The Influence of Three Working Harnesses on Thoracic Limb Kinematics and Stride Length at Walk in Assistance Dogs

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Abstract:

Studies have investigated the kinematics of the healthy canine thoracic limb (TL), but there is currently no research to the authors' knowledge investigating the influence of the working harness on TL kinematics. The aim of this study was to compare the TL stride length (SL) and shoulder, elbow and carpal joint range of movement (ROM) of assistance dogs when wearing three different harnesses (H1 and H2 Y-shaped harnesses; H3 the dog's original harness) with differing handle designs (A and B type handles; all dogs used an A type handle with H3, their original harness), in comparison to a standard collar at walk. Thirteen dogs were analysed at walk in each condition: Harness 1, H1 (B-handle); Harness 2, H2 (A-handle); Harness 3, H3 (A-handle, and the dog's original working harness); and the Collar with the lead held between 20-40cm. A series of Friedman's analyses with post-hoc Wilcoxon Signed Rank tests compared SL and joint ROM at peak protraction and retraction of the TL. *Results:* The results show significant TL kinematic changes in H1 (B-handle): SL in H1 was significantly reduced in comparison to the Collar (6%; P=0.008). In TL protraction, a significant reduction in shoulder extension was recorded for H1 in comparison to H3 (6%; P=0.005). In TL retraction, a significant reduction in carpal extension was observed in H1 in comparison to the collar (4%; P=0.008), H2 (2%; P=0.005) and H3 (4%; P=0.005). *Conclusions:* Differences in canine locomotion were observed between conditions in comparison to when the dog was at walk in the collar. Our findings suggest the harness handle type may result in the TL kinematic changes observed. Significant TL SL and ROM restrictions were noted in H1, the only harness in the study with a specific handle design (B-handle type). The increase in proximal TL joint ROM and a subsequent reduction in distal TL joint ROM suggests an alteration to the energy efficiency of locomotion when compared to previous literature. These results were seen only in H1 and not H2, a similar design of harness, therefore suggesting the B-handle type may be the key factor in the kinematic changes observed.

Keywords:

Canine, harness, biomechanics, collar, working dog, welfare, assistance dog

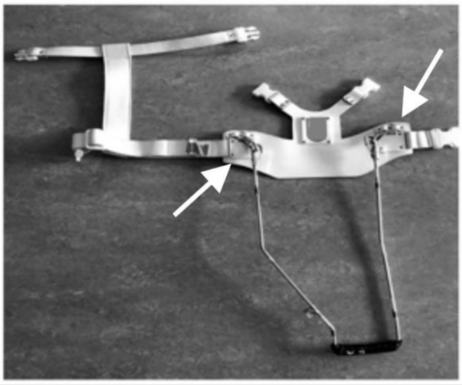
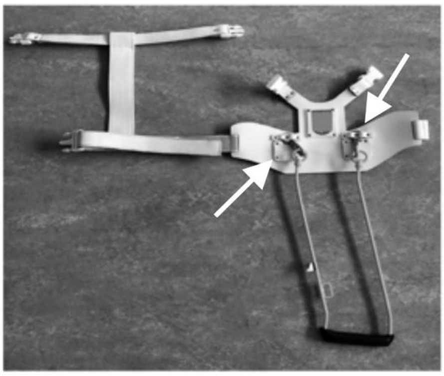
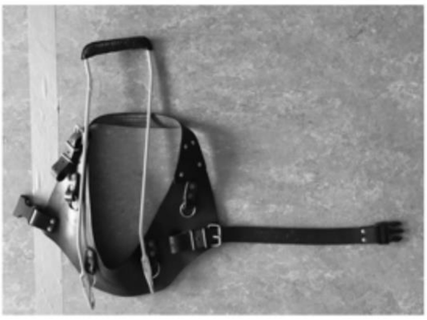
Introduction

