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Variance associated with subject velocity and trial repetition during 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 of clinically normal dogs, we hypothesized that the dog subject effect would account for the majority of variance in peak vertical force (PVF) and vertical impulse (VI) at a trotting gait, and that narrow velocity ranges would be associated with less variance.

Data from twenty normal dogs were obtained. Each dog was trotted across a force platform at its habitual velocity, with controlled acceleration (±0.5m/s^2). Variance effects from twelve trotting velocity ranges were examined using repeated-measures analysis-of-covariance. Significance was set at $P<0.05$. Mean dog body weight was 28.4 ± 7.4 kg. Individual dog and velocity significantly affected PVF and VI for thoracic and pelvic limbs ($P<0.001$). Trial number significantly affected thoracic limb PVF ($P<0.001$). Limb (left or right) significantly affected thoracic limb VI ($P=0.02$). The magnitude of variance effects from largest to smallest was dog, velocity, trial repetition, and limb. Velocity ranges of 1.5–2.0 m/s, 1.8–2.2 m/s, and 1.9–2.2 m/s were associated with low variance and no significant effects on thoracic or pelvic limb PVF and VI. A combination of these ranges, 1.5–2.2 m/s, captured a large percentage of trials per dog (84.2±21.4%) with no significant effects on thoracic or pelvic limb PVF or VI. We conclude wider velocity ranges facilitate capture of valid trials with little to no effect on GRF in normal trotting dogs. This concept is important for clinical trial design.

Keywords

Gait analysis; Dog; Velocity range; 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.

Introduction

Ground reaction forces (GRF) obtained by canine force platform gait analysis represent an important outcome measure in clinical trials. Peak vertical force (PVF) and vertical impulse (VI), best correlate with limb function (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. During locomotion, if limb pain is present, the resulting lameness leads to decreased PVF and VI. Many clinical trials use PVF and VI to evaluate limb function before and after medical therapy or surgical treatment (Budsberg et al., 1999a; 1988; Malek et al., 2012; Voss et al., 2008).

Reference ranges for GRF of clinically normal dogs remain unclear. Factors that contribute to GRF variability include: breed size and conformation, trial velocity, trial repetition, and day-to-day variation (Budsberg et al., 1987; Jevens et al., 1993; Riggs et al., 1993; McLaughlin and Roush, 1994; Nordquist et al., 2011). Current guidelines for minimizing variability are to normalize GRF to bodyweight, and to use a narrow velocity range (±0.3 m/s) with controlled acceleration (±0.5 m/s^2) (Riggs et al., 1993; Budsberg et al., 1999b; Bertram et al., 2000). A limitation with these ideas is that supporting experimental work used small, homogenous populations of normal dogs. Consequently, these recommendations may not be applicable to the heterogeneous dog populations typically found in clinical trials.

Analysis of force platform data across a heterogeneous canine population presents a unique challenge. The standard process of GRF normalization with body weight alone appears insufficient to control for all size-dependent variability (Voss et al., 2010). When additional dog-specific morphometric measurements are used for data normalization, significant differences between breeds are still recognized (Voss et al., 2011; Krotscheck et al., 2014). It has been suggested to use breed-matched groups in clinical trials, but this would adversely affect trial recruitment.

Studies investigating the effect of trial velocity have determined that trotting ranges are more sensitive than walking ranges for evaluating lameness (Voss et al., 2007). Currently, no standardized canine trotting velocity range is available. More than ten unique trotting velocity ranges, narrow and wide, have been used in veterinary trials to-date (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). The variance effects of these velocity ranges on GRF in a heterogeneous population have not been investigated. Velocity range selection has a potential relationship with trial repetition. Differences in size and body condition may affect an individual dog's ability to trot at a predetermined velocity. Such effects would be most evident with narrow velocity ranges. In lame dogs, these effects may be enhanced, as excessive trial repetition may exacerbate lameness during trial collection, perhaps to the point of limiting trial collection (Evans et al., 2003; Beraud et al., 2010).

