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*Full Length Research Paper*

# Evaluation of pacing as an indicator of musculoskeletal pathology in dogs

**Theresa M. Wendland, Kyle W. Martin, Colleen G. Duncan, Angela J. Marolf and Felix M. Duerr***

Department of Clinical Sciences, Colorado State University, United States.

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**Little is currently known about the pacing gait in dogs and it has been speculated that pacing may be utilized by dogs with musculoskeletal pathology. The goals of the present study were to determine if pacing in dogs is associated with musculoskeletal disease and to establish if controlled speed impacts pacing. Dogs underwent orthopedic and lameness assessments. Musculoskeletal pathology, when identified, was further defined with radiography of the affected area. Dogs were considered musculoskeletally normal (MSN) if no pathology was detected and they had no history of musculoskeletal disease. All others were considered musculoskeletally abnormal (MSA). Animals were then evaluated for pacing using digital-video-imaging under three conditions: Off-lead, lead-controlled, and on a treadmill. Thirty-nine dogs were enrolled (MSN: *n* = 20; MSA: *n* = 19). Overall, pacing was observed more frequently in dogs under lead-controlled than off-lead conditions (*P* < 0.001). Lead-controlled MSN dogs were observed to pace significantly more frequently (*n* = 17/20) than lead-controlled MSA dogs (*n* = 10/19; *P* = 0.029). There was no significant difference within each group for the frequency of pacing under treadmill or off-lead conditions. Pacing always occurred at speeds between a walk and a trot, speeds ranged from 0.98 to 2.84 m/s, (mean 1.8 m/s). Pacing was demonstrated in MSN and MSA dogs under all study conditions. Pacing should be considered a gait variation that can be observed in clinically normal dogs. Relative speed and leash walking was determined to be a factor in the use of the pacing gait.**

**Key words:** Pacing, gait analysis, lameness, canine locomotion, symmetrical gait, lateral gait, amble.

## INTRODUCTION

Gait and lameness assessments are major aspects of the orthopedic examination; therefore, knowledge of gait patterns is essential for recognition of pathologic conditions (Zink and Van Dyke, 2013). In dogs, the walk, trot, and gallop are considered normal gait patterns; however, it is unclear whether pacing is normal or pathologic in dogs (Hildebrand, 1968; Blaszczyk and Dobrzecka, 1989; Zink and Van Dyke, 2013). The pace (Figure 1) is a 'lateral-couplet' symmetrical gait in which ipsilateral limb pairs move in synchrony (Hildebrand, 1968; Leach et al., 1977; Biknevicius and Reilly, 2006). It has been suggested that dogs which consistently pace in

*Corresponding author. E-mail: felix.duerr@colostate.edu.

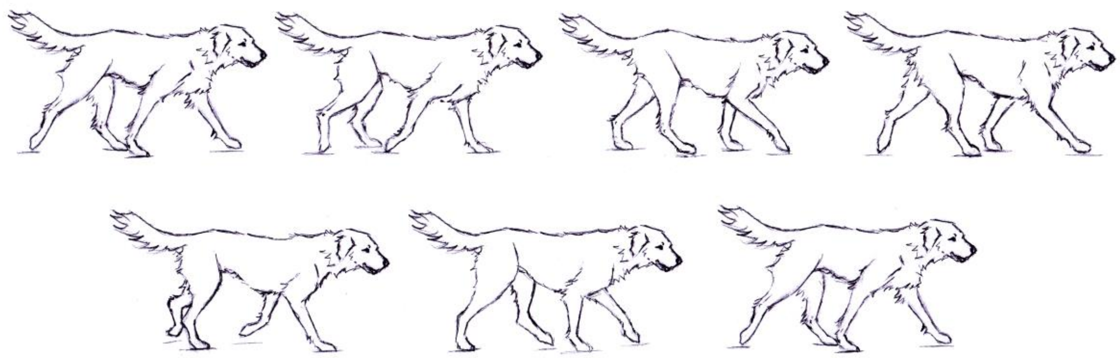

**Figure 1.** Pace: Two beat 'lateral-couplet' symmetrical gait in which ipsilateral limb pairs move synchronously; image illustrates the stride sequence of the pace; Illustrated by TM Wendland.

