was defined as a 4-beat gait without synchronous diagonal limb contacts, whereas trotting was defined as a 2-beat diagonal gait.

### *3-D kinematic analysis*

Before data acquisition, the measurement volume of the KinemaTracer system (Kissei Comtec)

**Table 1**—Baseline characteristics of the study Beagles.

| Dog | Sex | Age (y) | Body weight (kg) | Height at withers (cm) | BCS |
|---|---|---|---|---|---|
| Goma | M | 8 | 14.7 | 40.5 | 6 |
| Kinako | F | 4 | 11.8 | 39 | 4 |
| Ponyo | F | 7 | 10.5 | 37 | 6 |
| Renault | M | 8 | 12.5 | 40 | 5 |
| San | F | 8 | 10 | 38.5 | 4 |
| Zunda | M | 4 | 14.3 | 40.5 | 5 |
| Yomogi | M | 4 | 13.4 | 39 | 5 |
| Rotus | M | 8 | 11.6 | 39.5 | 5 |
| Mean ± SD | — | 6.4 ± 2.0 | 12.4 ± 1.7 | 39.3 ± 1.2 | 5.0 ± 0.8 |

The results are presented for 8 healthy Beagles; BCS was assessed using a 9-point scale
BCS = Body condition score. F = Female. M = Male

was calibrated using a cube-shaped control object placed within the treadmill capture space according to the manufacturer's procedure. After calibration, the control object was removed, and treadmill walking trials were recorded. The motion of the left pelvic limb was recorded using a 3-D motion analysis system (KinemaTracer) with 4 cameras at 60 Hz. Color markers (20 mm in diameter) were attached to the skin over anatomical landmarks using double-sided adhesive tape (Kabetakku sponge double-sided adhesive sheet; Nichiban Co Ltd) and kinesiology tape (Battlewin tape; Nichiban Co Ltd). For this analysis, markers were placed over the iliac crest, greater trochanter, femorotibial joint, lateral malleolus, and distolateral aspect of the fifth metatarsal, consistent with previous kinematic canine protocols.[12,13] This analysis focused on the left pelvic limb because the objective was to characterize speed-related changes in pelvic limb joint motion, particularly at the hip, stifle, and tarsus. The 3-D coordinate data were smoothed using a digital low-pass filter, with a cutoff frequency of 8 Hz.[13]

The sagittal-plane flexion-extension angles of the hip, stifle, and tarsal joints were calculated as intersegmental angles from the smoothed coordinates.[13] Larger values represent greater extension. All kinematic data were reviewed frame by frame by the same evaluator.[12,13] To account for differences in stride duration, each gait cycle waveform was time normalized from 0% to 100% of the gait cycle and resampled to 201 points. For each dog at each speed, the 10 recorded gait cycles were first averaged to generate a single representative waveform so that the dog, rather than the individual gait cycle, remained in the experimental unit.[12,13] The peak extension angle, peak flexion angle, and ROM were calculated from the representative waveform for each joint, with ROM defined as the peak extension angle minus the peak flexion angle. For descriptive waveform visualization, the dog-level representative waveforms were subsequently averaged across dogs at each speed, and SD was calculated at each normalized time point.

### *Statistical analysis*

All statistical analyses were performed using R, version 4.5.2 (R Foundation for Statistical Computing). The dogs represented the experimental units. For each joint and outcome variable (peak extension, peak flexion, and ROM), separate linear mixed-effects models were fitted with dog as a random intercept to account for repeated measurements across treadmill speeds.

Two complementary model specifications were used. First, speed was entered as a continuous fixed effect to estimate the average change in each outcome for every 1-km/h (0.28 m/s) increase in walking speed across the studied range; regression coefficients and Wald 95% CIs were extracted from these models. Second, speed was entered as a categorical fixed effect to test for differences among the 4 walking speeds without assuming linearity. For the categorical models, the overall significance of speed was assessed via likelihood ratio testing against a nested null model without the speed term. Because the 3.2-km/h (0.89 m/s) condition was excluded for 1 dog, the data set was unbalanced; mixed-effects models were used to accommodate this unbalanced repeated-measures structure while retaining all remaining observations. Differences were considered significant at $P < .05$.