The purpose of this study was to determine within a single statistical model the extent to which each model factor (dog subject, trial velocity, trial repetition, and limb [left or right]) contributes to variance in PVF and VI within a heterogeneous population of clinically

normal dogs at a trotting gait. The variance effects from eleven unique velocity ranges were analyzed. We hypothesized that dog subject effect would account for the majority of variance in PVF and VI. We further hypothesized that narrow velocity ranges would be associated with less variance, but perform poorly at capturing valid trials.

Materials and methods

Clinical cohort

Force platform gait analysis was performed at the University of Wisconsin-Madison UW Veterinary Care Hospital with approval from the Institute for Animal Care and Use Committee. Medium to large breed client-owned dogs with no history of orthopaedic disease were recruited. A veterinarian examined all dogs. Dogs were excluded if an orthopaedic abnormality was identified. Gait analysis was performed in twenty-six dogs. After gait analysis, PVF of thoracic and pelvic limb pairs was examined for significant differences (see Statistical Analysis). If differences in PVF were identified, the dog was excluded. During recruitment, six dogs were excluded for significant differences in PVF. Data from twenty dogs were analyzed for variance effects.

Force platform gait analysis

All trials were collected using a single biomechanical platform that measured 3-dimensional forces and impulses (OR6-6-1000 Biomechanics Platform with SGA6-4 Signal Conditioner/Amplifier, Advanced Mechanical Technologies Inc., Newton, MA). Velocity was measured by 3 photoelectric cells mounted one meter apart. The force platform system was calibrated for measurement of GRF using weights. Photocells were calibrated for measurement of velocity using a pendulum. A handler guided dogs across the platform at their habitual 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 at the trotting gait. If a dog was observed to walk across the platform during a trial, then that trial was excluded. If a dog could not perform a minimum of twenty valid trials in a single session the dog was excluded. Twenty to thirty trials were collected for each dog after habituation to trotting across the force-platform for a short period.

The force platform was connected to commercially available satellite data acquisition system to interface with the computer software used for gait analysis (Acquire v7.30, from Sharon Software Inc., Dewitt, MI). Data were sampled at 1000 Hz without filtering. PVF and VI were measured and normalized to percent body weight (100*N/N) by the data acquisition software. PVF was normalized to percent body weight with the following equation: $PVF_{\%BW} = PVF/(m*g)$, where m is body mass (kg) and g is gravitational acceleration (9.81 m/s^2). VI was normalized using a similar equation [$VI_{\%BW} = VI/(m*g)$].

Velocity range selection

A PubMed search performed in October 2013 using the following search phrase *'gait analysis + dog'* identified a total of 279 peer-reviewed publications. Articles were reviewed for veterinary studies in which force platform gait analysis was an outcome measure. All

velocity ranges were recorded. In total, fifteen distinct trotting velocity ranges were identified. Ten described velocity ranges were selected for use in this study based on their overlap with one another (Table 1). A velocity range in use in a clinical trial at the University of Wisconsin-Madison Veterinary Care Hospital was also included. Variance effects associated with the eleven trotting velocity ranges were initially considered. After data acquisition, trials were reviewed and data from valid trials were coded with one or more of the eleven velocity ranges of interest. During statistical analysis, an additional unique velocity range was created based on the initial results and was also analyzed in the statistical model (Table 1).

Statistical analysis

During initial screening of dogs, PVF 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. Repeated-measures analysis-of-covariance was then used to analyze force platform data. Initially, dog, trial number, limb (left or right), and velocity were analyzed for significant contribution to data variance. Subsequently, the variance effects of the twelve velocity ranges of interest 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. All analyses were performed using computer software (STATA v13.1, College Station, TX). Data were reported as mean ± standard deviation (SD). Results were considered significant at $P<0.05$.

Results

Clinical cohort

Data from 20 dogs were studied. All dogs were >1 year of age. Mean body weight was 28.4±7.4 kg (range 18.5–46.2 kg). Breeds included were Labrador Retriever ($n = 3$), Springer Spaniel ($n = 2$), Siberian Husky ($n = 2$), and one each of Alaskan Malamute, Australian Shepherd, Samoyed, Belgian Malinois, Chesapeake Bay Retriever, Golden Retriever, Doberman, Border Collie, and German Pointer. Remaining dogs were mixed breeds ($n = 4$). Eight dogs were neutered males, three dogs were male, eight dogs were spayed female, and one dog was female.