Assistance dogs that guide the vision impaired are highly specialised dogs (Calabró-Folchert, 1999) whose movements are communicated, detected and interpreted by their handler through a harness and handle (Peham et al. 2013) (Figure 1). An average working life for these dogs is typically 8.5 years, whilst 16% of the dogs are retired early due to health conditions, 28% of these are due to musculoskeletal disease (Caron-Lormier et al. 2016). For working dogs it is important to optimise musculoskeletal health by ensuring joints and soft tissues are able to function optimally as the presence of any degree of immobilisation could potentially impact on function resulting in joint inflammation, impaired synthesis of joint cartilage and cartilage degradation over time (Andriacchi et al. 2009; Cook, 2010; Millis and Ciuperca, 2015). The maintenance of normal movement patterns can minimise compensatory movement and has been shown to reduce the risk of injury (Fischer et al. 2013). Therefore, to optimise the musculoskeletal health and maximise the longevity of working life for these assistance dogs, it is beneficial to reduce the impact of any degree of immobilisation caused by equipment used during locomotion, such as the harness and handle.

The use of a harness has been anecdotally proposed to improve canine welfare in comparison to the use of a collar and lead, which is considered to exert increased and potentially damaging pressure on the dog’s neck and throat if the dog pulls (Pauli et al. 2006; Landsberg et al. 2013; Grainger et al. 2016). However, few studies to date have investigated the physical effects of collar or harness use in pet or assistance dogs. Shoulder range of movement (ROM) has been investigated in harness and collar by Lafuente, Provis and Schmalz (2018) however this was a treadmill study, thus the kinematic findings may not be comparable to gait on land. The standard harness used with assistance dogs is designed to lie over the TL proximal musculature (Figure 2). These muscles are responsible for locomotion of the TL and postural stability in weight bearing and weight transfer (Millis and Levine, 2013). Peham et al. (2013) reported that a working harness (comparable to H3 in this study, Figure 1) produced asymmetrical pressures over the dog’s sternal region secondary to the unilaterality of the handler. This results from the dogs most commonly being led on the left of the handler. In the equine literature, the girth which fixes the saddle in place, is comparable to the position of the sternal chest strap of the canine harness. The pressures exerted by the horses’ girth have been shown to have a direct effect on the horses’ TL kinematics, with increased peak pressure of the girth there is a subsequent reduction in the TL SL (Wyche, 2003; Wright, 2010; Murray et al. 2013; Murray et al. 2017). The equine and canine TL are similar in their reliance on extrinsic musculature at the shoulder for body weight support, transmission and economical movement (Wilson et al. 2003; Carrier et al. 2006). The effect of harness design and the impact of its influence on TL kinematics therefore requires further investigation to optimise our understanding of how it functions and promote evidence-based practice in this field.

Canine harnesses lie over the TL proximal musculature known as the thoracic sling, the function of which is to maintain posture and postural stability during locomotion (Millis and Levine, 2013; Lafuente, Provis and Schmalz, 2018). The Y-shaped harnesses (H1 and H2) may exert pressure over the Latissimus Dorsi, Cranial and Caudal Trapezius, Cervio-thoracic Epaxials, Acromio-Deltoid, Braciocephalicus and Deep Pectorals (Figure 2). The dogs’ original harness (H3) has potential to influence Caudal Trapezius, Cervio-Thoracic Epaxials, Latissimus Dorsi, Cleidobrachialis, Deep Pectorals, Triceps, Acromio- and Scapulo- Deltoid and Biceps Brachialis function (Figure 2). Despite this, limited research has explored the impact of harness use on canine locomotion.