## Results

All 8 dogs completed the walking trials at 1.1 km/h (0.31 m/s), 1.8 km/h (0.50 m/s), and 2.5 km/h (0.69 m/s). At 3.2 km/h (0.89 m/s), the

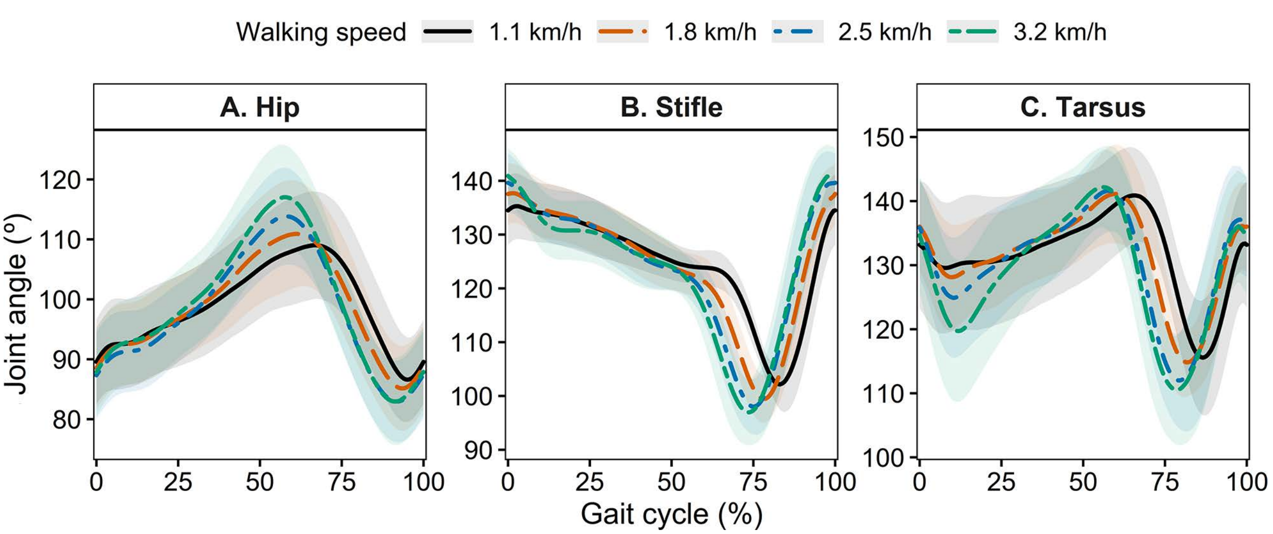


**Figure 1**—Group means of representative sagittal-plane joint angle waveforms of the hip, stifle, and tarsus across walking speeds. Sagittal-plane joint angle waveforms for the hip (A), stifle (B), and tarsus (C) in healthy Beagles during treadmill walking at 1.1 km/h (0.31 m/s), 1.8 km/h (0.50 m/s), 2.5 km/h (0.69 m/s), and 3.2 km/h (0.89 m/s). Each waveform represents the group mean of dog-level representative waveforms, with each dog-level waveform derived from 10 gait cycles/dog; shaded areas represent the SD. The 3.2-km/h (0.89 m/s) waveform is based on 7 dogs because the trial data for 1 dog were excluded after gait classification identified trot rather than walk.

gait of 1 dog (Rotus) was classified as trot and was excluded from the walk-only analysis; therefore, the results for 3.2 km/h (0.89 m/s) were based on 7 dogs, whereas the results for the other speeds were based on 8 dogs.

**Figure 1** presents the group mean representative waveforms for the hip, stifle, and tarsal joints at each walking speed. For all 3 joints, the overall waveform shape appeared visually similar across walking speeds, whereas motion amplitude increased with speed. This separation of group mean waveforms was most evident in the hip and stifle joints. **Table 2** presents the dog-level descriptive statistics and mixed-model estimates for peak extension angle, peak flexion angle, and ROM. The ROM data are presented in **Figure 2** and the peak extension and peak flexion angles in **Figure 3**.

Range of motion increased significantly with walking speed for all 3 joints (overall categorical effect, *P* < .001 for each joint). With the increase from 1.1 km/h (0.31 m/s) to 3.2 km/h (0.89 m/s), hip ROM increased from 22.81 ± 4.63° to 35.03 ± 4.00°, stifle ROM from 34.13 ± 3.65° to 45.81 ± 6.64°, and tarsal ROM from 26.89 ± 5.60° to 34.45 ± 5.14°. In the continuous-speed model, with each 1-km/h (0.28 m/s) increase in speed, hip ROM increased by 6.11° (95% CI, 5.37 to 6.86), stifle ROM by 5.37° (95% CI, 4.17 to 6.56), and tarsal ROM by 3.66° (95% CI, 2.41 to 4.90).

