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Variance associated with the use of relative velocity for force platform gait analysis in a heterogeneous population of clinically normal dogs

Nicola Volstad, Brett Nemke, Peter Muir *

Comparative Orthopaedic Research Laboratory, School of Veterinary Medicine, University of Wisconsin-Madison, 2015 Linden Drive, Madison, WI 53706, USA

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ABSTRACT

Factors that contribute to variance in ground reaction forces (GRFs) include dog morphology, velocity, and trial repetition. Narrow velocity ranges are recommended to minimize variance. In a heterogeneous population, it may be preferable to minimize data variance and efficiently perform force platform gait analysis by evaluation of each individual dog at its preferred velocity, such that dogs are studied at a similar relative velocity (V^*).

Data from 27 normal dogs were obtained including withers and shoulder height. Each dog was trotted across a force platform at its preferred velocity, with controlled acceleration (± 0.5 m/s^2). V^* ranges were created for withers and shoulder height. Variance effects from 12 trotting velocity ranges and associated V^* ranges were examined using repeated-measures analysis-of-covariance. Mean bodyweight was 24.4 ± 7.4 kg. Individual dog, velocity, and V^* significantly influenced GRF ($P < 0.001$). Trial number significantly influenced thoracic limb peak vertical force (PVF) ($P < 0.001$). Limb effects were not significant. The magnitude of variance effects was greatest for the dog effect. Withers height V^* was associated with small GRF variance. Narrow velocity ranges typically captured a smaller percentage of trials and were not consistently associated with lower variance. The withers height V^* range of 0.6–1.05 captured the largest proportion of trials ($95.9 \pm 5.9\%$) with no significant effects on PVF and vertical impulse. The use of individual velocity ranges derived from a withers height V^* range of 0.6–1.05 will account for population heterogeneity while minimizing exacerbation of lameness in clinical trials studying lame dogs by efficient capture of valid trials.

Introduction

Force platform gait analysis is an important method for canine lameness assessment. Peak vertical force (PVF) and vertical impulse (VI) are ground reaction forces (GRFs) commonly used for analysis (Evans et al., 2005; Fanchon and Grandjean, 2007). PVF represents the maximal load exerted by the paw during the stance phase, while VI represents the area under the force–time curve.

Breed and conformation, velocity, trial repetition, and day-to-day change may influence GRFs (Budsberg et al., 1987; Jevens et al., 1993; Riggs et al., 1993; McLaughlin and Roush, 1994; Nordquist et al., 2011). To minimize variance, GRFs are normalized to bodyweight, and a narrow velocity range (± 0.3 m/s) with controlled acceleration (± 0.5 m/s^2) is typically used (Riggs et al., 1993; Budsberg et al., 1999; Bertram et al., 2000). Such guidelines have been based on experiments using small, homogeneous populations of normal dogs.

Considerable GRF variance is observed in clinical trials with heterogeneous dog populations with regard to weight and conformation (Budsberg et al., 1999; Mölsä et al., 2010). To overcome the problem of population heterogeneity, variance associated with weight, conformation, and velocity must be accounted for to obtain GRF values that are comparable between dogs of different morphologies (Voss et al., 2010). Small dogs must travel at a higher relative velocity than large dogs to cover the same distance over the same time period (Bertram et al., 2000; Voss et al., 2010). Trial capture becomes inefficient with the use of narrow velocity ranges in heterogeneous populations. Using wider trotting velocity ranges can improve the efficiency of trial capture with little effect on PVF and VI variance in heterogeneous populations (Hans et al., 2014).

Another approach to reduce GRF variance is to normalize velocity to body size using withers height (Voss et al., 2010). Based on the theory of dynamic similarity, relative velocity (V^*), or Froude number, is a dimensionless value in which velocity is re-scaled to body size (Voss et al., 2010). When dogs of different conformations are trotted over a force plate at a set subject velocity, their V^* will be different and their GRF will not be perfectly comparable (Bertram et al., 2000). Within a heterogeneous population, it may be preferable to evaluate each dog at its preferred velocity, such that dogs are studied at a consistent V^* (Voss et al., 2010).