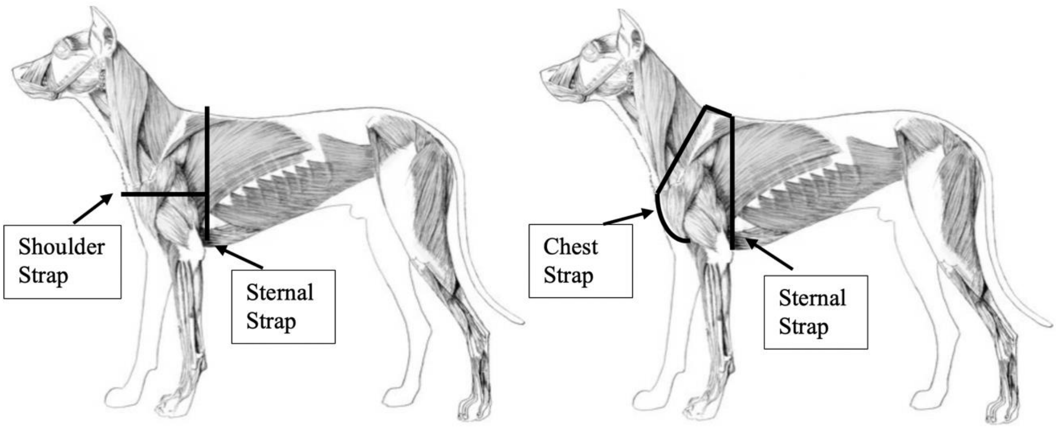
Figure 1

Harness Design	
	**A. Harness 1 (H1)** **B-handle** The points of contact of the harness shown by the arrows are much wider and laterally situated than that for the A-handle. The bend in the handle can also be noted.
	**B. Harness 2 (H2)** **A-handle** The points of contact of the harness shown by the arrow are much narrower than in the B-type handle above, shown by the arrows. There is no bend in the handle.
	**C. Harness 3 (H3)** **A-handle**

Shows the harnesses utilised throughout the study. A: Harness 1 - B handle, B: Harness 2 – A handle, C: Harness 3 – A handle.

Various studies have analysed kinematics of the canine TL and pelvic limb (PL) using joint range of movement (ROM), SL or ground reaction force (GRF) (Bertram et al. 2000; Griffin et al. 2004; Holler et al. 2010; Carr et al. 2013; Carr, et al. 2015; Volstad et al. 2016; Kopec et al. 2017). Gait is defined as limb movement typically characterised by distinctive, coordinated and repetitive movements of the feet and limbs (Decamp et al. 1997). Walk is a symmetrical gait characterised by movements at one side of the body and repeated on the other side, it is a four beat gait meaning each foot strikes the floor at an independent time and the movement is typically in a pattern of right PL, right TL, left PL, left TL (Griffin et al. 2004). Since assistance dogs for people with vision impairment are usually worked in the harness at walk, this gait pattern should be investigated, despite other gait patterns having been shown to require greater TL SL in kinematic analysis whilst not wearing a harness (Carr et al. 2015).

Figure 2



Outline of annotated harnesses superimposed over muscular anatomy of dog (Purpose Games, 2019). The dog on the reader's left shows H3 design, whilst the dog on the reader's right depicts H1 and H2 designs.

The extrapolation of findings from equine literature into equipment use and changes to the horse's locomotion and muscular contraction efficiency, supports that there is a need for further understanding of the effects of the use of the canine harness on the assistance dog's movement. The aim of this study was to investigate the influence of harness type on TL stride kinematics (TL joint ROM, TL SL) of the left TL of dogs at walk, when wearing three different working harnesses in comparison to at walk wearing a standard collar and lead.

Methods:

Animals

All study procedures were reviewed and approved by Hartpury University Ethics Committee. A convenience sample of 13 healthy, neutered (desexed) dogs, aged 15-22 months were used from an assistance dog training site. To be included in the study dogs were required to be Labrador, Golden Retriever or a cross-breed of Labrador and Golden Retriever. Dogs were required to have no past medical history of skin sensitivity and a current clear orthopaedic medical record. The weight of each dog in kilograms (kg) was provided from their records and not measured during data collection. Each dog was also examined by a Chartered Physiotherapist (Association of Chartered Physiotherapists registered, ACPAT) who undertook a physical assessment and orthopaedic examination to ensure participating dogs were healthy and sound. Throughout the study, dogs were led by their usual handler; dogs were given a period of 2 minutes to acclimatise to the study room off-lead whilst the handler was given a verbal introduction to the study. Any dogs that demonstrated stress behaviours, such as those identified by Döring et al. (2009), within the study environment or which became distressed during trials were removed from the study.

