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Kinematics and kinetics of dogs completing jump and A-frame exercises

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RESEARCH ARTICLE

Abstract

Many police dogs do not reach their expected retirement age as they are no longer able to cope with the physical demands of the job. Annual licensing requires police dogs to complete a series of agility tasks, including jumping and negotiating an A-frame obstacle, both of which are associated with higher injury rates in canine agility competitors. This study sought to measure conformational, kinematic, and kinetic parameters of actively employed police German Shepherd Dogs (GSDs), whilst completing a 55 cm jump hurdle, and a standard A-frame. Each dog completed three repetitions of each obstacle and was also recorded at both walk and trot. Contact pressures and forces were measured, whilst joint kinematics were recorded using reflective markers and a high-speed camera. Results found that static hip angle was significantly correlated with hip flexion at trot, during jump suspension and at the apex of the A-frame. Stifle and hock flexion were greatest during the suspension phase of jump (56.98±11.710° and 54.51±17.430°). Shoulder and elbow flexion were greatest at the apex of A-frame (104.34±16.744° and 75.72±20.804°), whilst carpal extension was highest upon landing from the jump (125.77±7.071°). Peak vertical force (PFz) when normalised for body mass (BM) increased when landing from A-frame (14.28 N/kg BM) as opposed to landing from the jump obstacle (12.055 N/kg·BM). Our results show that increased range of motion (ROM) is required during both jumping and negotiation of A-frame compared to walk and trot, but more significantly, greater forces are incurred upon landing from the A-frame than compared to jumping. It was also observed that dogs were subject to high degrees of torsion in the distal limbs upon landing from the A-frame due to trained behaviours. We conclude that use of agility equipment generates greater forces through the musculoskeletal system and requires a greater ROM than what is experienced at walk and trot, which may contribute to early retirement ages in police dogs.

Keywords: biomechanics, canine, dog agility, injury, performance

1. Introduction

German Shepherd Dogs are a breed renowned across the globe as a steadfast family pet, yet still remain one of the most widely employed police service dogs in the world (NPDF, 2020). Exact figures regarding the cost of training a police dog are hard to come by but anecdotally are estimated at between £18,000 to £24,000. This sum may be considered a poor investment if the animal is forced to retire early due to work injury or poor health.

It has been suggested that the average retirement age of a police dog is between 7-8 years (PSOPM, 2018), however, a recent study in New Zealand found that out of 182 GSDs used for police service, nearly 60% did not reach planned retirement age, with the most prevalent reason being no

longer physically capable of meeting the demands of the job (Worth *et al.*, 2013). Degenerative musculoskeletal disease was cited as a primary factor for retirement, and when both retired and euthanised dogs were considered, 27% were no longer serving due to conditions of the spine, with a high proportion of these believed to involve the lumbosacral joint (Worth *et al.*, 2013). This is in stark contrast to an average 16% of domestic GSDs reported to suffer from any musculoskeletal disease, with the assumption being that spinal conditions would make up a small proportion of the overall percentage (O'Neill *et al.*, 2017). It has been well documented that when an animal is asked to perform unnatural activities on a regular basis there is an increased risk of injury (Cullen *et al.*, 2013, 2018; Lafuente and Whyle, 2018; Levy *et al.,* 2009; Montalbano *et al.*, 2019), so the purpose of this study is to examine objective variables that

may contribute to these high rates of early retirement, as well as understanding some of the forces involved in specific elements of a police dogs training and annual licensing. This knowledge may allow conclusions to be drawn regarding the best way to ensure the health and longevity of dogs employed as public protectors, as well as those that engage in agility tasks on a regular basis.

2. Materials and methods

The material in this chapter has been acquired according to modern ethical standards and has been approved by the Animal Welfare and Ethics Committee of Writtle University College. The approval number is 98363809/2019. A written informed consent was obtained from the owners of the participants of the study.

Dogs

Thirteen male and one female GSD were provided for the study, all were on active duties and had previously completed jump and A-frame training. Ages ranged from 3.5 to 7 years, with a mean of 5±1.45 years old. Weight ranged from 31.90 kilograms to 44 kg, with a mean of 37.5±3.430 kg, whilst mean dog height measured from dorsal border of scapula spine to ground was 65.29±5.134 cm. All but four of the dogs were unneutered. All were declared fit and well prior to the study, however all were also given a visual gait analysis as well as basic palpation prior to active participation in the study to ensure they had no undiagnosed injuries. Each dog attended the study individually with its handler present to direct the

animal. Prior to data collection each handler was given the opportunity to warm the dog up in a manner that they felt was appropriate (not standardised).

To enable the angles of joints of interest to be measured, reflective circular markers measuring 20 mm in diameter were attached to the left side of the dog using a commercially available double-sided tape. The anatomical locations of interest as defined in previous studies (Appelgrein *et al.,* 2018; Birch and Leśniak, 2013; Birch *et al.,* 2015), were dorsal border of scapula spine, greater tubercle of the humerus, lateral epicondyle of the humerus, styloid process, lateral aspect metacarpal V, dorsal iliac spine, greater trochanter, lateral epicondyle of the femur, lateral malleolus and lateral aspect of metatarsal V (Figure 1). To limit displacement of markers it would have been preferable to have shaved the coat of each dog to allow placement, however handlers were unwilling to allow, so markers were placed directly onto the dog's coat. The anatomical markers were placed on each animal by the same researcher to ensure location was consistent. Once the markers were placed the distance between markers at the dorsal border of scapula and greater tubercle of humerus was measured using a commercially available tape measure, to allow for software calibration.

Experiment set-up

A bar jump was placed in front of an A-Frame used by a police dog training facility to allow video capture of each dog negotiating both pieces of equipment without having to relocate them. The A-frame measured 194 cm at its
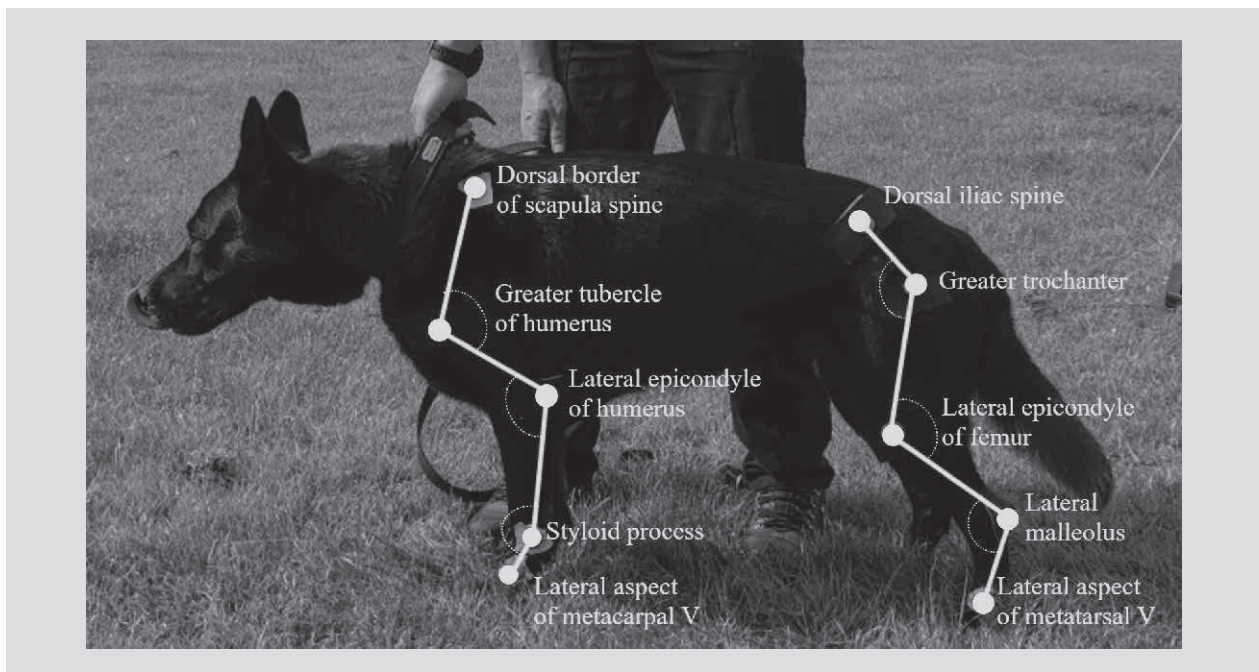

Figure 1. Location of anatomical markers on police dog used in trial.

peak with a 50° angle of incline. The bar jump was 125 cm wide with removable plastic bars. Bar height was set at 55 cm. A single high-speed video camera was mounted in a level position on a tripod, approximately 8 m from the A-frame, with one LED spotlight (500 W) to illuminate the reflective markers. Camera collected data at 240 Hz (resolution 1,334×750 pixels, 720p HD, 240 fps at 10 m distance), with a field of view capturing approximately 2 m either side of the A-frame. The camera was connected to a single laptop to enable video data capture (Figure 2).