**Table 1.** Lameness grading scale used in this study.

| Grade | Description of lameness |
|---|---|
| 0 | Clinically sound (no identifiable lameness; animal evenly weight-bears when standing) |
| 1 | Barely detectable lameness (possible lameness at walk or trot; animal evenly weight-bears when standing) |
| 2 | Mild lameness (subtle but definite lameness at walk and/or trot; animal mildly off-weights affected limb when standing) |
| 3 | Moderate lameness (obvious lameness at walk and/or trot; animal definitely off-weights affected limb when standing) |
| 4 | Severe lameness (carries limb when trotting but at least occasionally weight bearing walking or standing) |

preference to trotting should be examined to rule out injuries that may make trotting difficult (Zink and Van Dyke, 2013). Additionally, it has been implied that dogs which are tired, out of condition, or have a diagnosable orthopedic abnormality may pace (Nunamaker and Blauner, 1985). In contrast, the pace has also been described as normal and naturally occurring in some dogs: For example, several researchers recorded pacing in healthy, athletic dogs in two separate studies and regarded this as a normal gait (Maes et al., 2008; Maes and Abourachid, 2013). Others attribute pacing to dogs with proportionally long legs and/or at speeds between those of a walk and a trot (Hildebrand, 1968; Brown and Dalzell,1986). One final proposition suggests pacing is neither a pathology nor a normality, but that dogs may be trained to pace by handlers consistently leash-walking them at speeds between walk and trot speeds (Zink and Van Dyke, 2013).

Despite the controversy regarding the clinical significance of pacing, there are currently no peer-reviewed publications describing the incidence of pacing in musculoskeletally abnormal dogs to the authors' knowledge. Moreover, little data exists describing speeds at which canids pace and the impact that controlled speed has on gait pattern. Since pacing is easily recognized during visual examination, information on the significance of this gait as a potential indicator of pathology would be useful for veterinarians, trainers, and owners. The goal of the present study was to evaluate dogs with and without musculoskeletal abnormalities for evidence of pacing. We hypothesized that dogs with musculoskeletal pathology would pace more frequently than normal dogs. Another goal of the study was to characterize the relationship between a dog's relative speed and pacing. We hypothesized that dogs would pace at speeds between walk and trot speeds and that they would pace more frequently when speeds were controlled than when dogs were released off-leash.

## MATERIALS AND METHODS

### Animals

A convenience sample of 39 healthy, privately owned pet dogs were enrolled. The study protocol was reviewed and approved by the Colorado State University Institutional Animal Care and Use Committee (#14-4908A) and written owner consent was obtained. Stress monitoring of the dogs was performed by behavioral assessment and by utilizing a heart rate monitor (Polar Ft1 Heart Rate Monitor, Polar Electro Inc) (Cohen and Obrist, 1975; Vincent and Leahy, 1997; Beerda et al., 1998; Essner et al., 2013). Dogs showing an obvious, strong stress-response during the study were to be excluded.

Dogs were required to be capable of trotting continuously for a minimum of 10 min. Medium to large breed dogs of any weight, breed, and body proportion were included. Dogs were excluded if their body condition scores were less than 4/9 or greater than 6/9 (Brady et al., 2013). A detailed medical history was obtained from each owner. Dogs underwent complete physical examination and orthopedic evaluation by a board certified veterinary surgeon and were assigned a subjective lameness score (scale 0 to 5; 0 = no lameness, and 5 = severe lameness, Table 1). Evaluation was performed prior to application of test conditions so an individual