Harness design

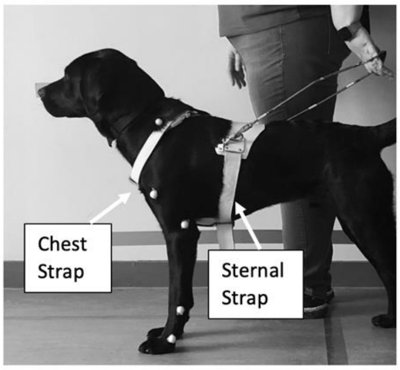
Three harnesses were used: the dog's original working harness (H3) of which all used an A-handle; and two harnesses of similar design one with a B-handle (H1) and the other an A-handle (H2) (Figure 1 and 3). The handle attachments on the harness differed between A and B, the A handle is rectangular shaped handle which fits more upright onto the dorsal aspect of the harness, whilst the B-handle is more triangular in shape fitting more laterally around the sternal chest strap (Figure 1 and 3). Although there is no current supporting research, in practice the B-handles are typically used for handlers who require more obvious interpretation of the dog's movement for safe guidance. The collar condition in this study was considered as the control comparison. Each dog's own collar, which was a standard issue leather collar, was used for standardisation. The tightness of the collar was standardised prior to data collection by ensuring two fingers fit under the collar, this is a procedure used in practice however there is no supporting evidence to underpin this. The dog’s lead was used and marked to be held between 20 and 40cm from the collar attachment allowing adequate handler control which the dog was used to from training.

Figure 3

HARNESS 1:

Y-type harness with B-HANDLE.

Lateral fitting of B handle onto harness shown.



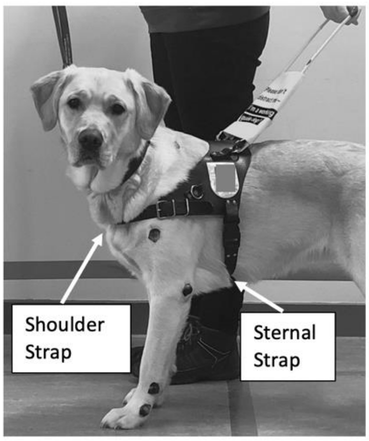
HARNESS 2:

Y-type harness with A-HANDLE.

HARNESS 3:

Original design of harness, A-HANDLE.

Dog’s own harness was used.



COLLAR:

Leather collar, standard issue.

Dog’s own was used.

Shows the harnesses utilised throughout the study in situ. A: Harness 1 - B handle, B: Harness 2 – A handle, C: Harness 3 – A handle.