Data collection and analysis

After placing the markers, the dog was photographed in a square stance. Each still photograph was analysed using ImageJ public domain image processing program to measure hip angulation, using the markers placed at dorsal iliac spine, greater trochanter, and lateral epicondyle of the femur. Scapula length was measured using the markers at the dorsal border of scapula and greater tubercle of humerus, and spine length was calculated from the dorsal base of neck to the tuber sacrale. Each dog's height was also measured from the dorsal border of scapula to the ground, using the same software.

Kinematic data collection and analysis

While completing walk, trot and jump for the kinetics analysis, dogs have been also recorded with the high-speed camera. Furthermore, three videos of a complete completion of A-frame obstacle were registered for each dog. High-speed video data were recorded and downloaded to a laptop and processed using two-dimensional motion capture (Quintic Biomechanics v31; Quintic Consultancy, Coleshill, UK). Automatic marker tracking was used to investigate maximum forelimb and hindlimb joints extension and flexion, extension of carpus and tarsus versus ground, stride length, vertical displacement over jump, take-off and landing distance for the jump, height of dismount

Figure 2. Layout of equipment for trial.

from A-frame, spine length over A-frame. All raw data were smoothed using a Butterworth low-pass filter, fourth order with a cut-off frequency of 10 Hz.

Joint flexion and extension for hip, stifle, hock, tarsus, shoulder, elbow, and carpus were measured during a single stride calculated from when the forelimb was vertical to subsequently vertical. Stride length was also calculated using the same frames. A mean value was then taken from the three values recorded for each joint.

Carpal extension during mount of the A-frame was measures, as well as thoracic, lumbosacral, hip, stifle, hock, shoulder, and elbow angulation at the apex of a-frame. Extension of spine at the apex and height of dismount was also measured. A mean value was then taken from the three values recorded for each joint, as well as extension of spine and height of dismount.

For the jump obstacle, the distance between take-off and landing was measured using the point when last paw left the ground, to first paw landing. Maximum hip and hock extension was measured at the commencement of the aerial phase as the last paw left the ground. Maximum shoulder, and elbow flexion on landing, and maximum carpal extension on landing was also measured during the stance phase of the leading forelimb. Vertical displacement was measured at the point when the dorsal iliac spine was deemed to be above and in line with the jump equipment and was measured from marker to ground. A mean value was then taken from the three values recorded for each variable.

Kinetic data collection and analysis

Whilst completing the exercises for kinematic analysis, data was also collected using a commercially available pressure measuring mat (Tekscan Walkway Pressure Mat; Tekscan, Boston, MA, USA). The system consisted of two sensing tiles mounted together on a rigid platform, to form a single low-profile walkway with an overall size of 148.5×58.4 cm and sensing area of 146.3×44.7 cm. The mat contained 4 sensels per cm^2. The mat was 0.6 cm thick and had a maximal sample rate at 185 Hz. The walkway was calibrated as per manufacturer guidelines, using pressures which were appropriate for the weight of the dogs to be recorded. The walkway was covered by a 1 mm thick rubber sheet to ensure the dogs did not damage the equipment and did not slip. Two 'Tekscan EH-2 Evolution' handles were used to connect this system to a laptop computer, allowing kinetic data to be analysed using proprietary software (Tekscan Walkway, v7.02). Data from the three walk, trot and trail forelimb jump landing recordings were averaged for each dog to obtain measures of peak vertical force (PFz, the highest force applied through the ground during stance time), contact pressure (CP) and mean vertical ground
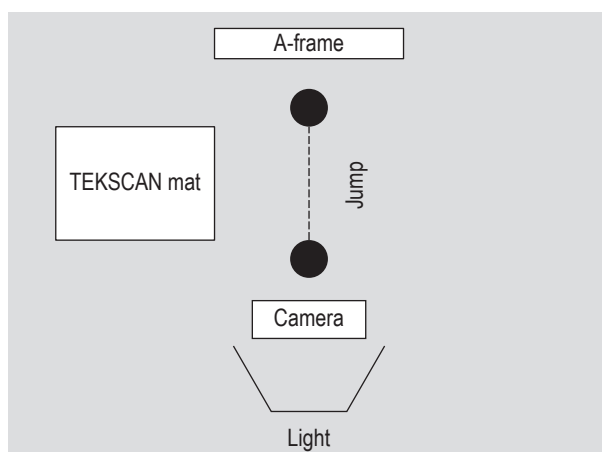
reaction force (Fz). A mean value was then calculated for each variable based on the number of data points collected, and PFz values were normalised to the dog's body mass. This simple procedure facilitates making comparisons between dogs of different sizes and weights.

Statistical analysis

The kinetics and kinematics data for the three repeats for each dog was averaged. Tabulated data from both video and pressure mat analysis was then imported into SPSS v. 24 (IBM Corporation, Armonk, NY, USA) for statistical analysis. Kinetic and kinematic outcome parameters were assessed for normality using Shapiro-Wilk test of normality. Data were defined by movement condition. For the correlations tested, Pearson's product-moment correlation was used when data was parametric and Spearman's rank-order correlation when non-parametric data was detected. To assess differences between two sets of data, data was analysed by paired t-test if normally distributed, and if data were not normally distributed a Wilcoxon signed rank test was used. For comparison of means between 3 sets of data, all data was normally distributed, therefore analysis was carried out using ANOVA for repeated measures and a Bonferroni correction. The peak vertical force (PFz) and respective vertical displacement during jump were plotted against one another to show the relationship between limb force and height jumped. A linear regression lines was calculated for the two parameters. a linear model regression procedure was used. This model used the SPSS based macro of Hedeker *et al.* (1994). The limb force (PFz) associated with A-frame dismount height was calculated from the regression line.

The following analyses were then completed:

1. Correlations
   A. Weight vs carpal extension at walk, trot and contact with A-frame, forelimb and hindlimb forces at walk and trot, forelimb and hindlimb contact pressures at walk and trot, force and pressure at jump landing and peak force;
   B. Scapula length versus shoulder flexion and extension at walk, trot, during jump and negotiating the A-frame;
   C. Hip angle version hip flexion and extension at walk, trot, during jump and negotiating the A-frame;
   D. Force at walk and trot versus carpal, elbow hock, stifle, hip extension and shoulder flexion;
   E. Contact pressure at walk and trot versus carpal, elbow hock, stifle, hip extension and shoulder flexion;
   F. Shoulder and elbow flexion at jump landing to peak force;
   G. Jump take off distance to landing distance.

2. Regression
   A. To predict maximum force incurred due to take off height from A-frame.
3. Differences
   A. Joint motion at trot versus A-frame, jump take off, suspension and landing;
   B. Length of spine (static) versus length at apex of A-frame.

3. Results

Data are mean ± standard deviation, unless otherwise stated.

Conformational traits

Mean hip angle measured from the dorsal iliac spine, greater trochanter and lateral epicondyle of the femur was 125.99±20.510°, with a mean length of spine measured from dorsal border of scapula to sacrum was 51.01±0.745 cm. Mean scapula length, measured from the dorsal border of the scapula spine to the greater tubercle of the humerus was 20.51±2.697 cm.

Kinematics of walk and trot

Full results of the kinematic analysis of all joints at both walk and trot can be seen below in Table 1, with the greatest range of motion (ROM) seen in the carpus and elbow, and smallest seen in the shoulder and hip. Stride length at walk was 1.12±0.256 m and increased by 28.5% at trot to 1.44±0.295 m.