Effect of velocity range on trial capture

A total of 586 trials were obtained. The mean number of trials collected per dog was 29.3±2.3. The mean habitual trotting velocity of each dog ranged from 1.67±0.12 m/s to 2.44±0.22 m/s. The mean velocity for all trials was 1.95±0.24 m/s. In general, narrow velocity ranges captured a smaller proportion of trials per dog compared to wider velocity ranges (Table 2). The velocity range that captured the greatest number of trials was 1.5–2.5 m/s, with 558 of 586 (95.2%) total trials. The mean proportion of trials captured per dog for this velocity range was 94.5±10.7%. The velocity range that captured the least number of trials was 2.0–2.5 m/s, with 195 of 586 (33.3%) total trials. The mean proportion of trials per dog for this velocity range was 33.8±27.9%. In total, six velocity ranges captured greater than 50% of trials per dog: 1.5–2.0 m/s, 1.7–2.1 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. A novel range created during statistical analysis, 1.5–2.2 m/s, also captured

greater than 50% of trials per dog. Mean PVF and VI varied across all velocity ranges (Table 2).

Effect of velocity range on vertical ground reaction forces

Individual dog and velocity had significant effects on PVF and VI for both thoracic and pelvic limbs (P <0.001, Table 3). Trial number had a significant effect on thoracic limb PVF (P <0.001, Table 3). Post-hoc analysis found that PVF in the initial two trials for the thoracic limb was significantly less than subsequent trials. Mean PVF for trial number 1 was significantly less than trial numbers 12, 14, 16, 17, 19, 20, and 22–30. Mean PVF of trial number 2 was significantly less than trial number 23. Limb (right or left) had a significant effect on thoracic limb VI (P = 0.02, Table 3), although the effect size associated with this result was small. Overall, the magnitude of variance effects from largest to smallest for PVF and VI of the thoracic and pelvic limbs was dog, velocity, trial number, and limb, respectively (Table 3).

Of the 11 velocity ranges initially studied, narrow velocity ranges were not consistently associated with lower variance (Table 4). The velocity range 1.8–2.8 m/s had the lowest variance effect on thoracic limb PVF. The velocity range 1.5–2.0 m/s had the lowest variance effect on thoracic limb VI. The velocity range 2.0–2.5 m/s had the lowest variance effect on pelvic limb PVF. The velocity range 1.9–2.2 m/s had the lowest variance effect on pelvic limb VI.

Velocity ranges 1.5–2.0 m/s, 1.8–2.2 m/s, and 1.9–2.2 m/s were associated with low variance and had no significant effects on thoracic or pelvic limb PVF and VI (Table 4). Of these ranges, 1.5–2.0 m/s captured the largest proportion of trials per dog (63.4%), while 1.9–2.2 m/s captured the lowest proportion of trials per dog (41.9%). Based on these results, an additional velocity range of 1.5–2.2 m/s was created by combining those velocity ranges with low variance and no significant effects on GRF. The range 1.5–2.2 m/s performed similarly, with low variance and no significant effects on PVF and VI (Table 5). This velocity range captured 501 of 586 total trials (85.5%), with a high proportion of trials captured per dog (84.2 ± 21.5%).

Discussion

These results are consistent with previous literature identifying differences between individual dogs, trial velocity, and trial repetition as significant sources of GRF variance. Differences between individual dogs accounted for the largest variance effect in this heterogeneous population, confirming our primary hypothesis. This was anticipated (Bertram et al., 2000; Voss et al., 2010; 2011). Our data were normalized using percent body weight (100*N/N) before analysis, as is typically performed in clinical trials. Morphometric normalization of GRF does reduce GRF variance (Voss et al., 2010), but does not eliminate it (Voss et al., 2011; Krotscheck et al., 2014). Breed differences will likely remain a source of GRF variability until a method that fully normalizes GRF between breeds is determined. Normalization to whithers height, shoulder height (limb length), trunk length, or contact time may help address this problem.