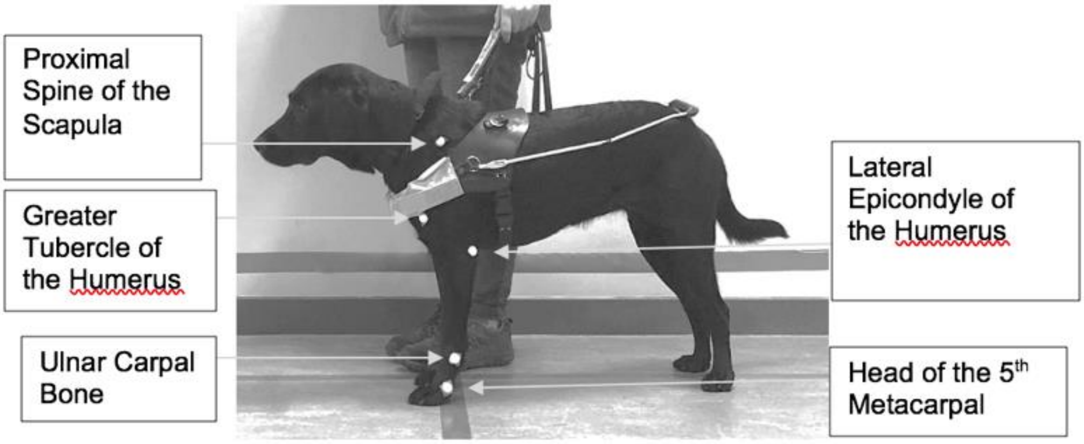
Marker placement

During this procedure the dog's humeral (median 13.00 + 1.91cm) and radial lengths (median 18.50 ± 1.51cm), and wither height (median 60.00 ± 3.21cm) were recorded by the ACPAT Chartered Physiotherapist. Polystyrene hemi-sphere markers (diameter 1 centimetre; negligible weight) were applied prior to data collection by an experienced ACPAT Chartered Physiotherapist, to optimise intra-observer reliability. Marker placement was completed in the study room following acclimatisation and using double sided tape which had been pre-prepared; this was a standardised method to minimise the effect of skin displacement on marker positioning as reported by (Kim et al. 2017). Markers were placed on the left side of the dog on the proximal aspect of the spine of the scapula, greater tubercle of the humerus, lateral epicondyle of the humerus, lateral aspect of the ulnar carpal bone and the lateral aspect of the fifth metacarpal bone in accordance with the method used in Kopec et al. (2017) (Figure 4). In reducing variability a standardised approach to marker application was used (Kim et al. 2017). To minimise marker displacement dogs with longer hair were trimmed with scissors in the marker placement areas listed above. Scissor trimming was favoured over clippers as the dogs had not been exposed to clippers previously and the study required the dogs to be relaxed (Simpson, 1997; Beerda et al. 2000; Döring et al. 2009; Grainger et al. 2016).

Experimental Design

A 2-D kinematic analysis was undertaken of each dog at walk, this was performed three times per condition, for all four conditions: H1, H2, H3 and Collar; dogs were randomised to condition exposure using a Latin Square to minimise habituation to the data collection process. Velocity was controlled for by recording the dog's natural walking speed aligning the beat of a metronome with the left TL foot strike, this was completed after the acclimatisation period when the handler walked the dog on the walkway for up to two minutes whilst the researcher timed the metronome beats to the TL foot strike. The metronome was audible throughout the study set as per Keebaugh et al. (2015), and set to the natural walking speed of the dog allowing the observer to identify any obvious changes in the dog's speed throughout each condition trial.

Figure 4



Placement of the thoracic limb markers on the dog.

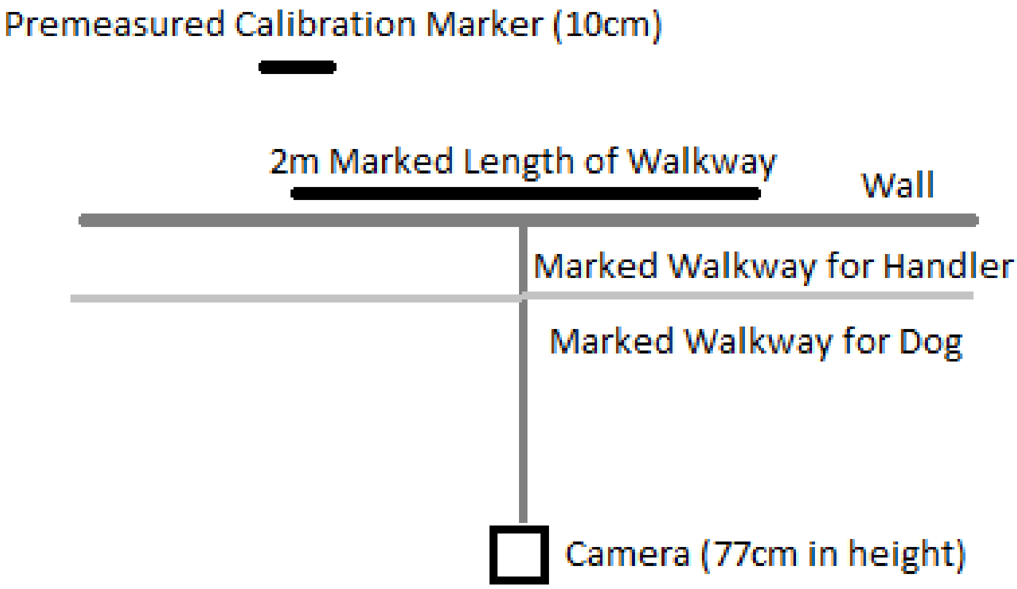
The equipment set up was calibrated and standardised across four days of data collection in order to maximise external validity of the study design. The experimental set-up was comparable to that used in previous kinematic studies (Holler et al. 2010; Millard et al. 2010; Carr et al. 2013; Kopec et al. 2017). The recording was videoed with a 12-megapixel iPhone 8 camera (Apple; Infinite Loop, Cupertino, CA) on a mounted tripod at 240 frames per second (fps) by the researcher in the sagittal plane, which differs to that used by other studies (Carr et al. 2013; Kopec et al. 2017). 240fps recording aimed to optimise visibility of subtle differences at end range TL protraction and retraction during each condition at analysis. One camera was used with a panning distance of 3.6-metres, a 2-metre length was marked centrally on the walkway for the dog's gait data to be analysed to ensure minimisation of acceleration/ deceleration alterations to movement (Walter and Carrier, 2009). Kinovea™ 2-D kinematic analysis software has been shown to have high reliability of results for sagittal plane recording in comparison to 3-D software with the limitation of inability to detect rotational movement (Schurr et al. 2017), whilst the goniometry tool has recorded high intra and inter reliability (Elrahim et al. 2016). The dog was walked on the left of the handler allowing full visibility of the left TL. Previous studies have shown that any differences in kinematic analysis measurements between right and left were non-significant (Agostinho et al. 2011).