For the hip, both the peak extension and peak flexion angles changed significantly with speed (overall categorical effect, *P* < .001 for both). With the change from 1.1 km/h (0.31 m/s) to 3.2 km/h (0.89 m/s), hip peak extension angle increased from 109.33 ± 9.04° to 117.77 ± 8.32°, and hip peak flexion angle decreased from 86.52 ± 7.05° to 82.73 ± 7.21°. In the continuous-speed model, for every 1-km/h (0.28 m/s) increase in speed, hip peak

**Table 2**—Peak extension angle, peak flexion angle, and range of motion (ROM) of hind limb joints at each walking speed.

| Joint | Variable | 1.1 km/h (0.31 m/s) | 1.8 km/h (0.50 m/s) | 2.5 km/h (0.69 m/s) | 3.2 km/h (0.89 m/s) | Overall *P* | Slope (°/km/h) | 95% CI |
|---|---|---|---|---|---|---|---|---|
| Hip | Peak extension angle | 109.33 ± 9.04 | 111.44 ± 8.74 | 114.20 ± 7.87 | 117.77 ± 8.32 | < .001 | 3.99 | 3.15 to 4.82 |
| | Peak flexion angle | 86.52 ± 7.05 | 84.94 ± 7.06 | 82.78 ± 6.85 | 82.73 ± 7.21 | < .001 | −2.13 | −3.03 to −1.24 |
| | ROM | 22.81 ± 4.63 | 26.50 ± 4.42 | 31.42 ± 3.24 | 35.03 ± 4.00 | < .001 | 6.11 | 5.37 to 6.86 |
| Stifle | Peak extension angle | 135.53 ± 6.04 | 137.86 ± 5.57 | 139.91 ± 5.54 | 141.48 ± 5.79 | < .001 | 2.55 | 1.75 to 3.36 |
| | Peak flexion angle | 101.39 ± 4.37 | 98.77 ± 3.77 | 96.77 ± 5.57 | 95.67 ± 6.01 | .001 | −2.80 | −3.97 to −1.62 |
| | ROM | 34.13 ± 3.65 | 39.08 ± 5.72 | 43.14 ± 6.21 | 45.81 ± 6.64 | < .001 | 5.37 | 4.17 to 6.56 |
| Tarsus | Peak extension angle | 141.82 ± 7.27 | 143.64 ± 6.17 | 143.34 ± 5.88 | 143.79 ± 6.24 | .085 | 1.12 | 0.20 to 2.05 |
| | Peak flexion angle | 114.93 ± 9.01 | 113.76 ± 6.01 | 110.68 ± 8.39 | 109.34 ± 8.37 | .002 | −2.53 | −3.70 to −1.37 |
| | ROM | 26.89 ± 5.60 | 29.88 ± 3.61 | 32.66 ± 5.03 | 34.45 ± 5.14 | < .001 | 3.66 | 2.41 to 4.90 |

The results are reported as mean ± SD. Speed headings are reported as km/h (m/s). Overall *P* values were obtained from linear mixed-effects models with dog as a random effect and speed as a categorical fixed effect. Slope values indicate the estimated change in joint angle for every 1-km/h increase in speed based on linear mixed-effects models treating speed as a continuous variable. The 3.2-km/h (0.89 m/s) condition is based on 7 dogs because trial data for 1 dog were excluded after gait classification identified trot rather than walk.