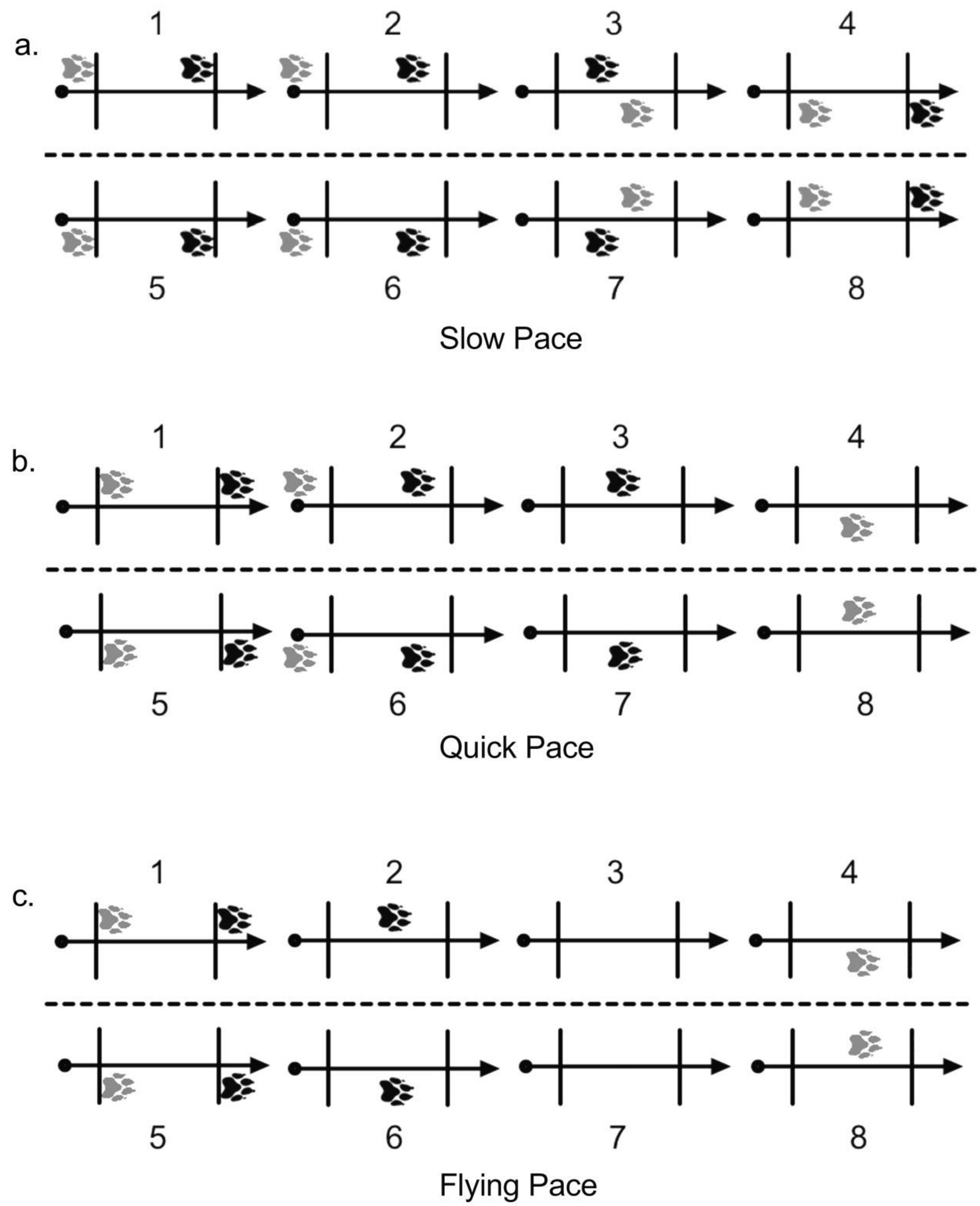


**Figure 2.** Footfall patterns of the pace at various speeds with black paw prints representing thoracic limb feet and grey paw prints representing pelvic limb feet. Each numbered unit represents foot placement during a moment in time with 8 moments represented for each speed. (a) During the slow pace two feet are in contact with the ground at all times. The left ipsilateral pair supports the dog for half a stride. The rear left foot then lifts as the hind right foot strikes the ground and the dog is supported by diagonal limbs. The left fore foot then lifts at the same time the right fore foot strikes the ground so that the dog is again supported by ipsilateral limbs. (b) The quick pace is similar to the slow pace except that diagonal pairs of feet do not touch the ground at the same time, instead, the contralateral forelimb is lifted as the hind foot strikes the ground. (c) The flying pace uses the same sequence of limb movement but is characterized by a moment of suspension;

dog's pacing status was unknown by the evaluator other than the gait which was observed during orthopedic examination. Dogs with a lameness score of three or greater were excluded from the study. Dogs with no history of lameness, no abnormal findings on physical