Trial velocity is a pre-determined aspect of experimental design, and thus a variance source within the control of investigators. When velocity was evaluated in our statistical model, it was consistently the second largest source of GRF variance overall. However, variance associated with individual velocity ranges was much smaller. We hypothesized that controlling velocity within a narrow range would reduce variance, but this does not appear to be true. Variance effects from individual velocity ranges were not closely related to the magnitude of the range. These observations may be related to whether or not a specific range included extreme values. In the present study, mean trotting velocity was 1.95m/s. Velocity ranges (1.5–2.0, 1.5–2.2, 1.8–2.2, and 1.9–2.2 m/s) associated with low variance and no significant effects on PVF or VI generally spanned this value. A novel velocity range of 1.5–2.2 m/s also captured 84% of all trials per dog. Subject velocity should be considered as part of trial design to minimize variability in GRF, but narrow velocity ranges are not required to achieve this goal. However, for analysis of GRF data from individual dogs, it will likely be important to collect trials at similar velocities at each time point to minimize data variance, as velocity would be the principle source variance in this situation.

Wider velocity ranges may be advantageous for use in clinical trial design. Constraining trial velocity to a narrow range in treatment trials may also mask improvement, since an increase in velocity after treatment could be interpreted as an indicator of improvement. In general, trial number had a greater variance effect than each of the velocity ranges studied. This observation argues that emphasis should be placed on minimizing the number of trial repetitions in force platform gait analysis. In clinical trials with heterogeneous canine populations, utilizing narrow velocity ranges may force individual dogs to trot outside their habitual gait, making valid trial collection more challenging. Many narrow velocity ranges captured less than 50% of trials per dog, which would clinically correlate to more attempted trials for completion of gait analysis. Exercise is known to exacerbate lameness, resulting in significant variability in GRF (Beraud et al., 2010). Further evaluation of narrow and wide velocity ranges in a clinically lame heterogeneous canine population is needed to better clarify 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, particularly in dogs with unilateral lameness.

In this clinically normal population, trial repetition significantly affected thoracic limb PVF, particularly the first two trials, suggesting that additional habituation to the force-platform would have been helpful. In this study, dogs were trotted across the biomechanical platform before trial capture until they appeared comfortable. The thoracic limb makes first contact with the force platform and thus is more susceptible to changes in surface. Dogs may initially be less willing to fully load the limb, despite the appearance of trotting normally. These findings suggest that it is a good practice to discard the first two trials during gait analysis, even if the dog appears habituated to the force-platform.

The reason limb had a significant effect on thoracic limb VI is unclear. All dogs were screened for lameness before analysis. The lack of any significant effects on PVF from limb supports the concept that the dogs of this report were not lame at the time of gait analysis. However, homotypic variation may exist in dogs (Colborne 2008). Asymmetries between the left and right pelvic limbs of normal trotting dogs have been described (Colborne 2008;

Colborne et al., 2011). The variance effect associated with this observation was small, and the significance was less than those reported for either dog or velocity.

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 29 trials per dog. After coding, many velocity ranges captured >10 trials per dog, increasing the number of trials available for analysis. Velocity ranges with high trial capture rates, excluding the 1.5–2.2 m/s range, generally had an equal trial distribution amongst the 20 dogs studied. An unequal distribution of trials amongst the population was more likely for ranges with low capture rates. GRF are also susceptible to non-specific day-to-day variability (Nordquist et al., 2011). Trials from all dogs were obtained in a single session. While the magnitude of day-to-day variability is low, repeated force platform sessions with these same dogs may be useful to evaluate repeatability of our results. Specific dog morphometric measurements were not recorded in this study. GRF data normalization can be performed using body weight, or using morphometric measurement. In a recent canine gait analysis study, velocity was normalized to body size using whithers height (Voss et al., 2010). Relative velocity or Froude number is a dimensionless value calculated using the equation relative velocity = $V/(g*WH)^{1/2}$ (Voss et al., 2010). Analysis of relative velocity in the context of the velocity ranges of this report may also help understand variance associated with particular velocity ranges. We excluded dogs if significant asymmetry in PVF was identified in thoracic or pelvic limbs. An alternative approach, such as defining an asymmetry cutoff, for example 5%, may have retained dogs with a preference for weight-bearing in left or right limbs (Colborne 2008, Colborne et al., 2011).

