Published in final edited form as:

Vet J. 2016 January ; 207: 80–84. doi:10.1016/j.tvjl.2015.08.014.

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

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Abstract

Factors that contribute to variance in ground reaction forces (GRF) 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 ($\pm 0.5 \text{ m/s}^2$). 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 $24.4 \pm 7.4 \text{ kg}$. 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. 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.

Keywords

Dog; Gait analysis; Relative velocity; Force platform; Clinical trial

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Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

Appendix: Supplementary material

Supplementary data associated with this article can be found in the online version at ...setters please insert doi number

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 (GRF) 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 GRF (Budsberg et al., 1987; Jevens et al., 1993; Riggs et al., 1993; McLaughlin and Roush, 1994; Nordquist et al., 2011). To minimize variance, GRF are normalized to bodyweight, and a narrow velocity range (± 0.3 m/s) with controlled acceleration (± 0.5 m/s²) 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 regards 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 morphology (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 use of narrow velocity ranges in heterogeneous populations. Use of wider trotting velocity ranges can improve efficiency of trial capture with little effect on PVF and VI variance in heterogeneous populations (Hans et al., 2014).

Another approach to reducing 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 rescaled to body size (Voss et al., 2010). When dogs of different conformation 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; 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 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 orthopedic 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 3-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 $\pm 0.5 \text{ m/s}^2$. 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:

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

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

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

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 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:

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

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 $\alpha_1 = 1 - (1 - \alpha)^{1/n}$.

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 $\pm$ 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 $25.7 \pm 7.4 \text{ kg}$ (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. Remaining dogs were mixed breeds ($n = 10$). Thirteen dogs were neutered males, one dog was male, 11 dogs were spayed females, and two 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 dog compared to wider ranges (see Tables 2 and Appendix: Supplementary Table S1). The absolute velocity range that captured the greatest number of trials was 1.5-2.5 m/s, with 695 of 731 (95.1%) total trials. The mean proportion of trials captured per dog for this velocity range was $94.6 \pm 8.9\%$. The absolute velocity range that captured the least number of trials was 2.0-2.5 m/s, with 272/731 (37.2%) total trials. The mean proportion of trials per dog for this velocity range was $36.9 \pm 30.3\%$. In total, 7/12 absolute velocity ranges captured >50% of trials per dog: 1.5-2.0 m/s, 1.7-2.1 m/s, 1.5-2.2 m/s, 1.5-2.5 m/s, 1.8-2.8 m/s, 1.3-2.1 m/s, and 1.8-2.2 m/s. Mean PVF and VI varied across all absolute velocity ranges (Appendix: Supplementary Table S1).

The mean withers height V^* of each dog ranged from 0.70 ± 0.10 to 0.97 ± 0.15 . The mean withers height V^* for all trials was 0.83 ± 0.08 . In general, narrow withers height V^* ranges captured a smaller proportion of trials per dog compared to wider ranges (see Table 2 and Appendix: Supplementary Table S1). The withers height V^* range that captured the greatest number of trials was 0.6-1.05, with 703/731 (96.2%) total trials. The mean proportion of trials captured per dog for this withers height V^* range was $95.9 \pm 5.9\%$. The withers height V^* range that captured the least number of trials was 0.73-0.95, with 359 of 731 (49.1%) total trials. The mean proportion of trials per dog for this range was $49.1 \pm 30.9\%$. In total, 6/7 withers height relative velocity ranges captured >50% of trials per dog: 0.55-0.93, 0.6-0.9, 0.6-0.95, 0.6-1.05, 0.7-0.93, and 0.73-1.15. Mean PVF and VI varied across all withers height V^* ranges (see Table 2 and Appendix: Supplementary Table S1).

The mean shoulder height V^* of each dog ranged from 0.78 ± 0.06 to 1.13 ± 0.18 . The mean shoulder height V^* for all trials was 0.94 ± 0.10 . In general, narrow shoulder height V^* ranges captured a smaller proportion of trials per dog compared to wider ranges (Appendix: Supplementary Table S1). The shoulder height V^* range that captured the greatest number of trials was 0.7-1.2, with 695/731 (95.1%) total trials. The mean proportion of trials captured per dog for this shoulder height V^* was $94.7 \pm 8.0\%$. The shoulder height V^* range that captured the least number of trials was 0.83-1.1, with 342/731 (46.8%) total trials. The mean proportion of trials per dog for this range was $46.4 \pm 27.3\%$. In total, 5/7 shoulder height V^* ranges captured > 50% of trials per dog: 0.65-1.05, 0.7-1.1, 0.7-1.2, 0.8-1.05, and 0.83-1.3. Mean PVF and VI varied across all shoulder height relative velocity ranges (Table S1).