The purpose of this study was to determine whether analysis of V^* in the context of published velocity ranges (Rumph et al., 1993; Borer et al., 2003; Ballagas et al., 2004; Lopez et al., 2006; Havig et al., 2007;

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* Corresponding author. Tel.: +1 608 263 9819.
E-mail address: muirp@vetmed.wisc.edu (P. Muir).

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Table 1
Velocity and relative velocity[a] ranges used for this study.

Velocity range (m/s)	Source	Efficiency of trial capture (%)[b]	Withers height relative velocity range	Shoulder height relative velocity range
1.3–1.9	Malek et al., 2012	45.5 ± 32.5		
1.3–2.1	Fahie et al., 2013	75.9 ± 26.6	0.55–0.93	0.65–1.05
1.5–2.0	Rumph et al., 1993	63.4 ± 31.5	0.6–0.9	0.7–1.0
1.5–2.2	Hans et al., 2014	84.2 ± 21.5	0.6–0.95	0.7–1.1
1.5–2.5	Borer et al., 2003	94.5 ± 10.7	0.6–1.05	0.7–1.2
1.6–1.9	Brown et al., 2013	39.3 ± 27.9		
1.7–2.1	Havig et al., 2007	62.4 ± 24.0	0.7–0.93	0.8–1.05
1.8–2.2	Hans et al., 2014	60.8 ± 21.7	0.73–0.95	0.83–1.1
1.8–2.8	Lopez et al., 2006	74.6 ± 24.1	0.73–1.15	0.83–1.3
1.85–2.15	Voss et al., 2008	47.4 ± 20.9		
1.9–2.2	Rialland et al., 2012	41.9 ± 22.6		
2.0–2.5	Ballagas et al., 2004	33.8 ± 27.9		

[a] Relative velocity $V^* = V/(g\cdot H)^{1/2,}$ where V is the velocity (m/s), g is the gravitational acceleration (9.81 m/s^2), and H represents withers or shoulder height (m).
[b] Efficiency of trial capture (%) as reported by Hans et al. (2014). Data represent mean ± standard deviation.

Voss et al., 2008; Malek et al., 2012; Rialland et al., 2012; Brown et al., 2013; Fahie et al., 2013; Hans et al., 2014) would aid efficient collection of valid trials with low GRF variance beyond the use of the velocity range of 1.5 to 2.2 m/s (Hans et al., 2014) for gait analysis in heterogeneous dog populations.

Materials and methods

Clinical cohort

Force platform gait analysis was performed at the University of Wisconsin-Madison UW Veterinary Care Hospital. The study was approved by the Animal Care and Use Committee of the School of Veterinary Medicine (protocols V1070 and V1600; dates of approval 8 May 2013 and 9 July 2013, respectively) and with informed consent of owners.

Client-owned dogs with no history of orthopaedic disease were recruited. Gait analysis was performed after a veterinarian examined all 29 dogs. Dogs were excluded if an orthopaedic abnormality was identified. Withers and shoulder height (m) were measured. PVF and VI of thoracic and pelvic limb pairs were examined for symmetry (see Statistical analysis section below). Dogs were excluded if the symmetry index (Voss et al., 2007) for PVF was >15% or if the Dunn–Šidák corrected *P* value for PVF was <0.0019. Data from 27 dogs were analyzed for variance effects. Two dogs did not meet the inclusion criteria. New gait data were obtained from five dogs studied previously (Hans et al., 2014).

Force platform gait analysis

Trials data were collected using a single biomechanical platform that measured three-dimensional forces and impulses (OR6-6-1000 Biomechanics Platform with an SGA6-4 Signal Conditioner/Amplifier, Advanced Mechanical Technologies). Velocity was measured by three photoelectric cells mounted 1 m apart. A handler guided dogs across the platform at their preferred trotting velocity. An observer evaluated each pass to confirm foot strikes and gait. A successful trial was defined by a thoracic limb hitting the platform followed by the ipsilateral pelvic limb with acceleration of ±0.5 m/s^2. The trial was excluded if the dog was observed to walk across the platform. Nineteen to 39 trials were collected for each dog after habituation to trotting across the platform.