Conclusions

In conclusion, there is a complex interplay of variance factors during force platform gait analysis. The factors with the largest to smallest variance effects on PVF and VI in our heterogeneous canine population were individual dog, velocity, trial number, and limb, respectively. Velocity ranges do influence variance. However, selection of a narrow velocity range is not essential for minimizing GRF variance. Wider velocity ranges can facilitate capture of valid trials with little to no effect on PVF and VI in clinically normal trotting dogs. These results suggest that wider velocity ranges, such as 1.5–2.2 m/s, may be valuable for lameness studies in heterogeneous dog populations, where efficiency of trial capture is likely important for minimizing variance in GRF data.

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Table 1

Twelve velocity ranges used for analysis

Velocity Range (m/s)	Source
1.3 – 1.9	Malek et al., 2012.
1.3 – 2.1	Fahie et al., 2013
1.5 – 2.0	Rumph et al., 1993
1.5 – 2.2	Created after statistical analysis
1.5 – 2.5	Borer et al. 2003
1.6 – 1.9	Brown et al., 2013
1.7 – 2.1	Havig et al., 2007
1.8 – 2.2	UW-Madison clinical trial in progress
1.8 – 2.8	Lopez et al., 2006
1.85 – 2.15	Voss et al., 2008
1.9 – 2.2	Railland et al. 2012
2.0 – 2.5	Ballagas et al. 2004

Table 2

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

Velocity Range (m/s)	Total Trials	%Trials per Dog	Thoracic Limb PVF (100*N/N)	Thoracic Limb VI (100*N/N)	Pelvic Limb PVF (100*N/N)	Pelvic Limb VI (100*N/N)
1.3–1.9	272	45.5 ± 32.5	101.5 ± 11.7	16.4 ± 1.8	68.6 ± 9.4	9.5 ± 1.2
1.3–2.1	452	75.9 ± 26.6	103.7 ± 10.9	16.1 ± 1.8	70.3 ± 8.7	9.4 ± 1.1
1.5–2.0	379	63.4 ± 31.5	103.8 ± 10.6	16.1 ± 1.7	70.6 ± 8.3	9.6 ± 1.1
1.5–2.2	501	84.2 ± 21.5	104.6 ± 10.4	16 ± 1.7	70.7 ± 7.9	9.4 ± 1
1.5–2.5	558	94.5 ± 10.7	104.5 ± 10.4	15.9 ± 1.7	70.6 ± 8.1	9.3 ± 1
1.6–1.9	235	39.3 ± 27.9	103.1 ± 10.8	16.1 ± 1.6	69.7 ± 8.3	9.3 ± 1
1.7–2.1	372	62.4 ± 24.0	105.8 ± 9.0	15.8 ± 1.6	71.9 ± 7.1	9.3 ± 1
1.8–2.2	361	60.8 ± 21.7	106.7 ± 8.7	15.8 ± 1.5	72.2 ± 6.5	9.2 ± 0.9
1.8–2.8	435	74.6 ± 24.1	106.3 ± 8.9	15.6 ± 1.6	71.6 ± 7.6	9.1 ± 0.9
1.85–2.15	282	47.4 ± 20.9	107.1 ± 8.1	15.8 ± 1.6	72.6 ± 6.4	9.2 ± 0.9
1.9–2.2	248	41.9 ± 22.6	107.1 ± 8.5	15.8 ± 1.6	72.3 ± 6.6	9.3 ± 0.9
2.0–2.5	195	33.8 ± 27.9	106.0 ± 9.5	15.5 ± 1.6	70.9 ± 7.7	9.1 ± 0.9

Note: PVF - peak vertical force; VI - vertical impulse. PVF and VI are presented as percentage of body weight (100*N/N). Data represent mean ± standard deviation