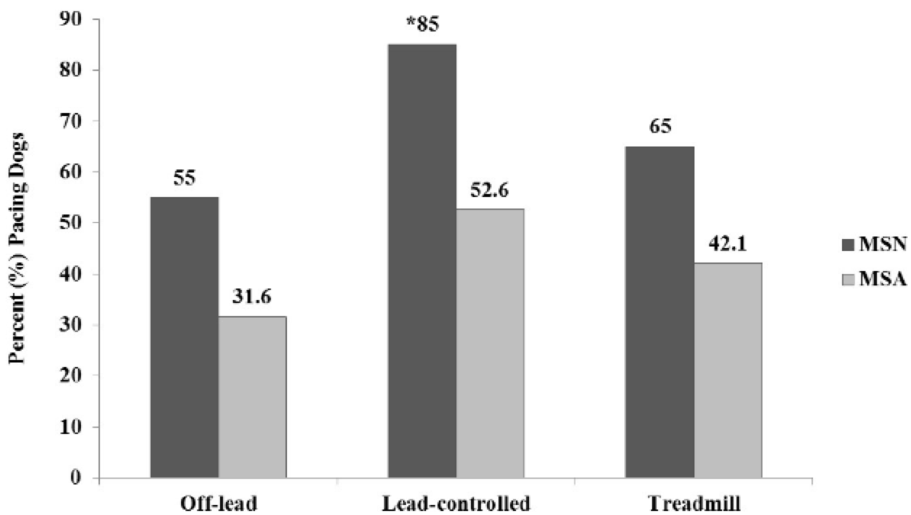


**Figure 3.** Comparison of pacing frequency between musculoskeletally normal (MSN) and musculoskeletally abnormal (MSA) groups under off-lead, lead-controlled, and treadmill conditions. Dogs in the MSN group ($n$ = 17/20; 85%) were observed to pace significantly more frequently than dogs in the MSA group ($n$ = 10/19; 52.6%) under lead-controlled conditions ($P$ = 0.029).

examination, and a lameness score of zero were assigned to the musculoskeletally normal (MSN) group. All other dogs were assigned to the musculoskeletally abnormal (MSA) group. Any orthopedic abnormality or lameness was further investigated with radiography. Radiographs were evaluated by a board certified veterinary radiologist and findings were recorded. Consistently repeatable abnormal examination findings, even if not supported by radiographic changes were considered 'abnormal' for the sake of this study since no soft tissue imaging (such as MRI, PET-CT, or ultrasound) was performed.

Breed or detailed physical description of mixed-breeds was recorded. Height from the ground to the highest point of the withers and length from the point of the greater tubercle of the humerus to the tuber ischium were recorded. Leg-to-body ratios were calculated as previously described (Brown and Dalzell,1986). Briefly, leg length was measured from the ground to the deepest part of the chest. Chest depth was measured from the bottom of the chest dorsally to the point of the withers. The measured leg length was then divided by the measured chest depth. These measurements were taken with an adjustable 48-inch drywall square (Swanson Tool Co, Inc).

## Procedures

Following physical examination and group assignment, dogs were evaluated under three conditions: Off-lead unrestricted movement, lead-controlled movement, and ambulation on a treadmill (Large DogTread, PetZen Products). Animals were recorded with video cameras from the front, back, and sides. The animals' gaits were later evaluated for pacing by reviewing digital videos recorded from all test conditions. Dogs were evaluated on two days to accomplish treadmill habituation: On day one, dogs were habituated to the treadmill by walking and trotting for eight to 10 minutes for at least two discrete sessions separated by a 30-min rest period to increase compliance and to help reduce artifacts in movement induced by the use of the treadmill (Fanchon and Grandjean, 2009; Gustas et al., 2013). The dogs were also introduced to the enclosed outdoor area used for recording unrestricted movement. On day two, video recordings were collected off-lead, followed by lead-controlled, and the treadmill last as outlined in the following.

### *Off-lead*

The dogs were individually released off-lead into a fenced enclosure of approximately 5 × 12 m. They were recorded while free-roaming using a digital video camera held at the dogs' shoulder heights. Continuous recording was performed during a minimum of three walk-to-trot and three trot-to-walk transitions. When a dog stopped ambulating for 10 consecutive seconds, a handler walked within the enclosure and verbally called to the dog to encourage movement.