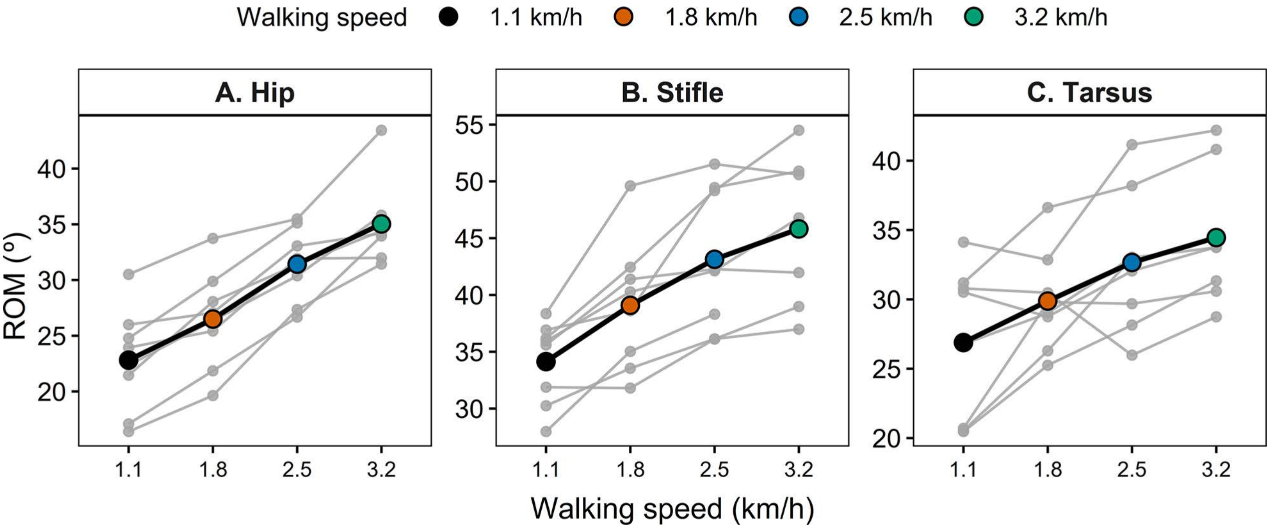


**Figure 2**—Range of motion (ROM) of the hip, stifle, and tarsus across walking speeds, showing individual dog-level ROM values for the hip (A), stifle (B), and tarsus (C). Thin gray lines represent individual dogs, the thick black line connects group means, and colored circles indicate group means at each speed. The 3.2-km/h (0.89 m/s) condition includes 7 dogs because the trial data for 1 dog were excluded from the walk-only analysis after gait classification identified trot rather than walk.