Table 3

Summary of the variance effects for variance factors on peak vertical force and vertical impulse in the thoracic and pelvic limbs of a clinically normal heterogeneous population of client-owned 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	0.6372 *	0.5793 – 0.6632	0.6601 *	0.6053 – 0.6847	0.7503 *	0.7087 – 0.769	0.6613 *	0.6067 – 0.6858
Velocity	0.2395 *	0.1802 – 0.2976	0.3758 *	0.3147 – 0.4312	0.1098 *	0.0648 – 0.1607	0.3721 *	0.311 – 0.4276
Trial Number	0.1206 *	0.0313 – 0.1255	0.0582	0.0 – 0.0458	0.0465	0.0 – 0.0289	0.0322	0.0 – 0.006
Limb	0.0002	0.0 – 0.0093	0.0098 *	0.0001 – 0.0327	1.4×10^{-5}	0.0 – 0.0038	0.0011	0.0 – 0.0136

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

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

Table 4

Summary of the variance effects for eleven 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	0.5822 *	0.5165 – 0.6113	0.6078 *	0.5454 – 0.6356	0.7027 *	0.6533 – 0.7246	0.6216 *	0.5609 – 0.6485
Trial Number	0.1 *	0.0138 – 0.1	0.0737	0.0 – 0.0663	0.0513	0.0 – 0.0352	0.031	0.0 – 0.003
1.3–1.9	0.0262 *	0.0061 – 0.0588	0.0698 *	0.0335 – 0.1148	0.0061	0.0 – 0.026	0.0549 *	0.0231 – 0.097
1.3–2.1	0.0305 *	0.0082 – 0.0646	0.0188 *	0.0027 – 0.0477	0.0103 *	0.0002 – 0.034	0.0163 *	0.0018 – 0.0438
1.5–2.0	0.0017	0.0 – 0.0158	2.0×10^{-5}	0.0 – 0.0045	0.0005	0.0 – 0.0114	0.0031	0.0 – 0.0194
1.5–2.5	0.0018	0.0 – 0.0161	0.0033	0.0 – 0.0199	0.0003	0.0 – 0.0097	0.0126 *	0.0007 – 0.0379
1.6–1.9	0.01 *	0.0001 – 0.3334	0.06 *	0.0267 – 0.1029	0.0003	0.0 – 0.001	0.0887 *	0.0477 – 0.1371
1.7–2.1	0.0072	0.0 – 0.0283	0.0028	0.0 – 0.0186	0.0086 *	0.0 – 0.0308	0.0006	0.0 – 0.0116
1.8–2.2	0.0005	0.0 – 0.011	0.0	0.0 – 0.0192	0.0038	0.0 – 0.0211	0.0045	0.0 – 0.0228
1.8–2.8	0.0003	0.0 – 0.099	0.0072	0.0 – 0.0282	0.008 *	0.0 – 0.0298	0.0074 *	0.0 – 0.0287
1.85–2.15	0.008 *	0.0 – 0.0297	0.0002	0.0 – 0.0088	0.0051	0.0 – 0.024	0.0052	0.0 – 0.0243
1.9–2.2	0.0036	0.0 – 0.207	0.0031	0.0 – 0.0196	0.0028	0.0 – 0.0187	6.9×10^{-5}	0.0 – 0.0068
2.0–2.5	0.0008	0.0 – 0.0126	0.0026	0.0 – 0.0182	1.2×10^{-7}	0.0 – 1.0	0.0012	0.0 – 0.014

Note: PVF - peak vertical force; VI - vertical impulse; ES - effect size; CI - confidence interval;

* - $P<0.05$. Velocity ranges are reported in m/s.

Table 5

Summary of the variance effects associated with a novel velocity range with high efficiency of trial capture

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	0.581 *	0.516 – 0.611	0.609 *	0.546 – 0.636	0.702 *	0.653 – 0.724	0.622 *	0.562 – 0.649
Trial Number	0.103 *	0.016 – 0.103	0.073	0.0 – 0.0651	0.051	0.0 – 0.034	0.031	0.0 – 0.004
1.5–2.2	0.006	0.0 – 0.026	0.004	0.0 – 0.022	0.007	0.0 – 0.027	0.005	0.0 – 0.025

Note: PVF - peak vertical force; VI - vertical impulse; ES - effect size; CI - confidence interval;

* - $P<0.05$. Velocity ranges are reported in m/s.

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