### *Lead-controlled*

The dogs were led on a loose lead over a flat paved area between two traffic cones marking a 20 m path at incremental speeds estimated by the person handling the dog via a GPS (global positioning system) tracking device (Bad Elf 2200 GPS Pro, Bad Elf LLC). The first pass along the path was made with the dog ambulating at a subjectively determined consistent four-beat walk. Speed was increased during subsequent passes between cones until the dog was subjectively determined to consistently trot. Animals were observed and recorded with digital video imaging from the side, front, and back simultaneously.

### *Treadmill*

Dogs were reintroduced to the treadmill to ensure gait normalization. Reintroduction consisted of a treadmill session starting with the dog walking, increasing the speed until the dog trotted, and subjectively assessing both gaits to be normal. The reintroduction session was limited to five minutes for any test subject. During the reintroduction phase, the speed for a consistent walk was determined and recorded. This walking speed was used as the starting treadmill belt speed for the subsequent treadmill trial. Once dogs were habituated to the treadmill, they were given a 2 to 5 min break, then underwent a single treadmill session for gait evaluation. Video recording was initiated and dogs were started on the treadmill at the previously determined walking speed. The treadmill belt speed was then increased by 0.3 km/h increments and each increment was maintained for 15 s. Belt speed was increased until the dog reached a consistent working trot, then the session was ended. The treadmill speeds were verbally dictated into the video camera microphone at each incremental change to be noted during video evaluation.

#### *Video evaluation*

Each dog was evaluated for pacing by a single observer. Footfall pattern recognition was facilitated by post-processing film to one-quarter speed (Apple i-Movie). A symmetrical lateral-couplet gait in which ipsilateral limbs move in synchrony was considered ‘pacing’. Slow, quick, and flying pace (Figure 2) were defined according to previous publications (Hildebrand, 1968; Hollenbeck, 1981; Nunamaker and Blauner, 1985; Brown and Dalzell, 1986; Maes et al., 2008; Zink and Van Dyke, 2013) and were grouped into a single category, ‘pacing.’ The minimum average speed and maximum average speed at which each dog paced relative to the treadmill belt were also recorded at this time.

#### Statistical analysis

Statistical analysis was performed utilizing commercially available software (SPSS, IBM). The frequency of pacing in different groups and under different conditions was compared using chi-square tests. The leg-to-body ratios of pacers versus non-pacers were compared using t-test analysis. Statistical significance was set at $P < 0.05$.

## RESULTS

### Dogs

Dog breeds included Labrador Retriever (*n* = 13), Golden Retriever (9), Border Collie (3), Heeler (2), Pit Bull (2), Standard Poodle Mixes (2), mixed breed (2), Portuguese Water Dog (1), German Shepherd (1), Bernese Mountain Dog (1), Husky mix (1), Shepherd mix (1), and Golden Retriever mix (1). Dogs ranged in age from 1-13 years (mean 4.87 ± 3.2 years). Weight ranged from 13.2 to 49.2 kg (mean 26.85 ± 7.7 kg). Mean height from floor to withers was 59.51 ± 5.33 cm (range 50.80-78.74 cm). Mean body length measured from the greater tubercle of the humerus to the tuber ischium ranged was 63.58 ± 6.93 cm (range 50.80-81.28 cm). No dog required exclusion due to stress.

Sixteen of nineteen MSA dogs had a single abnormality detected and 13/19 MSA dogs had multiple abnormal examination and radiographic findings. Orthopedic examination abnormalities included: Decreased elbow range of motion and/or reactivity to manipulation and/or effusion (*n* = 9), decreased carpal range of motion and/or reactivity to manipulation and/or effusion (9), decreased hip range of motion and/or reactivity to extension and abduction (8), decreased stifle range of motion and/or reactivity to manipulation and/or effusion/periarticular thickening (6), reactivity to palpation of lumbar spine (3), reactivity to shoulder flexion (2), decreased tarsal range of motion, effusion, and crepitus (1). Radiographic abnormalities in the MSA group included: Elbow osteoarthritis (*n* = 7), carpal osteoarthritis (5), coxofemoral osteoarthritis (5), accessory carpal enthesopathy (4), lumbar spondylosis and/or osteoarthritis (3), healed femoral fractures with internal fixation (2), glenohumoral osteoarthristis (1), tarsal osteoarthritis (1), stifle osteoarthritis (1), bilateral stifle osteoarthritis with healed tibial plateau leveling osteotomies (1), irregularly marginated lateral fabella (1).