The indoor non-slip flooring was familiar to the dogs and was marked with a walkway beside a wall for the handler whilst handling of the dogs was standardised throughout recording to minimise movement deviations (Figure 5). Dogs were walked in each condition until three satisfactory recordings were obtained for analysis during which the dogs moved at a consistent velocity, in a straight line without exaggerated head or body movements as in Kim et al. (2011a), Kim et al. (2011b), Millard et al. (2010) and Kopec et al. (2017).

Video Analysis

Videos were uploaded on to Kinovea**™** 0.8.15 (http://www.kinovea.org/) software for 2-D kinematic analysis in the sagittal plane. Joint angles were tracked throughout the video and measured at peak retraction (the point of peak carpal extension before the step through cycle of gait) and at peak protraction (the joint angles at the moment of foot contact on the floor initiating stance phase) (Gillette and Angle, 2008; Holler et al. 2010; Millis and Levine, 2013; Lafuente, Provis and Schmalz, 2018). The shoulder, elbow and carpal ROM angles were measured at each of these stages throughout the gait cycle by tracking the TL frame by frame on Kinovea™; two strides, and thus two measurements of joint angles during peak limb protraction and peak limb retraction were taken per recording. SL was defined and measured as the distance travelled between peak retraction and peak protraction of the left TL (Decamp et al. 1997; Holler et al. 2010; Carr et al. 2015; Kopec et al. 2017). For each dog, three successful trials for each condition were selected for statistical analyses, the medians and inter-quartile ranges (IQR) for shoulder, elbow, carpus ROM and SL at peak protraction and peak retraction of the TL were calculated by transferring data into a Microsoft Excel (version 14.7.7; 2011) as by Agostinho et al. (2011), Carr et al. (2013) and Kopec et al. (2017).

Figure 5



A schematic diagram of the data collection study set-up. This is not to scale.

Velocity was determined by the use of a 10cm premeasured marker on the wall behind the walkway to calibrate the distance on the video recording and was recorded in metres per second (m/s) (Kopec et al. 2017). The median velocity was calculated within participants for the three trials per condition and compared between participants.

Data Analyses

IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, N.Y., USA) was used for all statistical calculations. Data met non-parametric assumptions therefore median joint angles (shoulder, elbow and carpus) and SL were taken per trial for each dog. A series of Friedman's analyses determined if differences in joint angles and SL occurred across the cohort and within individual dogs' trials (alpha: $P<0.05$). Where significant differences existed, post-hoc Wilcoxon Signed-Rank tests were used to identify how SL and joint angles differed between the collar and harness conditions for peak protraction and peak retraction (Bonferroni adjusted alpha: P<0.02) (Winter et al. 2001).

Results

Participants

To ensure sample homogeneity, the wither height, humeral and radial lengths were recorded for each dog in centimetres (cm) using the TL surface anatomy outlined by Kopec et al. (2017) (Table 1). Measurements were taken consistently by the researcher using a tape measure and were aligned with breed standards for Golden Retrievers (GR) and Labradors (Lab) (The Kennel Club, 2019a; The Kennel Club, 2019b). This approach enabled generalisation to the wider dog population which consisted predominately of Labrador and Golden Retriever- Labrador cross breeds (Caron-Lormier et al. 2016). (Table 1).