Table 1. Joint extension, flexion and range of motion (ROM) in degrees of angle at walk and trot.[1]

Joint	Exercise	Extension (º)	Flexion (º)	ROM (º)
Hip	walk	142.83±19.067	102.89±16.769	39.93±7.502
	trot	142.91±19.721	103.88±19.292	39.03±10.038
Stifle	walk	125.60±18.652	78.45±14.904	50.04±16.612
	trot	137.13±41.962	77.69±11.415	59.44±35.088
Hock	walk	136.81±23.890	82.10±21.444	54.71±15.813
	trot	125.97±16.070	74.89±13.036	51.08±9.207
Tarsus	walk	104.90±28.473	36.67±23.515	68.31±15.137
	trot	99.58±8.567	28.99±7.833	70.587±6.944
Shoulder	walk	120.83±22.205	94.61±21.007	26.12±6.212
	trot	130.63 ±31.901	106.64±31.630	33.75±19.762
Elbow	walk	145.27±36.303	81.52±37.921	63.754±6.953
	trot	132.30±11.800	71.45±14.884	60.86±16.722
Carpus	walk	105.42±7.244	23.93±7.451	81.43±7.835
	trot	99.44±8.750	21.19±8.305	74.58±17.587

[1] Data are mean ± standard deviation.

Kinetics of walk and trot (force)

Forelimbs average PFz at walk was 5.93±1.219, whilst hindlimbs was 4.52±0.953. Forelimbs average PFz at trot was 7.67±2.314 N/kg BM, with hindlimb average forces of 5.25±0.659 N/kg BM meaning a 59.4/40.6 ratio of forces fore/hind at trot. Centre of mass had therefore shifted more cranially compared to walk, which showed a 56.7/43.7% ratio of force distribution between fore and hind. PFz (walk) in the forelimbs (5.93±1.219 N/kg BM) increased by 29.1% to 7.67±2.314 N/kg BM at trot, whilst in the hindlimbs forces also increased by 15.8% from walk to trot, from 4.52±0.953 to 5.25±0.659 N/kg BM.

Kinetics of walk and trot (pressure)

Mean pressure at walk in kilopascals (kPa) for both fore-limbs 211.97±38.071 kPa, with an average hindlimb pressure of 150.23±30.005 kPa. Mean pressure in trot was similar to walk in that average pressure of 249.77±34.311 kPa was observed in the forelimbs with reduced pressure of 190.68.53±33.815 kPa in the hindlimbs. Pressure is therefore 11% higher in the forelimbs than the hindlimbs at walk, but 31% higher in the forelimbs versus the hindlimbs at trot. A summary of these results is given in Table 2.

Kinematics of jump

As can be seen in Table 3, maximum extension of hip at take-off was 150.93±19.097° and maximum extension of hock was 130.72±37.145°. Mean take off distance measured from point at which hind limb left ground to vertical middle of jump obstacle was 1.07±0.250 m.

Vertical displacement measured at reflective marker on metatarsus when paw left ground to one frame prior to start of descent was 1.25±0.179 m. Maximum flexion at the hip was 100.68±24.457° which did not differ greatly from hip flexion at walk of 102.89±16.769°. Maximum stifle flexion at walk/trot was 77.69±11.415°, whilst when jumping this increased by 36% to 56.98±11.710°. Hock flexion also varied greatly from walk/trot from 82.10±21.444° to 54.51±17.430°.

Table 2. Forelimb and hindlimb and mean pressure in kilopascals (kPa) and mean vertical ground reaction force (Fz in Newtons (N) at walk and trot.

	Gait	Pressure (kPa)	Mean vertical ground reaction force (N/kg BM)
Forelimb	walk	211.97±38.071	5.93±1.219
	trot	249.77±34.311	7.67±2.314
Hindlimb	walk	150.23±30.005	4.52±0.953
	trot	190.68.53±33.815	5.25±0.659

Table 3. Maximum mean flexion (F) and extension (E) during phases of jump.[1]

Joint	Take off	Suspension	Landing
Hip	159.03±19.097° (E)	100.68±24.450° (F)	–
Hock	130.72±37.145° (E)	54.51±17.430° (F)	–
Stifle	–	56.98±11.710° (F)	–
Shoulder	–	–	118.13±15.584° (F)
Elbow	–	–	87.23±10.683° (F)
Carpus	–	–	125.77±7.071° (E)

[1] Data are mean ± standard deviation. – = no data collected.

One interesting observation of all police dogs jumping was that during the suspension phase they tucked their hind limbs under the body (proflexion) which is in contrast to what might be considered standard in other breeds who retroflex.

Maximum flexion at the shoulder was 118.13±15.584° which is less than the 94.61±21.007° seen at walk/trot, however maximum flexion at the elbow was 87.23±10.683° which is 22% greater than the 71.45±14.884° maximum observed at walk/trot. Maximum carpal extension was 125.77±7.071° which as expected is greater than the maximum extension of 105.42±7.244° seen at walk. Landing distance measured from vertical middle of jump obstacle was 1.24±0.330 m, a difference in symmetry of 0.86 or 0.17 m with n=1 being perfect symmetry.

Kinematics of A-frame

As shown in Table 4, mean carpus extension at contact with the A-frame was 107.70±12.920° which does not differ greatly from walk. This may be explained by the fact that all dogs leapt at the A-frame, mounting it a considerable distance from the ground. At the apex hip flexion did not increase compared to walk at 100.00±21.224° and 91.60±14.200° respectively. Only minor differences were seen in hock (79.19±17.048°) shoulder (104.34±16.744°) and elbow flexion (75.72±20.804°). Extension at the cervical/thoracic junction was 153.55±6.427°, with extension at the lumbosacral junction of 154.82±5.733°. Spine length at rest (from dorsal border of scapula to sacrum) was 0.51±0.745 m, however this increased significantly at the apex to 0.77±0.112 m, an overall increase of 51%. No dog completed the full length of A-frame, with the mean dismount jump height being 1.47±0.452 m This also meant no kinetic data was able to be collected for landing from A-frame as all dogs chose to jump laterally from the frame at varying distances.

Table 4. Joint and spine angles observed at A-frame.[1]

Joint	Flexion (°)	Extension (°)	Phase
Carpus	-	107.70±12.920	contact
Hip	100.00±21.224	–	apex
Stifle	91.60±14.200	–	apex
Hock	79.19±17.048	–	apex
Shoulder	104.34±16.744	–	apex
Elbow	75.72±20.804	–	apex
Cervical/thoracic spine	–	153.55±6.427	apex
Lumbosacral spine	–	154.82±5.733	apex

[1] Data are mean ± standard deviation. – = no data collected.

Kinetics of jump

Mean vertical ground reaction force (GRF) of trail forelimb at landing was 13.56±3.719 N/kg BM and mean contact pressure was 109.15±20.755 kilopascal (kPa). Peak vertical force (PFz) of trail forelimb was 12.0558±1.46 N/kg·BM (range10.48-14.46·N/kg·BM).

Kinetics of A-frame dismount

Peak values of vertical GRF during the dismount from A-frame were predicted by the regression equation obtained from jump vertical displacement and PFz during jump landing. The equation used was y=292.239+(128.140x), meaning: PFz = 292.239 + (128.140 × height of dismount).

Estimated peak vertical GRF at landing from A-frame was therefore 480.31±57.90 N (range 412.69-584.4 N). When normalised by dog's weight, PFz during A-frame landing was predicted to be an average 14.28±0.83 N/kg BM (range 10.01-17.72 N/kg·BM) for the trail forelimb.

Correlations and regression

Only statistically significant correlations have been reported.