### Pacing

Pacing was observed in both MSN and MSA groups under all conditions (Figure 3). Pacing was seen significantly more often than expected under lead-controlled conditions (27/39, 69.2%, $P$ = 0.016) but not off-lead (17/39, 43.6%, $P$ = 0.423) or on the treadmill (21/39, 53.8 %, $P$ = 0.631). The overall frequency of dogs pacing under lead-controlled conditions was significantly greater than those pacing during off-lead conditions (27/39, 69.2% compared to 17/39, 43.6%; $P$ <0.001). All dogs that paced under off-lead conditions and/or treadmill conditions also paced during lead-controlled conditions.

Under lead-controlled conditions, MSN dogs (*n* = 17/20, 85.0%) were observed to pace significantly more frequently than MSA dogs (*n* = 10/19, 52.6%, $P$ = 0.029). There was no significant difference between the frequency of pacing for MSN dogs (*n* = 11/20, 55.0%) and MSA dogs (*n* = 6/19, 31.6%) under off-lead conditions ($P$ = 0.140) or under treadmill conditions (MSN: *n* = 13/20, 65.0%; MSA: 8/19, 42.1%; $P$ = 0.152). When MSN/MSA groups were evaluated separately, MSN dogs were more likely to pace under lead-controlled conditions (n = 17/20, 85.0%, $P$ = 0.002) but not under off-lead (n = 11/20, 55.0% $P$ = 0.655) or treadmill (n = 13/20, 65.0%, $P$ = 0.180) conditions. There was no statistically significant difference in the frequency of pacing for any of the conditions for the MSA group (off-lead: $P$ = 0.108; lead-controlled: $P$ = 0.819; treadmill: $P$ = 0.491).

All dogs that paced did so at a speed between a four-beat walk and a two-beat trot with land treadmill speeds ranging from 0.98 m/s to 2.84 m/s (mean minimum speed 1.42 ± 0.21 m/s; mean maximum speed 2.14 ± 0.38 m/s). Leg to body ratios ranged from 0.77 to 1.5 (mean 1.22 ± 0.15) with a mean ratio for pacers of 1.22 ± 0.16 and 1.24 ± 0.13 for non-pacers. There was no significant difference between the leg-to-body ratios of pacers and non-pacers ($P$ = 0.726).

## DISCUSSION

Many reasons for pacing have been proposed including body proportion (Hildebrand, 1968; Brown and Dalzell, 1986). Pacing has been correlated with a short-coupled body and long legs since pacing eliminates interference of diagonal pair feet that may occur during trotting (Brown and Dalzell,1986). Hildebrand observed pre-recorded archived film and dog show footage that showed 37 different dog breeds ambulating. The author assigned dogs into three groups based on subjective visual impressions of relative leg length, however, no measurements were taken (Hildebrand, 1968). The dogs that were observed to pace were all long legged breeds and none of the short-legged breeds were observed to pace (Hildebrand, 1968). Of the 37 represented dog breeds, only eight were observed to pace or use a similar lateral-couplet gait (Hildebrand, 1968). Unfortunately, Hildebrand only reported pacing by breed but did not report how many individuals paced. It was also unknown whether these dogs were musculoskeletally normal. Additionally, speed was qualified as slow, moderate, and fast, but never quantified. Further confounding this study, pacing has long been disallowed for most breeds by the dog show community and therefore, dog handlers will make an effort to keep dogs from pacing in the show ring (Brown and Dalzell,1986).

Brown et al. followed up Hildebrand's observations and quantified leg-length to body-length ratios as a calculation obtained from the measured leg length below the chest divided by the measured chest depth, as performed in the present study (Brown and Dalzell,1986). The authors reported that Great Danes and Salukis, breeds that have been reported to pace, have average leg-to-body ratios of 1.22 and 1.32, respectively (Brown and Dalzell,1986), meaning that these dogs have long legs relative to their body proportions. Brown notes that he observed a dog show class of 30 Great Danes in which 10 dogs appeared to pace (Brown and Dalzell,1986), but these observations were never followed by an objective study. The present study has shown much overlap between leg-to-body ratios of pacers and non-pacers with no significant difference between these groups. It should also be noted that the individual with the smallest leg-to-body ratio (0.77) was observed to pace under all three conditions. Of the two individuals with the largest leg-to-body ratio (1.50), one was observed to pace only on lead and the other was not observed to pace. Our results are inconsistent with Hildebrand's and Brown's findings.