Effect of absolute velocity range and relative velocity range on vertical ground reaction forces

Individual dog, velocity, withers height V^* and shoulder height V^* had significant effects on PVF and VI for both thoracic and pelvic limbs ($P < 0.05$; Table 3 and Appendix: Supplementary Tables S2, 3). Trial number had a significant effect on thoracic limb PVF ($P < 0.05$; Table 3 and Appendix: Supplementary Tables S2, 3). For all measures of velocity, no

significant effects were detected beyond the first three trials. Limb effects were not significant ($P > 0.05$, Table 3 and Appendix: Supplementary Tables S2, 3). Analysis of effect sizes indicated that the magnitude of variance effects from greatest to smallest were dog, velocity, trial number, and limb for all measures of velocity.

Of the 12 velocity ranges and associated V^* ranges studied, narrow ranges typically captured a smaller percentage of trials. Narrow velocity ranges were not consistently associated with lower variance (Table 4 and Appendix: Supplementary Table S4). Velocity ranges 1.5-2.0, 1.6-1.9, 1.85-2.15, 1.9-2.2 and 2.0-2.5 m/s were associated with low variance and no significant effects on GRF. Of these ranges, the range of 1.5-2.0 m/s captured the largest proportion of trials (58.7%) (Appendix: Supplementary Table S4). The withers height V^* ranges 0.55-0.93, 0.6-0.9, 0.6-0.95 and 0.6-1.05 were associated with low variance and no significant effects on GRF. Of these ranges, the range of 0.6-1.05 captured the largest proportion of trials (95.9%) (Table 4). The shoulder height V^* ranges of 0.7-1.1, 0.7-1.2 and 0.83-1.1 were associated with low variance and had no significant effects on GRF (Table 4). Of these ranges, the shoulder height V^* range 0.7-1.2 captured the largest proportion of trials per dog (94.7%) (Appendix: Supplementary Table S4).

Mean thoracic limb PVF and VI at the overall mean withers height V^* (0.83 ± 0.1) was 109.0 ± 8.9 (range 96.2 - 121.9), and 15.9 ± 1.1 (range 14.5 - 18.1), respectively. Mean pelvic limb PVF and VI was 73.8 ± 10.1 (range 58.8-90.4), and 9.4 ± 0.6 , (range 8.5 - 10.3), respectively (Appendix; Supplementary Table S5).

Discussion

Dog morphology was the largest source of variance and is inherent to heterogeneous populations (Bertram et al., 2000; Voss et al., 2010; 2011, Hans et al., 2014). Our data were normalized using percent bodyweight before analysis. Morphometric normalization of GRF does reduce variance (Voss et al., 2010), but does not eliminate it (Voss et al., 2011; Krotscheck et al., 2014). We also considered withers and shoulder height V^* (Voss et al., 2010) in our analysis.

Trial velocity is a pre-determined aspect of experimental design. We found mean absolute velocity, withers height V^* and shoulder height V^* were 1.94 m/s, 0.83, and 0.94, respectively. Several ranges were associated with low variance and no significant effects on GRF. These ranges generally spanned their respective mean velocity or V^* value.

The withers height V^* range 0.6-1.05 captured the largest proportion of trials per dog (96.2%). Subject velocity should be considered as part of trial design to minimize GRF variance. Our results suggest that it is advantageous to use individual velocity ranges for canine gait analysis calculated from a V^* range to enable efficient trial capture without significant effects on GRF. Constraining trials to a narrow velocity range may also mask clinical improvement, since an increase in preferred velocity after treatment could be interpreted as improvement (Hans et al., 2014).

The magnitude of trial repetition variance approximated the variance associated with subject velocity, suggesting that trial repetition during gait analysis should be minimized. In

heterogeneous populations, use of narrow velocity ranges may prevent individual dogs from trotting at their preferred velocity, making valid trial collection more challenging. We found narrow absolute and relative velocity ranges captured fewer trials per dog compared to wider ranges. Since exercise typically exacerbates lameness, trial repetition in lame dogs could confound GRF measurement as a measure of lameness (Beraud et al., 2010).