Kinetics and kinematics of jump

Data regarding kinetics of jump was limited to 5 dogs as the additional 9 did not create satisfactory contact measurements upon landing. A linear regression was run to understand the effect of the maximum height during suspension on the PFz. Figure 3 shows vertical displacement during jump plotted against peak vertical GRF (PFz). Visual inspection of this plot indicated a linear relationship between the variables. There was homoscedasticity and normality of the residuals. The regression line shows that there is a linear relationship between the two parameters (r^2=0.949, P=0.005). A regression equation was then created to be able to calculate vertical GRF from the maximum height the dog reaches (jumping suspension or A-frame dismount): y=292.239+(128.140x), meaning: PFz = 292.239 + (128.140 × height of landing initiation). Height of suspension, meaning height of initiation of landing, statistically significantly predicted PFz, $F_{(1, 3)}$ = 56.142, P=0.005, accounting for 93.2% of the variation in PFz, a large size effect according to Cohen (1988).
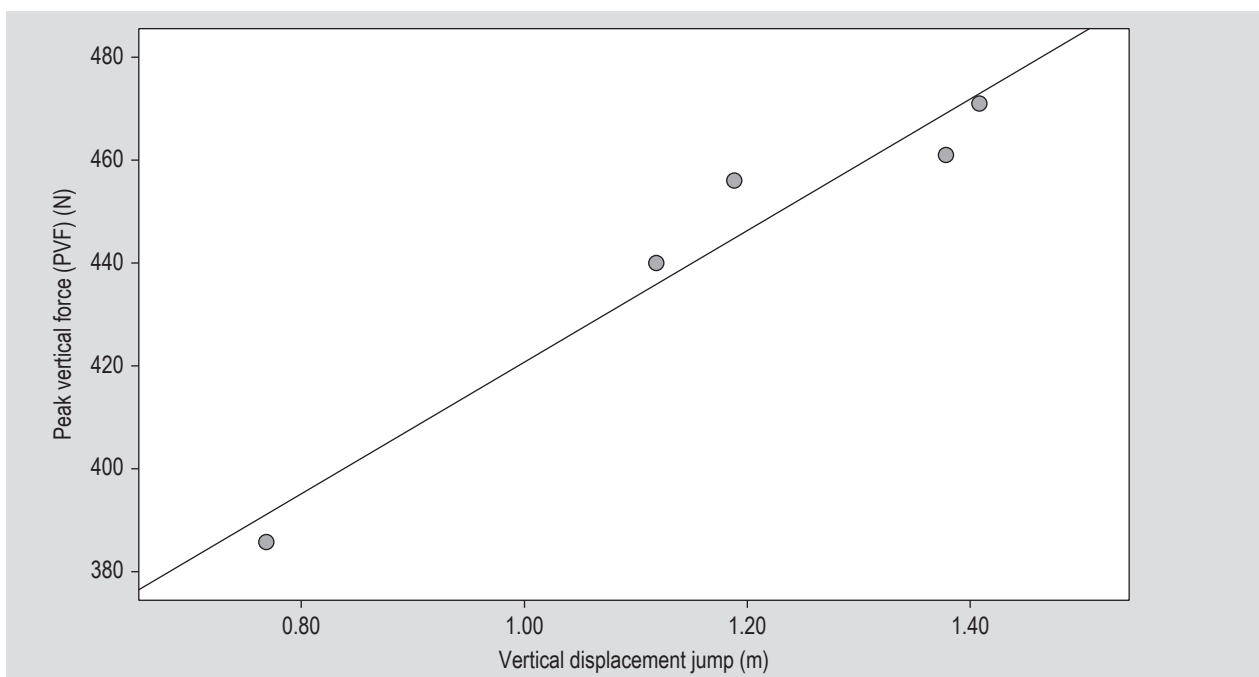

Figure 3. Peak vertical force (N) versus vertical displacement (m) (n=5).

Hip angle

Hip angle, hip flexion and extension at walk, trot, during jump and negotiating the A-frame data were subjected to a Shapiro-Wilk's test of normality. All results were parametric, and a Pearson's product-moment correlation test was then conducted. There was a statistically significant strong positive correlation found between static hip angle (125.99±20.510°) and hip flexion at walk (=102.89±16.769°) (r(2)=1.000, *P*<0.0005). Likewise, hip extension at walk (142.834±19.0665°) has also shown a strong positive correlation with hip angle (125.99±20.510°) has also shown to have a strong positive correlation with hip extension at walk (142.834±19.0665°), which was statistically significant (r(14)=0.759, *P*=0.00004).

During trot, hip extension and flexion have shown similar patterns to trot. Therefore, hip angle (125.99±20.510°) and hip flexion at trot (103.88±19.292°) were found to have a statistically significant strong positive correlation (r(14)=0.843, *P*<0.0008). Additionally, hip angle (125.99±20.510°) and hip extension at trot (142.91±19.721°) were found to have a strong positive correlation (r(14)=0.813, *P*<0.0006), which was also statistically significant.

Hip angle (125.99±20.510°) has also shown a statistically significant positive correlation (moderate) with hip extension at jump take-off (150.93±19.097°) (r(14)=0.615, *P*=0.019), and a statistically significant strong positive correlation with hip flexion during jump suspension phase (100.69±24.450°) (r(14)=0.801, *P*=0.00007). Lastly, there was a statistically significant strong positive correlation between hip angle (125.99±20.510°) and hip angle at apex of A-frame (108.00±21.224°) (r(14)=0.662, *P*=0.000019).

Jump take-off distance versus landing distance

A Shapiro-Wilk test for normality was conducted to assess jump take off distance (1.07±0.244 m) versus landing distance (1.24±0.329 m). Results were found to be non-parametric, so a Spearman's rank-order correlation test was subsequently completed which found a perfect positive correlation (r(13)=1.000, *P*<0.0005).

Exercise comparisons

PFz at jump and A-frame

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the trail forelimb PFz from landing from a 55cm jump compared to landing from the A-frame. The PFz normalised to the body mass (BM) was also analysed by the same means. Data are mean ± standard deviation, unless otherwise stated. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (*P*>0.05).

The PFz normalised by BM was statistically significantly increased during A-frame dismount (14.28±5.13 N/kg BM) in comparison with landing from the jump (12.055±1.46 N/kg BM), a significant increase of 2.4017 N/kg BM, t(4)=2.457, *P*=0.045.

Hip extension

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between hip extension during trot and hip extension during jump take-off. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (*P*>0.05). Hip extension at trot (142.91±19.720°) was less than hip extension during jump take-off (150.93±19.097°), there was not statistically significant decrease in extension between trot and jump take-off, t(13) = -2.021, *P*=0.064 (Figure 4).

Hock extension

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between hock extension during trot and hock extension during jump take-off. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (*P*>0.05). Hock extension at trot (125.97±16.069°) was less than hock extension during jump take-off (130.72±18.048°), there was not a
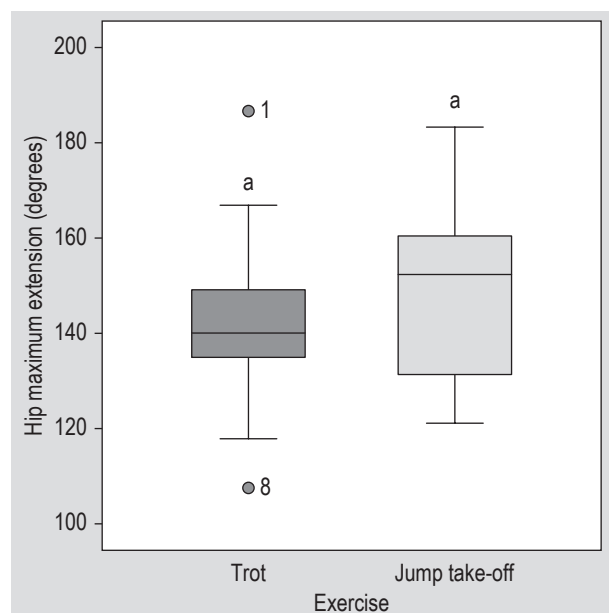

Figure 4. Box plots for hip maximum extension at both trot and during jump take-off. The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=13).

statistically significant decrease in hock extension between the exercises, t(13) = -1.028, *P*=0.323 (Figure 5).

Carpal extension

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in carpus extension during trot, contact with A-frame, or during the landing phase of jumping. There were no outliers in the data, as assessed by inspection of a boxplot. Carpal extension data have not violated the assumption of normality, as assessed by Shapiro-Wilk test (*P*>0.05). Mauchly's test of sphericity indicated that the assumption of sphericity was met, $\chi^2(2) = 1.629$, *P*=0.443. Carpus extension was statistically significantly different between the three exercises, F(2, 14) = 32.115, *P*=0.000006. Post hoc analysis with a Bonferroni adjustment revealed that carpal extension was statistically significantly increased at jump when compared to contacting the A-frame (25.626 (95% confidence interval (CI) 14.848 to 36.404)°, *P*=0.000435) and trot (29.78 (95% CI, 18.665 to 40.908), *P*=0.000204 (Figure 6).