Genetics may affect pacing in dogs, but this has not been investigated beyond anecdotal mention (Blaszczyk and Dobrzecka, 1989). A genetic mutation has, however, been linked to pacing ability in horses (Thiruvenkadan et al., 2009; Andersson et al., 2012). Walk, trot, and gallop are naturally occurring gaits in all equids, and some horses are able to use additional gaits (Andersson et al., 2012). This 'gaitedness' is a trait that has been selected for in many specialized breeds (Andersson et al., 2012). Many of these 'gaited' horses pace as a part of their normal gait repertoire while non-gaited horses only walk, trot, or gallop. It would be considered abnormal for these horses to pace (Andersson et al., 2012). It is possible that a similar mutation may be involved in the pacing ability of dogs and this should be investigated once commonly pacing breeds have been identified. With ongoing genetic mapping of the dog and linkage of mutations to phenotypic traits (Meyers-Wallen, 2003), comparison of genetically related pacers versus non-pacers may allow identification and analysis of repeatable gene sequences between groups to determine if certain mutations affect gaitedness.

It has been suggested that dogs are inadvertently trained to pace by leash-walking at speeds too quick for a comfortable walk and too slow for a comfortable trot (Zink and Van Dyke, 2013). Such conditions could potentially force 'non-pacing dogs' to pace. This suggestion is supported by our finding that a greater number of dogs paced under lead-controlled conditions than during off-lead conditions. One study reported self-selected comfortable human walking speeds with an average of approximately 1.43 m/s (Riley et al., 2007), a speed which falls within the minimum and maximum recorded pacing speeds of the medium to large breed dogs in the present study. Dogs paced at widely varying speeds between 0.98 to 2.84 m/s, which warrants further investigation. Pacing speeds vary depending on dog size and particularly the different types of pacing.

Limitations to this study include the lack of objective gait analysis, small sample size and wide inclusion criteria of the study population. The wide inclusion criteria of the present study make it difficult to classify specific characteristics of a pacer, however, it does increase the external validity of the study. It is possible that individual dogs in the MSN group may have had a degree of subtle musculoskeletal disease that was not detected with our screening procedures. Alternatively, it is possible that animals with non-clinical orthopedic disease should have been assigned to the MSN group. Finally, different footing and environments were present in each of the three study conditions making it difficult to exclude these as confounding factors, however, there has been no suggestion in the literature that footing affects pacing.

Despite the small sample size, our results indicate that pacing as a sole clinical sign should not be directly linked with musculoskeletal pathology in dogs. As suggested by the high proportion of sound pacing dogs in this study, it may not represent a sign of pathology at all. Rather, it may be a normal condition or associated with factors such as controlled speed, environment, genetics, or conditioning. In this study population, for instance, leash walking was associated with an increased incidence of pacing. Future research should further clarify the impact of environmental factors and musculoskeletal pathology on gait patterns in dogs. Such research could require serial, life-long evaluation of a larger number of dogs of various breeds. Fortunately, pacing as a gait variation is easily recognized without the use of specialized gait analysis equipment for this purpose. Further studies should include kinetic and kinematic analysis of pacing and digital musculoskeletal modeling to better understand the biomechanics of pacing and implications for dogs who utilize this gait (Dries et al., 2016; Holler et al, 2010).

In summary, the objectives of the present study were to evaluate dogs with and without musculoskeletal abnormalities for evidence of pacing and to characterize the relationship between a dog's relative speed and pacing under different study conditions. Pacing was demonstrated in MSN and MSA dogs under all study conditions and more frequently when dogs were walked on leash. Pacing should be considered a gait variation that can be observed in clinically normal dogs at speeds between walk and trot.

## Conflict of interest statement

The authors have not declared any conflict of interest.

## Abbreviations:

**MSN,** Musculoskeletally normal; **MSA,** Musculoskeletally abnormal.

## ACKNOWLEDGEMENTS

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