We found that the use of V^* ranges, especially wither height V^* , improved trial capture, compared with absolute velocity ranges. Withers height is easier to measure than shoulder height, which is subject to left-right variation. Our results suggest that use of individual absolute velocity ranges derived from the wither height V^* range of 0.6-1.05 would further improve efficiency of valid trial capture, relative to use of an absolute velocity range.

Individual absolute velocity ranges (m/s) can easily be calculated by use of the equation $V = V^* (g H)^{1/2}$ where V is the velocity (m/s), V^* is the relative velocity (see force platform gait analysis). Studies in a heterogeneous population of lame dogs are needed to understand the relationship between trotting velocity ranges and the effects of trial repetition, including any effects that asymmetry in limb velocity between left and right limb pairs may create.

A potential approach to gait analysis in dogs is to obtain GRFs at a single preferred V^* . When GRFs obtained at the overall preferred withers height V^* for the dogs of the present report were assessed, we found substantial variance. Thus, in a heterogeneous population of dogs, there is sufficient variation in preferred V^* between individual dogs that trial collection using a single V^* , rather than a range, is problematic.

In this clinically normal population, trial repetition affected thoracic limb PVF during the first three trials, suggesting that additional habituation is needed (Hans et al., 2014). In the present study, dogs were trotted across the platform before trial capture until they appeared comfortable. The thoracic limb makes first contact with the force platform and, thus, is more susceptible to variation. Initially, dogs may be less willing to fully load the limb, despite the appearance of trotting normally. It is a good practice to discard the first three trials, even if the dog appears habituated to the force-platform (Hans et al., 2014).

Limb did not have a significant effect on GRF supporting the observation that the dog cohort was sound. We defined exclusion criteria and set the asymmetry cutoff at <15%, to allow retention of dogs with a preference for weight-bearing in left or right limbs (Colborne, 2008; Colborne et al., 2011).

There were several limitations to this study. Typically, five valid trials from left and right limbs would be collected for each dog. We collected a mean of 27.1 trials per dog. Velocity ranges with high trial capture rates generally had an equal trial distribution amongst the cohort. An unequal distribution of trials amongst the population was more likely for ranges with low capture rates. Alternative methods exist for calculating relative velocity, such as the percentage of withers height covered per second. GRF are susceptible to non-specific day-to-day variability of low magnitude (Nordquist et al., 2011).

Conclusions

There is a complex interplay of variance factors influencing force platform gait analysis. The factors with the largest to smallest variance effects on GRF were dog, velocity, trial number, and limb, respectively. Velocity ranges influence variance. Selection of a wider velocity range can reduce trial repetition without significant effects on data quality in clinically normal trotting dogs. Use of individual absolute velocity ranges created from the wither height V^* range 0.6-1.05 can improve efficiency of trial capture. This may be important for lameness studies in heterogeneous dog populations, where GRF may change with trial repetition because of lameness exacerbation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

The authors acknowledge Dr. Eric Hans who helped develop the concept for this study. The authors are also grateful to students who assisted with force platform gait analysis. The project described was supported by the Clinical and Translational Science Award (CTSA) program, through the NIH National Center for Advancing Translational Sciences (NCATS), grant UL1TR000427. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

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Table 1

Velocity and ^a relative velocity ranges used for this study.

Velocity range (m/s)	Source	^b Efficiency of trial capture (%)	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	Railland et al., 2012	41.9 ± 22.6		
2.0 – 2.5	Ballagas et al., 2004	33.8 ± 27.9		

^aRelative velocity $V^* = V/(g \cdot H)^{1/2}$, where V is the velocity (m/s), g is the gravitational acceleration (9.81 m/s²), and H represents withers or shoulder height (m)

^bEfficiency of trial capture (%) as reported by Hans et al. 2014. Data represent mean ± standard deviation.

Summary of trial capture and associated ground reaction force values for wither height relative velocity ranges in a heterogeneous population of clinically normal client-owned dogs.