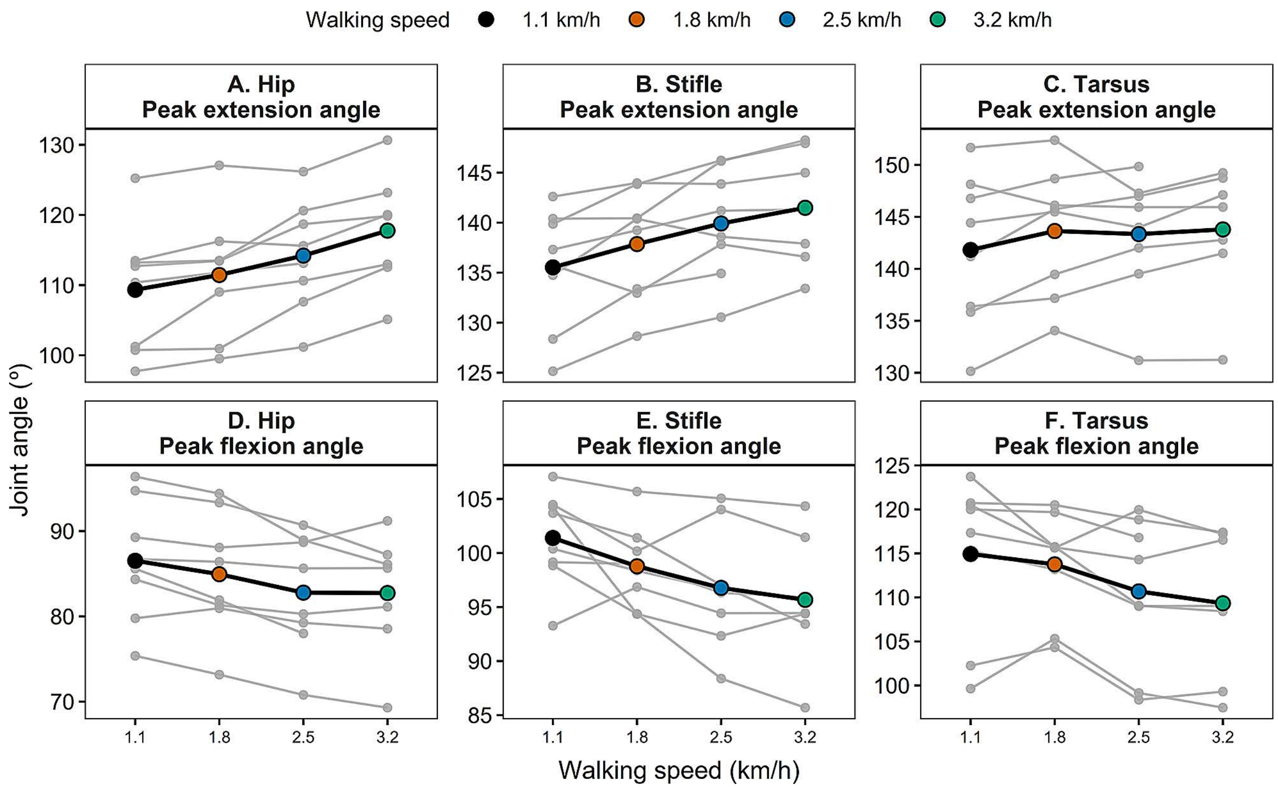


**Figure 3**—Peak extension and peak flexion joint angles across walking speeds. A–C—Peak extension angles for the hip, stifle, and tarsus. D–F—Peak flexion angles for the hip, stifle, and tarsus. Thin gray lines and gray points indicate individual dog-level values, the thick black line connects group means, and colored points indicate group means at each walking speed. The 3.2-km/h (0.89 m/s) condition includes 7 dogs because the trial from 1 dog was excluded from the walk-only analysis after gait classification identified trot rather than walk.

extension angle increased by 3.99° (95% CI, 3.15 to 4.82), and hip peak flexion angle decreased by 2.13° (95% CI, 1.24 to 3.03).

At the stifle joint, both the peak extension and peak flexion angles changed significantly with speed (overall categorical effect, $P < .001$ for both). With the increase from 1.1 km/h (0.31 m/s) to 3.2 km/h (0.89 m/s), stifle peak extension angle increased from 135.53 ± 6.04° to 141.48 ± 5.79°, whereas stifle peak flexion angle decreased from 101.39 ± 4.37° to 95.67 ± 6.01°. In the continuous-speed models, for every 1-km/h (0.28 m/s) increase in speed, stifle peak extension angle increased by 2.55° (95% CI, 1.75 to 3.36), and stifle peak flexion angle decreased by 2.80° (95% CI, 1.62 to 3.97).

At the tarsus, the peak extension angle changed only modestly across speeds, from 141.82 ± 7.27° at 1.1 km/h (0.31 m/s) to 143.79 ± 6.24° at 3.2 km/h (0.89 m/s), and the overall categorical effect of speed on peak extension angle was not significant ($P = .085$). In the corresponding continuous-speed model, for each 1-km/h (0.28 m/s) increase in speed, tarsal peak extension angle increased by 1.12° (95% CI, 0.20 to 2.05). In contrast, tarsal peak flexion angle decreased from 114.93 ± 9.01° at 1.1 km/h (0.31 m/s) to 109.34 ± 8.37° at 3.2 km/h (0.89 m/s), with a significant overall categorical effect of speed ($P = .002$) and an estimated decrease of 2.53° (95% CI, 1.37 to 3.70) per 1-km/h (0.28 m/s) increase in speed. Accordingly, the increase in tarsal ROM across speeds was associated primarily with a reduction in peak flexion angle rather than with marked change in peak extension angle.

## Discussion

In these healthy adult Beagles walking on a treadmill, hind limb ROM increased progressively with walking speed within the walking gait. This association was evident for the hip, stifle, and tarsal joints, although the manner in which ROM increased differed among the joints. At the hip and stifle, faster walking was associated with higher peak extension and lower peak flexion angles, whereas at the tarsal joint, the increase in ROM was driven primarily by a reduction in peak flexion angle. These findings identify walking speed as an important determinant of hind limb kinematics during treadmill walking, implying that joint-specific response patterns should be considered when interpreting ROM.

The direction of the observed effect is consistent with the findings of prior canine gait studies[7–9] showing that hind limb kinematics depend on locomotor task demands. Previous studies have emphasized that data collection conditions and analytical choices can influence measurements of joint motion.[1] Nonetheless, many prior studies have focused on comparing exercise modalities, inclination conditions, or breeds or have investigated methodological questions rather than examining walking speed as the primary variable of interest. This study addresses this gap by evaluating hind limb kinematics at multiple fixed treadmill speeds within the walking gait and by modeling speed as both a categorical and continuous predictor. This makes it possible to directly describe the association between ROM and walking speed over a clinically relevant range of walking speeds.