Stifle flexion

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in stifle flexion during trot, negotiating the apex

Figure 6. Box plots for carpal maximum extension at trot on contact with the A-frame and jump landing. The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=12).

of the A-frame, or suspension phase of jumping. There were no outliers in the data, as assessed by inspection of a boxplot. Stifle flexion was normally distributed at each condition, as assessed by Shapiro-Wilk test (*P*>0.05). Stifle flexion increased from 77.69±3.051° at trot, to 91.60±14.199° at the apex of A-frame but decreased to 56.983±3.130° during the suspension phase of jump. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 0.154$, *P*=0.926. Stifle flexion was statistically significantly different at trot, A-frame and jump, *F*(2, 26) = 53.667, *P*<0.00001. Post hoc analysis with a Bonferroni adjustment revealed that stifle flexion was statistically significantly decreased at trot when compared to negotiating the apex of the A-frame (-13.911 (95% CI = -23.497 to -4.326)°, *P*=0.00058). Flexion during jump suspension was statistically significantly increased compared to trot (20.708 (95% CI = 11.996 to 29.419)°, *P*=0.000058), whilst flexion at the apex of A-frame was statistically significantly increased when compared to flexion during jump (34.619 (95% CI = 25.235 to 44.003)°, *P*=0.0001) (Figure 7).

Hip flexion

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in hip flexion during trot, negotiating the apex
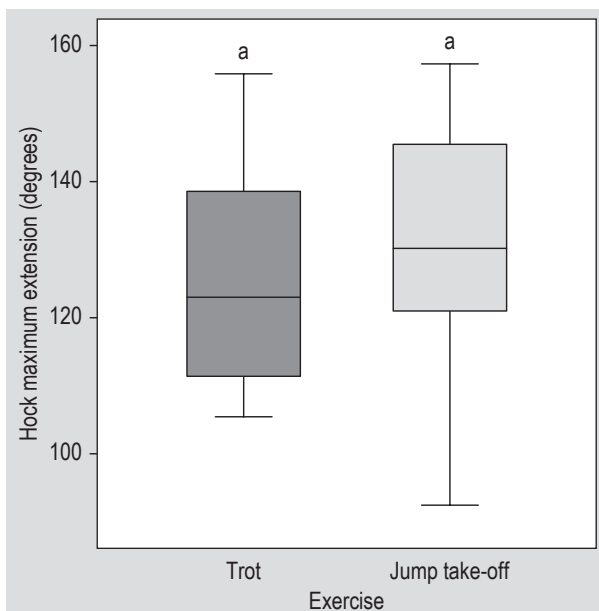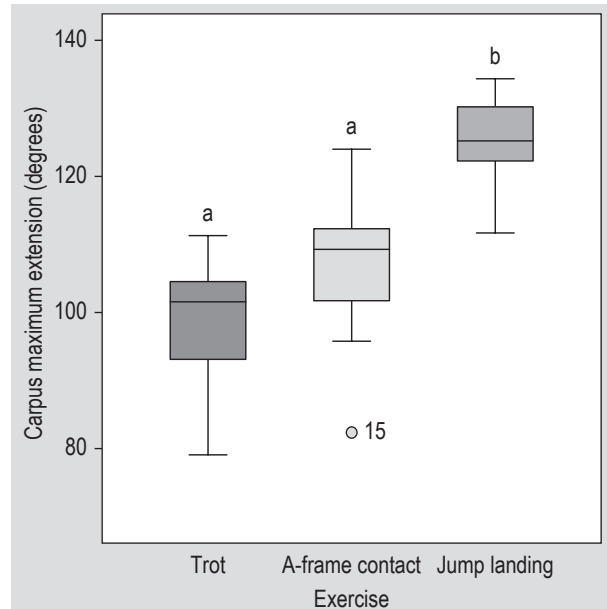

Figure 5. Box plots for hock maximum extension at both trot and during jump take-off. The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=13).
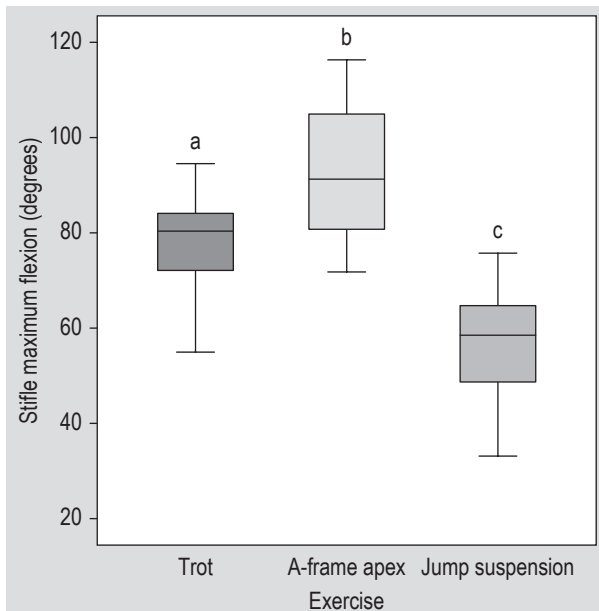
Figure 7. Box plots for stifle maximum flexion on the different exercises (trot, A-frame apex and jump suspension). The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=14).
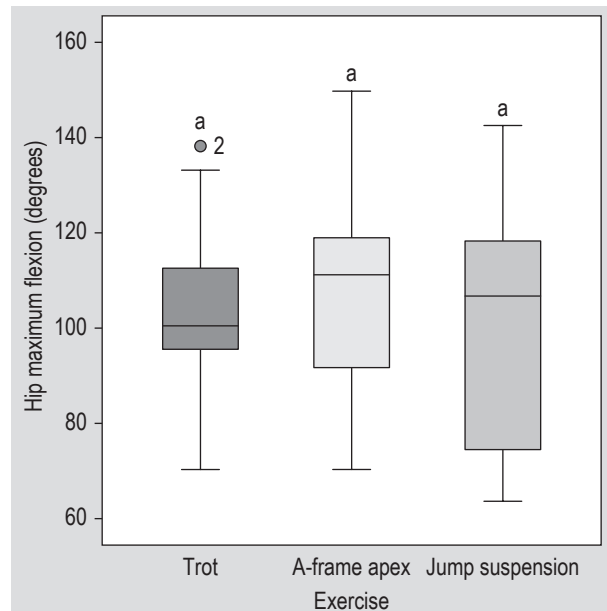

Figure 8. Box plots for hip maximum flexion on the different exercises (trot, A-frame apex and jump suspension). The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=14).

of the A-frame, or suspension phase of jumping. There were no outliers in the data, as assessed by inspection of a boxplot. Hip flexion was normally distributed at each condition, as assessed by Shapiro-Wilk test (*P*>0.05). Data are mean ± standard deviation. Hip flexion increased from 103.885°±5.156 at trot, to 108.007±5.672° at the apex of A-frame but decreased to 100.685±6.535° during the suspension phase of jump. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 0.475$, *P*=0.789. Hip flexion was not statistically significantly different at trot, A-frame or jump, F(2, 26) = 1.262, *P*<0.3 (Figure 8).

Elbow flexion

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in elbow flexion during trot, negotiating the apex of the A-frame, or during the landing phase of jumping. There were no outliers in the data, as assessed by inspection of a boxplot. Elbow flexion was normally distributed at each condition, as assessed by Shapiro-Wilk test (*P*>0.05). Elbow flexion decreased from 66.078±5.245° at trot, to 63.911±4.798° at the apex of A-frame but increased to 87.23±3.561° during the landing phase of jump. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 0.944$, *P*=0.624. Elbow flexion

was statistically significantly different at trot, A-frame and jump, F(2, 6) = 7.397, *P*<0.005. Post hoc analysis with a Bonferroni adjustment revealed that elbow flexion was statistically significantly decreased at trot when compared to the landing phase of jump (-21.158 (95% CI -37.748 to -4.568°), *P*=0.0015). Flexion during the landing phase of jump was statistically significantly increased compared to flexion at the apex of A-frame (23.324 (95% CI 2.708 to 43.940°), *P*=0.028) (Figure 9).