Dog	**Age (Months)**	**Dog Breed**	**Dog Sex (M/ Male; F/Female)**	**Wither (cm)**	**Humerus (cm)**	**Radius (cm)**	**Weight (kg)**
1	16	Labrador X Golden Retriever	M	65.00	14.00	20.00	29.45
2	18	Golden Retriever X Labrador	F	62.00	12.00	18.00	29.25
3	17	Labrador	M	60.00	13.00	20.00	28.00
4	16	Labrador X Golden Retriever	M	64.00	14.00	20.50	31.70
5	22	Labrador X Golden Retriever	F	60.00	13.00	18.50	29.90
6	19	Labrador	F	57.00	10.00	18.00	22.75
7	18	Golden Retriever X Golden Retriever	F	55.00	9.50	15.50	24.10
8	16	Labrador X Golden Retriever	M	64.00	15.50	21.00	30.25
9	18	Labrador	F	56.00	15.00	17.00	29.25
10	15	Golden Retriever X Labrador	M	63.00	14.50	18.00	29.05
11	19	Labrador X Golden Retriever	F	59.50	11.00	19.00	26.70

12	18	Golden Retriever X Golden Retriever	F	58.00	12.00	19.00	26.10
13	17	Labrador	M	60.00	14.50	18.00	29.35
		MEAN		**60.27**	**12.92**	**18.65**	**28.14**
		MEDIAN		**60.00**	**13.00**	**18.50**	**29.25**
		IQR		**58-64**	**12-14.5**	**18-20**	**25.1-29.63**

The median wither height of dogs in the sample was 60.00cm (iqr 58-64), median humerus length was 13.00cm (iqr = 12-14.5), and median radius length was 18.50cm (iqr =18-20). The median weight of the dogs was 29.25kg (iqr = 25.1-29.63).

(Table 1).

Table 1: Sample Characteristics of Canine Participants; wither height (floor to highest point of scapula); humeral and radial length in centimetres; weight in kilograms.

Thoracic Limb Protraction

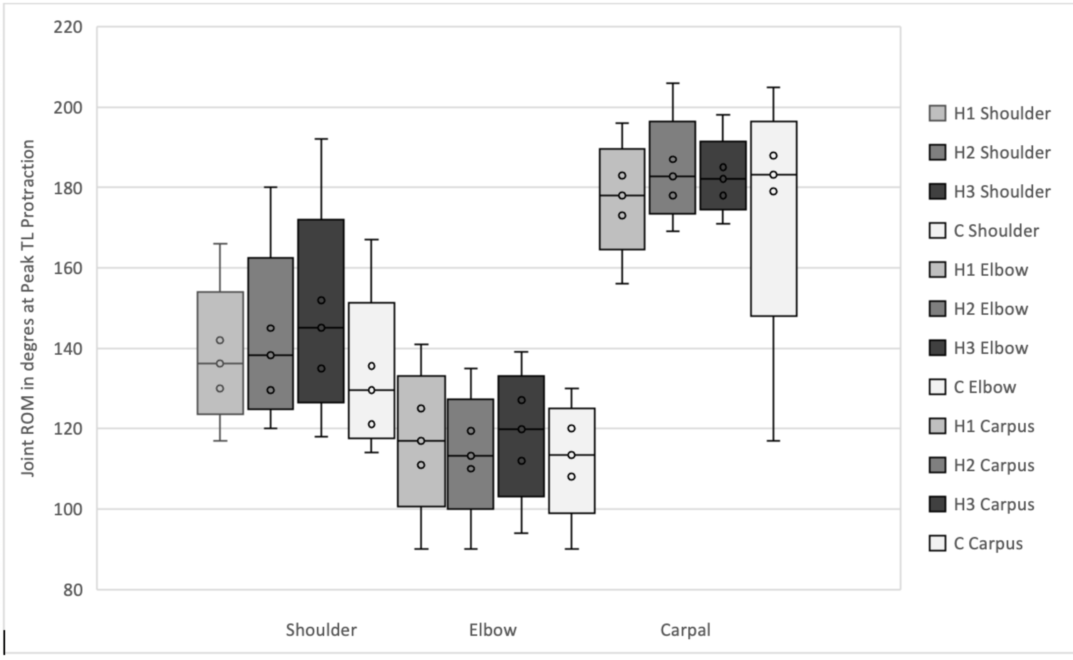
Shoulder extension in TL protraction varied across collar and harness use. Median shoulder ROM was greater in H3 (145° iqr = 135–152) and in H1 (136° iqr = 130-142) than in the Collar (130° iqr = 121-136) (Figure 6). Shoulder extension was found to be significantly reduced by 10% during TL protraction in the Collar (130° iqr = 121-136) compared to trials in H3 (145° iqr = 135–152; P = 0.0004) and by 6% in comparison to H1 (136° iqr = 130-142; P = 0.005). However no significant differences were found between the collar and H2 (P>0.05).