These findings are particularly relevant to rehabilitation settings in which dogs are evaluated repeatedly over time. When treadmill walking is used for postoperative monitoring, neurologic rehabilitation, or longitudinal assessment of functional recovery, ROM values obtained at different visits should be interpreted cautiously unless walking speed has been controlled or its effects modeled. This interpretation is supported by prior work showing that treadmill-derived ROM in healthy dogs can vary across examination days.[6] A dog that walks faster at follow-up may show a larger ROM even in the absence of treatment-related improvements in intrinsic limb function. Conversely, ROM values obtained at very slow walking speeds may still lie within the physiological range expected for that task. These results therefore support explicit control or statistical adjustment for speed whenever treadmill-based hind limb ROM is used as an outcome measure.

These joint-specific patterns are biomechanically informative. At the hip and stifle, the simultaneous increase in peak extension angle and decrease in peak flexion angle indicates that faster walking was accompanied by broader motion at both ends of the sagittal-plane waveform. By contrast, the tarsal joint exhibited relatively small changes in the peak extension angle, with a more prominent decrease in the peak flexion angle. Although this study was not designed to identify the kinetic or neuromuscular mechanisms underlying this difference, these findings suggest that speed-related scaling of hind limb motion is not uniform across joints. This interpretation is consistent with prior findings that changes in canine locomotor activity demand do not necessarily affect all joints in the same way.[7–9]

Group mean waveform shape appeared visually similar across the 4 walking speeds even though the amplitude increased. This clinically relevant finding suggests that under the present testing conditions, faster walking was achieved primarily by scaling the magnitude of joint motion rather than by marked changes in the basic waveform configuration. The highest speed tested here also warrants comment. Although only 1 dog transitioned to a trot at 3.2 km/h (0.89 m/s), this suggests that 3.2 km/h (0.89 m/s) may approach the walk-to-trot transition for some Beagles under comparable treadmill conditions.

This study had several limitations. First, the treadmill speeds were tested in a fixed ascending order rather than a randomized order, so an order effect cannot be completely excluded. Although the dogs underwent a structured 3-day habituation period before testing, residual learning or fatigue effects across successive speed conditions remained possible. Second, the study was limited to healthy adult Beagles, and the results cannot be extrapolated directly to other breeds or body conformations or dogs with orthopedic or neurological diseases. Third, skin-mounted marker systems are susceptible to soft tissue artifacts, and displacement of skin markers relative to the underlying skeletal landmarks has been demonstrated experimentally in dogs.[14] Although the measurement volume was calibrated before data acquisition using the KinemaTracer system, residual parallax, lens distortion, and marker tracking errors may have remained and could have affected the absolute joint angle values. In addition, the dogs walked with a collar and leash while being verbally encouraged by a handler standing in front of them. Although the leash was not used to pull or physically guide the dogs, the handling method may have influenced treadmill walking patterns. Another limitation is that forelimb kinematics were not included in this analysis. Inclusion of comparable forelimb data would have provided a more complete understanding of speed-related whole-limb and interlimb kinematic changes. Body condition score was recorded, and the study dogs were within a narrow body condition range; however, body condition can affect canine gait-related variables and joint kinematics.[15] Therefore, extrapolation to dogs with substantially different body condition should be cautious. Finally, this study specifically addressed treadmill walking; overground walking may yield related, but not identical, kinematic values.[4]

In conclusion, in these healthy adult Beagles, treadmill walking speed was strongly associated with hind limb ROM. Faster walking generated greater ROM at the hip, stifle, and tarsal joints; however, the joint-specific changes differed, with bidirectional expansion of motion in the hip and stifle, whereas ROM expansion at the tarsus was driven primarily by a lower peak flexion angle. These findings, which provide speed-stratified descriptive kinematic values for treadmill walking in healthy Beagles under this protocol, support explicit control or statistical adjustment for speed in future canine gait studies and rehabilitation assessments.

## Acknowledgments

None reported.

## Disclosures

During the preparation of this manuscript, ChatGPT (OpenAI; GPT-5.4 and GPT-5.5 versions) was used to improve grammar and phrasing and to condense the text. After using this tool, the authors reviewed and revised the manuscript. The authors take full responsibility for the final content of the article.