Table 2

Velocity or relative velocity range ^a	Total trials	%Trials per dog	Thoracic limb PVF ^b (%BW)	Thoracic limb VI ^b (%BW)	Pelvic limb PVF ^b (%BW)	Pelvic limb VI ^b (%BW)
0.55-0.93	610	83.4 ± 20.8	105.6 ± 10.4	16.0 ± 2.6	70.4 ± 8.5	9.2 ± 0.9
0.6-0.9	396	55.1 ± 37.5	104.0 ± 9.8	16.4 ± 1.7	68.8 ± 6.7	9.2 ± 0.9
0.6-0.95	627	85.6 ± 18.4	106.0 ± 10.3	16.0 ± 2.6	70.4 ± 8.6	9.1 ± 1.0
0.6-1.05	703	95.9 ± 5.9	106.4 ± 10.4	15.8 ± 2.6	70.4 ± 8.5	9.0 ± 1.0
0.7-0.93	527	70.8 ± 20.9	106.9 ± 9.4	15.9 ± 2.7	70.9 ± 8.4	9.1 ± 0.9
0.73-0.95	359	49.1 ± 30.9	108.3 ± 9.7	15.5 ± 1.8	69.7 ± 8.0	8.8 ± 1.0
0.73-1.15	602	81.5 ± 22.5	107.8 ± 9.8	15.5 ± 2.6	71.2 ± 8.5	8.9 ± 1.0

PVF, peak vertical force; VI, vertical impulse.

^aRelative velocity ranges are reported as Froude number.

^bPVF and VI are presented as percentage of bodyweight (%BW). Data represent means ± standard deviations.

Summary of the variance effects of model factors including withers height relative velocity on peak vertical force and vertical impulse in the thoracic and pelvic limbs of a clinically normal heterogeneous population of client-owned dogs.

Table 3

Variance factor	Thoracic limb PVF			Thoracic limb VI			Pelvic limb PVF			Pelvic limb VI		
	ES	95% CI	ES	95% CI	ES	95% CI	ES	95% CI	ES	95% CI	ES	95% CI
Dog	0.5970 *	0.5373 – 0.6198	0.2288 *	0.1466-0.2527	0.6925 *	0.6451-0.7109	0.5419 *	0.4759-0.5668				
Withers height relative velocity	0.1986 *	0.1476 – 0.2503	0.0553 *	0.0262-0.0923	0.0679 *	0.0354-0.1074	0.2278 *	0.1749-0.2801				
Trial number	0.1958 *	0.1005 – 0.2028	0.0342	0.0-0.0017	0.0425	0.0-0.0148	0.043	0.0-0.0157				
Limb	0.0025	0.0 – 0.0159	4.2×10 ⁻⁹	0.0-1.0	0.0003	0.0-0.0085	0.0037	0.0-0.0185				

PVF, peak vertical force; VI, vertical impulse; ES, effect size; CI, confidence interval

* $P < 0.05$. For limb, variance between left and right limb pairs was considered.

Table 4

Summary of the variance effects for seven withers height relative velocity ranges on peak vertical force and vertical impulse in the thoracic and pelvic limbs of a clinically normal heterogeneous population of dogs.

Variance factor	Thoracic limb PVF			Thoracic limb VI			Pelvic limb PVF			Pelvic limb VI		
	ES	95% CI		ES	95% CI		ES	95% CI		ES	95% CI	
Dog	0.5907 [*]	0.5303-0.6138		0.2261 [*]	0.1439-0.2498		0.667 [*]	0.6356-0.7031		0.4947 [*]	0.4240-0.5211	
Trial number	0.1616 [*]	0.0684-0.1644		0.0321	0.0-1.0		0.0334	0.0-0.0004		0.0448	0.0-0.0184	
0.55 – 0.93	0.0289	0.009-0.0584		0.0009	0.0-0.0112		0.0003	0.0-0.0089		0.0322	0.0109-0.0628	
0.6 – 0.9	0.0005	0.0-0.0098		0.0001	0.0-0.0075		0.002	0.30-0.0145		0.012	0.0011-0.0336	
0.6 – 0.95	0.0022	0.0-0.015		0.0001	0.0-0.0068		0.0013	0.0-0.0126		0.0044	0.0-0.0201	
0.6 – 1.05	0.0007	0.0-0.0104		0.0045	0.0-0.0203		0.001	0.0-0.0115		0.0004	0.0-0.0091	
0.7 – 0.93	0.019 [*]	0.0039-0.0445		0.0006	0.0-0.01		0.0006	0.0-0.0102		0.0009	0.0-0.0113	
0.73 – 0.95	0.0012	0.0-0.0121		0.0063 [*]	0.0-0.0238		0.0048	0.0-0.0208		0.0031	0.0-0.0171	
0.73 – 1.15	0.0132 [*]	0.0015-0.035		0.0027	0.0-0.0163		0.0166 [*]	0.0028-0.0408		0.0078	0.0000-4-0.0265	

PVF, peak vertical force; VI, vertical impulse; ES, effect size; CI, confidence interval

^{*} $P < 0.05$. The relative velocity ranges are reported as Froude number.