Shoulder flexion

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in shoulder flexion during trot, negotiating the apex of the A-frame, or during the landing phase of jumping. There were no outliers in the data, as assessed by inspection of a boxplot. Shoulder flexion was normally distributed at each condition, as assessed by Shapiro-Wilk test (*P*>0.05). Shoulder flexion decreased from 106.63±31.633° at trot, to 104.34±16.744° at the apex of A-frame but increased to 118.13±15.584° during the landing phase of jump. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(2)$ = 2.968, *P*=0.227. Shoulder flexion was not statistically significantly different at trot, A-frame or jump, *F*(2, 18) = 3.364, *P*=0.057 (Figure 10).
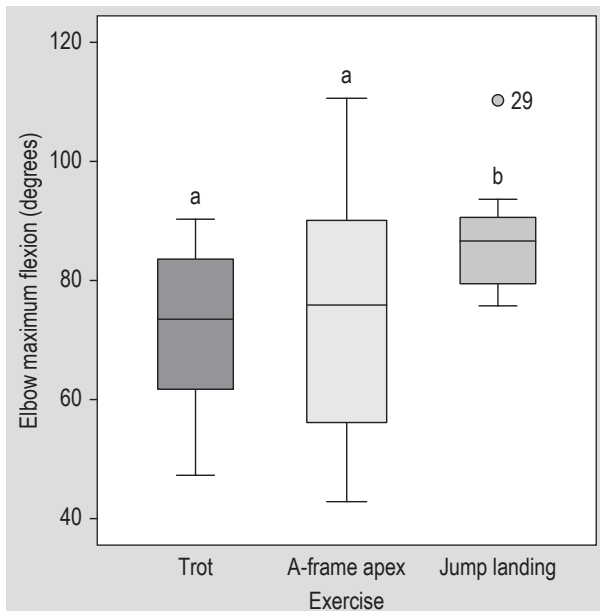
Figure 9. Box plots for elbow maximum flexion on the different exercises (trot, A-frame apex and jump landing). The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=14).
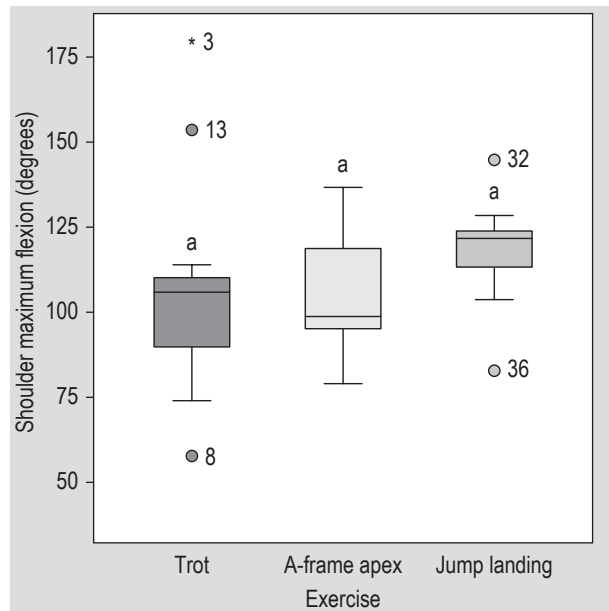

Figure 10. Box plots for shoulder maximum flexion on the different exercises (trot, A-frame apex and jump landing). The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=14).

Hock flexion

To determine whether there were statistically significant differences in hock flexion during trot, apex of A-frame, or during the suspension phase of jumping, one-way repeated measures ANOVA was conducted. There were no outliers in the data, as assessed by inspection of a boxplot. Hock extension had parametric distribution, as assessed by Shapiro-Wilk test (*P*>0.05). Mauchly's test of sphericity indicated that the assumption of sphericity was met, $\chi^2(2) = 1.889$, *P*=0.389. Hock flexion was statistically significantly different between the three exercises, *F*(2, 26) = 21.944, *P*=0.000003. Post hoc analysis with a Bonferroni adjustment revealed that hock flexion is higher during jumping suspension, being statistically significantly higher when compared to apex of A-frame (24.686 (95% CI, 15.949 to 33.424°), *P*=0.000009) and to trot (20.831 (95% CI, 9.052 to 31.709), *P*=0.001 (Figure 11).

Summary of kinematic results: differences

Flexion and extension of joints at trot versus percentage increase at jump and A-frame can be seen in Table 5.
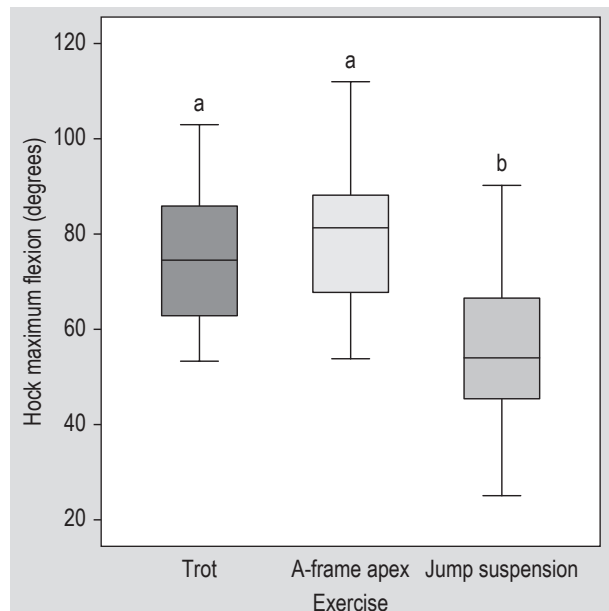
Figure 11. Box plots for hock maximum flexion on the different exercises (trot, A-frame and jump landing). The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Letters represent significant differences between means (*P*<0.05) by repeated measures ANOVA (n=14).

Table 5. Summary of results showing flexion and extension of joints at trot versus % increase at trot, jump and A-frame.

Joint	Movement	Trot (°)	Jump %	A-frame %
Hip	extension	142.91±19.067	+11.27	–
	flexion	103.88±16.769	+3.08	+3.83
Stifle	extension	137.13±18.652	–	–
	flexion	77.69±11.415	+36.05	-14.12
Hock	extension	125.97±16.070	+3.77	–
	flexion	74.89±13.036	+37.10	-6.14
Shoulder	extension	130.63±31.901	–	–
	flexion	106.64±31.630	-12.34	+3.45
Elbow	extension	132.30±11.800	–	–
	flexion	71.45±14.884	-18.08	-6.49
Carpus	extension	99.44±8.750	+26.40	+8.30
	flexion	21.19±8.305	–	–

4. Discussion

Static conformation and kinematics of walk and trot

As this study has shown, the static hip angle of GSDs has a strong positive correlation with hip flexion and extension at both walk and trot, flexion during the suspension phase of jumping and when negotiating an obstacle, such as an A-frame, as well as a moderate correlation with hip extension during initiation of jumping. A wider angle at the hip would imply that a larger ROM is achievable, meaning that the dog can move more efficiently at both the walk and trot, and is ultimately better able to cope with some of the other demanding traits of its job (Jones *et al.*, 2018). Nonetheless is has been previously speculated that conformationally, GSDs are predisposed to a sloped back (Breit and Künzel, 2001), creating a more closed angle at the hip. A study by Fischer *et al.* (2017) involving over 32 different breeds reports that the forelimb stride length of a GSD at walk was 1.2 m (show breed) and 1.3 m (working breed), with hindlimb stride length measured at 1.6 m for both. At trot forelimb stride was 1.9 m for working, and 2.1 m for show, whilst hindlimb was 2.5 m working and 2.6 m for show, which was actually the longest from the 32 breeds. The increased relative hindlimb stride length in the show line may, in the opinion of the author, be due to its sloped back conformation, meaning it needs to elongate its stride to maintain adequate ground coverage compared to the forelimb. Although the stride length of 1.12 m at walk and 1.44 m at trot measured in our work is less than seen in the Fischer study (2017), they are consistent with previous studies relating to GSDs (Tian *et al.*, 2011). These results may therefore have implications from a selection and training perspective for police forces. Anecdotally, difference police forces in the UK have different procurement methods – some dogs will be bred

specifically for police work, whilst others will be rescue animals or unwanted pets. Primarily however, police dogs are selected on the basis of character traits, and, depending on whether the dog is selected from pup or adult, may then undergo testing for inheritable phenotypes (Wilson *et al.*, 2011). Further investigation would need to be undertaken to establish an ideal hip angle, and at what age that may become apparent, but may ultimately prove beneficial during the selection process.