## Funding

The authors have nothing to disclose.

## References

1. Sandberg GS, Torres BT, Budsberg SC. Review of kinematic analysis in dogs. *Vet Surg.* 2020;49(6):1088–1098. doi:10.1111/vsu.13477
2. Kwon JW, Son SM, Lee NK. Changes of kinematic parameters of lower extremities with gait speed: a 3D motion analysis study. *J Phys Ther Sci.* 2015;27(2):477–479. doi:10.1589/jpts.27.477

3. Hottinger HA, DeCamp CE, Olivier NB, Hauptman JG, Soutas-Little RW. Noninvasive kinematic analysis of the walk in healthy large-breed dogs. *Am J Vet Res.* 1996;57(3):381–388. doi:10.2460/ajvr.1996.57.03.381
4. Torres BT, Moëns NM, Al-Nadaf S, Reynolds LR, Fu YC, Budsberg SC. Comparison of overground and treadmill-based gaits of dogs. *Am J Vet Res.* 2013;74(4):535–541. doi:10.2460/ajvr.74.4.535
5. Gustas P, Pettersson K, Honkavaara S, Lagerstedt AS, Bystrom A. Kinematic and spatiotemporal assessment of habituation to treadmill walking in Labrador Retrievers. *Acta Vet Scand.* 2016;58(1):87. doi:10.1186/s13028-016-0265-9
6. Pietsch S, Steigmeier-Raith S, Reese S, Meyer-Lindenberg A. Reliability of range-of-motion measurements of healthy dogs examined while walking on a treadmill. *Am J Vet Res.* 2021;82(11):897–902. doi:10.2460/ajvr.82.11.897
7. Marsolais GS, McLean S, Derrick T, Conzemius MG. Kinematic analysis of the hind limb during swimming and walking in healthy dogs and dogs with surgically corrected cranial cruciate ligament rupture. *J Am Vet Med Assoc.* 2003;222(6):739–743. doi:10.2460/javma.2003.222.739
8. Lauer SK, Hillman RB, Li L, Hosgood GL. Effects of treadmill inclination on electromyographic activity and hind limb kinematics in healthy hounds at a walk. *Am J Vet Res.* 2009;70(5):658–664. doi:10.2460/ajvr.70.5.658
9. Holler PJ, Brazda V, Dal-Bianco B, et al. Kinematic motion analysis of the joints of the forelimbs and hind limbs of dogs during walking exercise regimens. *Am J Vet Res.* 2010;71(7):734–740. doi:10.2460/ajvr.71.7.734
10. Surer E, Cereatti A, Evangelisti MA, Paolini G, Della Croce U, Manunta ML. A canine gait analysis protocol for back movement assessment in German Shepherd dogs. *Vet Sci.* 2020;7(1):26. doi:10.3390/vetsci7010026
11. Vilar JM, Rubio M, Carrillo JM, Domínguez AM, Mitat A, Batista M. Biomechanic characteristics of gait of four breeds of dogs with different conformations at walk on a treadmill. *J Appl Anim Res.* 2015;44(1):252–257. doi:10.1080/09712119.2015.1031778
12. Yoshikawa K, Tsubakishita S, Sano T, Ino T, Miyasaka T, Kitazawa T. Functional assessment of the gluteus medius, cranial part of the biceps femoris, and vastus lateralis in Beagle dogs based on a novel gait phase classification. *J Vet Med Sci.* 2021;83(1):116–124. doi:10.1292/jvms.20-0127
13. Yoshikawa K, Kitazawa T, Sano T, Ino T, Miyasaka T. Kinematic characteristics of canine hindlimb movement during sit-to-stand and stand-to-sit motions. *Res Vet Sci.* 2023;162:104944. doi:10.1016/j.rvsc.2023.104944
14. Schwencke M, Smolders LA, Bergknut N, Gustås P, Meij BP, Hazewinkel HA. Soft tissue artifact in canine kinematic gait analysis. *Vet Surg.* 2012;41(7):829–837. doi:10.1111/j.1532-950X.2012.01021.x
15. Brady RB, Sidiropoulos AN, Bennett HJ, Rider S, Posner LP, Wills TB. Evaluation of gait-related variables in lean and obese dogs at a trot. *Am J Vet Res.* 2013;74(5):757–762. doi:10.2460/ajvr.74.5.757