The force platform was connected by a cable to a data acquisition system and a computer with gait analysis software (Acquire v7.30, Sharon Software). Data were sampled at 1000 Hz without filtering. PVF and VI were measured and normalized to percent bodyweight (%BW). PVF was normalized with the following equation:

$$PVF_{\%BW} = 100 \cdot (PVF/[m \cdot g])$$

where m is body mass (kg) and g is gravitational acceleration (9.81 m/s^2). VI was normalized using a similar equation:

$$VI_{\%BW} = 100 \cdot (VI/[m \cdot g])$$

V* or Froude number for withers and shoulder height was calculated for each trial using the following equation:

$$\text{relative velocity } V^* = V/(g \cdot H)^{1/2}$$

where V is the velocity (m/s), g is the gravitational acceleration (9.81 m/s^2), and H represents withers or shoulder height (m) (Voss et al., 2010).

Relative velocity range selection

Trials were reviewed and data from valid trials were coded with one or more of 12 published velocity ranges (Table 1) (Hans et al., 2014). During data analysis, seven V* ranges were created for withers height and an equivalent series of ranges was created for shoulder height V*. The V* ranges were created to approximate absolute velocity ranges that yielded efficiency of trial capture above 60% (Table 1).

Statistical analysis

Initially, PVF and VI for five trials from the left and right limb pairs obtained at velocities that most closely approximated the mean for each dog were analyzed using the Student's *t* test for paired data. A symmetry index (SI) was calculated for the thoracic and pelvic limb pairs. The SI evaluates weight bearing between two limbs as symmetrical (0) or asymmetrical (>0<). The SI equation for each dog is:

$$SI = 200 \cdot [(PVF_1 - PVF_2)/(PVF_1 + PVF_2)]$$

where PVF$_1$ is the higher value and PVF$_2$ is the lower value (Voss et al., 2007). If SI > 15% or if significant differences in GRF were detected between limb pairs, the dog was excluded. Differences were considered significant at $P < 0.0019$ after Dunn–Šidák correction of $P < 0.05$ for multiple independent tests using $\alpha_1 = (1 - \alpha)^{1/n}$.

Repeated-measures analysis-of-covariance was used for data analysis. Dog, trial number, limb (left or right), and velocity or relative velocity were analyzed for significant contribution to data variance. Subsequently, the variance effects of the velocity or V* ranges were examined in the statistical model. The effect size of each factor in the model was calculated. Post-hoc analysis was performed using Tukey's test. GRFs obtained from 10 dogs with five trials at the overall preferred withers height V* were also analyzed. All analyses were performed using computer software (STATA v13.1). Data were reported as means ± standard deviation (SD). Results were considered significant at $P < 0.05$.

Results

Clinical cohort

Data from 27 dogs were analyzed. All dogs were >1 year old. Mean bodyweight was 25.7 ± 7.4 kg (range 14.8–46.2 kg). Breeds included were Labrador retriever ($n = 7$), Australian Shepherd ($n = 3$), and one each of Golden retriever, Doberman Pinscher, Springer Spaniel, Nova Scotia Duck Tolling retriever, Siberian Husky, Portuguese Water Dog and Pit Bull terrier. The remaining dogs were mixed breeds ($n = 10$). Thirteen dogs were neutered males, 1 dog was male, 11 dogs were spayed females, and 2 dogs were female.

Effect of absolute velocity range and relative velocity range on trial capture

In total 731 trials were obtained. The mean number of trials collected per dog was 27.1 ± 6.5. The mean preferred trotting absolute velocity of each dog ranged from 1.66 ± 0.15 m/s to 2.34 ± 0.37 m/s. The mean absolute velocity for all trials was 1.94 ± 0.2 m/s. In general, narrow velocity ranges captured a smaller proportion of trials per