Stride length measured at walk and trot is consistent with previous studies relating to GSDs (Tian *et al.*, 2011). The current study has shown that the increases in stride length are as a result of greater extension of the shoulder and stifle joints alongside an expected increase in stride frequency. ROM at the hip joint was shown to remain relatively constant between walk and trot, which is contrary to studies of other breeds which have shown increased ROM of the hip as stride changes from walk to trot (Fischer *et al.*, 2017). A study by Van der Walt *et al.* (2008) has also shown that hip extension in 30 normal canines when trotting at a speed of up to 2 m/s, was 119.97°, which is much lower than our study, which may indicate that although the ROM is consistent between walk and trot, a GSD uses considerably more hip extension overall. As was noted previously, GSDs have a higher stride versus body length than the majority of working dog breeds (Vilar *et al.*, 2015), which may be due to the greater hip extension. Nevertheless, the increases in stride length observed is kinematically generated via increased horizontal excursion at the shoulder in the forelimb, but below the stifle in the hindlimb. Efficiency of movement is generated through greater retraction of the forelimbs and proportionally higher protraction of the hindlimbs, so increased ROM at both the scapula and hip would be expected, however this study has shown that the increased hindlimb protraction is being generated at the stifle. It is virtually impossible to draw conclusions regarding these results with other studies of a similar nature, simply because of the huge variance in results – for example, when comparing ROM of the stifle with other studies using Labradors, ROM varies at trot from between 52° (Agostino *et al.*, 2011) and 61° (Clements *et al.*, 2005). Both studies used a similar treadmill protocol at approximately the same speed, so any comparison would be rudimentary at best. It is also important to note that when comparing gait of different breeds, almost all dogs can move at different velocities within the same gait (Vilar, 2015), so even if a treadmill velocity is consistent across studies, the gait may still vary.

Kinetics of walk and trot

Our results indicate an amount of variance between forelimbs and hindlimbs at both walk and trot. At walk 5.9 N/kg BM of force was at the forelimb, compared to 4.5 N/kg BM in the hind, which would indicate that 57% of

the overall force is being borne by the front limbs and 43% the hind, which differs from previously reported studies of 59/41%. Trot shows a greater distribution of body mass cranially at 59/41%, which again does differ from a 56/44 split for a heterogenous population of trotting dogs (Lee, 2004), which may be due to our study only using GSDs.

As seen in a previous study (Pfau *et al.*, 2011), pressures were higher in trot than in walk, but relatively balanced in comparison to force, highlighting the breeds ability to distribute bodyweight evenly at the two gaits measured, albeit trot does increase both force and pressure on the forelimbs. PFz at walk and trot was not collected during the study, however it would be expected that as stride length increases from walk to trot stance time decreases, increasing PFz, which has been noted as up to 125% of bodyweight in the forelimbs, and 85% of bodyweight in the hindlimbs (Holler *et al.*, 2010; Weigel *et al.*, 2005).

Interestingly, Vilar (2015) found that GSDs dogs experience approximately half of the PFz through their pelvic limbs in comparison to some other breeds, which would suggest that the musculoskeletal stress would be less overall for a GSD at walk and trot. One further point to note is that the greatest degree of differences between forelimbs and hindlimbs were seen at walk, which may be as a result of its four-beat gait pattern. As such, gait is disunited in comparison to the more symmetrical trot (Colborne *et al.*, 2011), placing increased demand on the musculoskeletal system. Although asymmetries were observed in both the kinematics and kinetics of walk and trot, previous work have concluded that dogs interlimb motion asymmetry can also be attributable to variation between trials (Sandberg *et al.*, 2017).

Jump kinematics and kinetics

The technique used for jumping by the animals observed in this study is unique to any previous work, in that the majority were instructed to sit by their handlers a relatively short distance away from the jump obstacle. This only allowed for the animal to rise and take one or two steps before initiating the take-off phase of the jump. As such they would be expected to have a different velocity than other studies, where dogs are given a run-up distance. During a lengthier approach, the animal would be more able to optimise body position, with a greater energy release from elastic structures contributing to the power needed to clear the jump (Gregersen and Carrier, 2004). The method of jumping used in this study led to a relatively sharp incline and decline angle at both take-off and landing, as well as causing the animal to maintain proflexion of the hindlimbs to clear the obstacle, all of which may result in different loading patterns and higher joint moments than seen in previous studies using higher approach speeds, which would allow for a flatter trajectory (Pfau *et al.*, 2011). Upon landing

it was also observed that although the elbow and shoulder flexed upon impact, momentum, and the dog's eagerness to turn towards its handler meant it effectively rolled over the axis of the shoulder joint, limiting both flexion but potentially increasing GRFs as the centre of mass shifted cranially, as well as increasing torsion forces through the forelimbs. This is of particular interest considering the shoulder is one of the most common sites of injury in agility dog (Cullen *et al.*, 2013; Levy *et al.*, 2009). It has also been previously noted that sharp turns, especially those observed during landing from height may place the shoulder close to its end range of abduction (Millis and Levine, 2014). Existing research has shown that upon landing one forelimb follows the other whilst ensuring that sufficient horizontal velocity is retained, allowing the hind limbs to clear the jump, but creating asymmetrical limb loading (Meershoek *et al.*, 2010; Söhnel *et al.*, 2020). The resulting rotation at the forelimb upon landing would also mean ground reaction force vectors may be misaligned with the limb, suggesting GRF moments could be counteracted by higher internal forces (Pfau *et al.*, 2011). Further investigation is needed to fully understand the relationship between kinematics and kinetics of jump landing, and if dogs use additional strategies such as abduction/adduction of the limb to reduce rotational forces.

Previous research by Birch *et al.* (2015) found that shoulder angles were significantly more flexed when take-off distance is reduced, which creates a steeper jumping arc, and would require greater propulsive forces to overcome inertia (Birch and Lesniak, 2013). A steeper jump arc would also lead to a more acute landing angle, which in turn would create higher vertical loading forces compared to a jump at speed, with greater take-off and landing distances created by a flatter trajectory (Pfau *et al.*, 2011; Voss *et al.*, 2010), which is further supported by our results showing jump take-off and landing distance were perfectly correlated.

Our study also found that shoulder and elbow flexion was actually less during the landing phase of the jump and negotiation of the A-frame than that experienced during walk or trot, as well as being less than reported in previous studies (Birch *et al.*, 2015; Birch and Lesniak, 2013). It is surmised that this is a consequence of the movement at landing previously described, but it must be remembered that less flexion/more extension when landing from height will increase concussive forces through the limb (Imhof *et al.*, 2007). Interestingly forelimb forces at trot were shown to have a negative correlation with pressures measured upon jump landing, suggesting that stance phase is reduced when comparing the two.

Flexion of the shoulder during landing was shown to have a perfect correlation with peak force, which was calculated at 12.05 N/kg when normalised for body mass. Research by Pfau *et al.* (2011) had previously reported a maximum load

of 45 N/kg at landing from height, however this was total load including both forelimbs, with a 60 cm jump height compared to our 55 cm, and with the dogs approaching the obstacle at gallop after a minimum of a 5 m run up. Our data was more in line with a study of dogs jumping from a platform, which showed PFzs of 13.67 N/kg per forelimb when jumping from a height of 55 cm (Pardey *et al.*, 2018). A previous study of 13 dogs also reported mean PFz of 30 N/kg for both forelimbs when jumping a height of 63 cm (Hulse *et al.,*1992). The study also suggested that more experienced dogs may land 'smoothly and easily' suggesting that less experienced dogs have a greater degree of limb stiffness, however experienced agility dogs show higher limb stiffness, decreased limb compression and higher limb length in take-off and landing in their forelimbs, than less experienced ones (Söhnel *et al.*, 2020). The level of experience of the dogs used in our experiment was not measured, however it is surmised that they are expected to both jump and negotiate obstacles on a daily basis, and as working police dogs would have been subject to a high degree of training, so we can infer a high level of expertise in these tasks. This lack of flexion of the proximal limb, along with torsion forces generated by the turn, could be subjecting the shoulder joint to immense biomechanical stress, highlighting a need for further investigation. Forces experienced during landing were also positively correlated with forces in the forelimbs at both walk and trot, whilst hindlimb force at trot and contact pressure upon landing were also positively correlated, which is also consistent with existing data (Lorke *et al.*, 2017; Maitre *et al.*, 2007). Because force = mass × acceleration this would suggest that maintaining an appropriate body condition score is also vital for working police dogs to minimise forces incurred during this kind of activity.

Research has not yet been able to conclude if dogs display handedness preference in jumping tasks (Branson and Rogers, 2006), although all of the animals in our study bar one were noted to land on their left forelimb and subsequently turn to the right (again to turn to their handler on the right hand side) which may mean that the left forelimb is consistently subjected to greater PFzs than the right, predisposing the dogs to musculoskeletal conditions on the one limb. Strength of paw preference has been associated with location of the owner during completion of obstacles by agility dogs (Siniscalchi *et al.*, 2013), raising questions over where a handler might stand during this type of training, and if it can be used to limit biomechanical stresses. An interesting point to note was that as mentioned earlier, all dogs landed on the left fore, but one dog did subsequently also turn left during all three repetitions, which was evidently contrary to its training.

Hip extension at take-off phase was a full 11.5% greater than the maximum seen at walk or trot, and larger than seen in previous studies. There was also a greater degree of hip flexion during both the suspension phase of the jump and whilst negotiating the apex of the A-frame in comparison to trot, indicating that completing both obstacles require increased ROM of the hip than normal ground activities. Hock extension also increases by nearly 4% at jump take-off when compared to trot, whilst flexion increased by 37% from its maximum at trot to during the suspension phase of the jump, again showing that a greater ROM of the hindlimb overall is required during jumping. This difference in flexion at the hock was the greatest difference seen in all variables measured but may be related to the jumping technique observed in this study. It is theorised that if the dog approached the jump at speed, it is likely that the hindlimbs would be retroflexed during the suspension phase, reducing overall ROM which would be in line with previous work (Birch *et al.*, 2015). As a further potential consequence of the proflexion during suspension, stifle flexion increased substantially during the suspension phase of jump when compared to trot, albeit less flexion was required at the apex of the A-frame.

Although data of spinal kinematics was not collected at jump, it can be hypothesised that sharp take-off and landing angles would impact the sacroiliac joint and lumbar spine. Equine and canine research has suggested that during the take-off phase of a jump, the angle at the sacroiliac joint increases in relation to the lumbar spine in line with increasing fence height, causing the lumbar spine to extend (Birch *et al.*, 2015; Dyson and Murray, 2003). It is therefore reasonable to assume that this increased extension would also be present during the jump phase of our investigation, with research also indicating an increased prevalence of injuries in dogs required to jump fences which are substantially greater than wither height (Birch *et al.*, 2015).

A-frame kinematics and kinetics

Once again, training and/or our experimental set up influenced results of our kinematic analysis of the initiation phase of the A-frame, simply due to the fact that its position within the police training facility only allowed dogs to have a very limited run up, and the handlers all instructed their animals to sit a short distance away from the obstacle. This meant that when released, the dog would take one or two full strides before leaping at the obstacle. This resulted in what is believed to be a reduced velocity when compared against the existing data available. It was also observed that many of the study participants pulled through the forelimbs at initial contact with the frame, prior to the hindlimbs landing on the frames surface.

Joint kinematics in comparison to trot and jump at the apex of the A-frame have already been discussed, however our data also showed that the angle of extension of the carpal joint at contact with the A-frame was less than that experienced during landing from jump, but higher than

that seen at walk. This can be partly explained by the way the animal mounted the obstacle, as the angle of the body would be somewhat closer to the angle of the frame than if it was met at a more horizontal angle. Only one canine study so far has looked at carpal extension during contact with A-frame, and as such reported a greater degree of extension than our dogs, although interestingly it was also noted that the majority of dogs made contact with the A-frame on the left forelimb (Applegrein *et al.*, 2018). Although carpal extension was less in our study, this again may be explained by velocity, as in the previous study dogs approached the A-frame from one end of a 25 m track, with the frame centred in the middle, suggesting a run up of at least 10 m, and with dogs approaching at an average of 6.34 m/s. Velocity and momentum would be expected to have a greater impact on carpal extension as more force would travel through the forelimb (Söhnel *et al.*, 2020*)*. Previous studies report peak carpal extension angle ranges from 150° to 160° when negotiating stairs or ramps and have been observed as high as 190° (Kopec *et al.*, 2018).

Stifle flexion was less at the apex of the A-frame when compared to trot, but at its greatest during the suspension phase of jump – as such there is little that can be concluded, with no current research with which to compare. Similarly, we now know that at the apex of the A-frame the cervical to thoracic spine increased in length by 50% from static, with an angle of circa 154° at the thoraco-lumbar and lumbo-sacral spine, compared to 164° and 162° respectively noted in a recent study (Surer *et al.*, 2020). Negotiating the A-frame has therefore considerably increased spinal flexion, with cervical and lumbar spine angles becoming significantly more flexed than those seen during normal ground movement. We could speculate that there are welfare implications of forced movement outside of the normal range (Millis and Levine, 2014), but again much further research is needed before conclusions can be made.

One result that is of particular importance is the increase in PFz upon dismount from the A-frame when compared to jumping. Our results show that PFz increased significantly from 12.05 N/kg at jump landing, to 14.28 N/kg. In comparison, PFzs experienced by a horse, galloping at a speed of 12 ms have been shown to be 12.79 N/kg in the lead forelimb, when equalised for body mass. (McGuigan, 2003). Similar behaviour was observed during A-frame dismount to jump in that upon landing the dog immediately turned right, towards its handler. The effects of such a turn have previously been discussed, but by the same measure the maximum height of dismount observed at the A-frame was 2.28 m, which would multiply the forces exponentially. Due to the varying heights of dismount we were unable to collect kinematic data upon landing, which would be worthy of further investigation, considering the prevalence of risk of injury at the obstacle.

There were a number of challenges that were present during our trial. To reflect actual training conditions handlers instructed their animals as they would do normally, meaning that there were variances in the jump protocol between subjects, which limited our ability to obtain comparable data. Nonetheless, a counter argument would suggest that if, as researchers we had imposed a protocol, this trial would not be representative of actual training conditions. We also did not expect the dogs to immediately turn back towards their handlers once landed from jump, or to exit the A-frame from height, both of which hindered our ability to obtain some kinematic and kinetic data. If the trial were to be repeated an ideal scenario would be for it to take place in a laboratory environment, which would allow for a number of force plates to be employed. Velocity could also be measured, as well as creating a set distance prior to jump take-off or mounting of the A-frame. A 3D analysis system might also be used to investigate torsion kinematics at both the fore and hindlimbs, which would give a comprehensive data set regarding kinetics and kinematics.

5. Conclusions

This study has shown that police dogs negotiating A-frame and jump obstacles do have significant alterations to their kinetics and kinematics when compared to walk and trot. Previous work has shown that the A-frame obstacle in agility is responsible for a higher prevalence of injuries, and our study would support this conclusion. With regards to the jump obstacle, although the forces identified were less than those on the A-frame, it needs to be remembered that the jump height used was 55 cm, whereas a training standard for police dogs is to jump through a window at 91 cm, which would significantly alter the kinematics and kinetics. The height of 91 cm is also less than half of the height that some dogs leapt from the A-frame. What is also evident is that the technique used for jumping, as well as initiating contact with the A-frame will also alter the biomechanics, and therefore forces incurred, which necessitates the need for further study to understand the safest way a dog may go about using these obstacles, to minimise the inherent risks.

What it has also shown is that there are some training behaviours that may put the dog at increased risk of injury, which include allowing it to dismount at high height from the A-frame, as well as requiring the dog to turn and face the handler after completion of both obstacles, which not only changes force vectors but applies torsion to the limbs. Agility competition does include multiple turns which may mirror some of the trained behaviours seen in our trial, which warrants further study. A possible solution to alleviate some level of risk is to train police dogs to use the contact zone marked on A-Frames for both entry on to, and exit from the obstacle, which would prevent them from leaping from the obstacle at height.

Negotiating both obstacles requires repetitive extension and flexion of multiple joints over and above what can be expected at walk and trot, especially at the shoulder, hip and stifle, which may explain why certain injuries more commonly occur in agility dogs. An argument could be made that regular training and repetition on the equipment may ultimately strengthen the musculoskeletal system, resulting in a decreased injury risk, but any conditioning would need to be completed in a controlled and progressive manner, which would require additional time and resources away from the dog and handlers normal duties.

To state that annual licensing requirements of police dogs contributes to prevalence of injuries however would be conjecture, especially considering the day to day demands of the job. What could be concluded is that if a police dog was required to perform the activities in our study on a regular basis, it is likely that injury rates would be higher, due to the larger ROM required to complete the obstacles, and greater impact forces generated.

It is becoming increasingly apparent that conformation creates huge variances in a range of different parameters, both kinematic and kinetic, yet there is a lack of appropriate research regarding homogenous populations of dogs, and none that have considered dogs as working animals as opposed to athletes.

Acknowledgements

Conflicts of interest

The authors declare no conflict of interest.

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