Elbow extension during TL protraction showed a general trend towards increased ROM in H3 (120° iqr = 112-127) in comparison to that observed in the Collar (114° iqr = 108-120), however no significant differences were observed between the conditions (P > 0.05).

Carpus ROM in TL protraction was greatest in the Collar. Median carpal recordings were significantly increased in the Collar (184° iqr = 179-188) in comparison to H1 (178° iqr = 173-183; 4%; P=0.008), but not for H2 and H3 (P >0.05).

A comparison of all joint ROM between conditions (harnesses and collar) are shown in Figure 6.

Figure 6



Shoulder, elbow and carpal joint ROM measurements in degrees at peak protraction of the left thoracic limb in harness 1 (H1), harness 2 (H2), harness 3 (H3) and collar (C). The box plot shows the maximum and minimum joint angle measurements, the median, and the first and third quartiles.

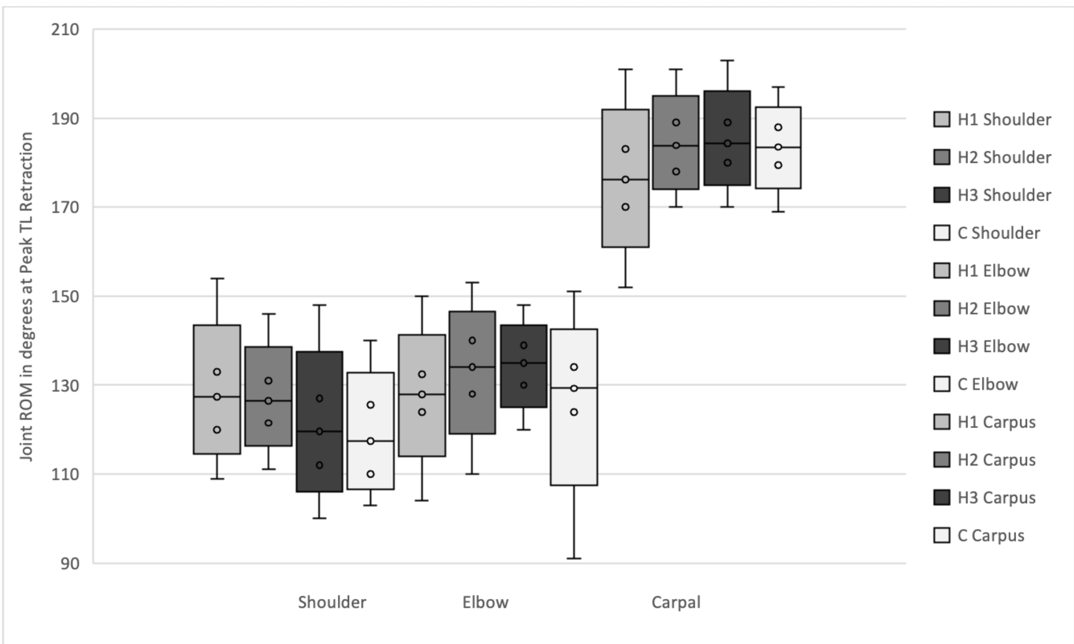
Thoracic Limb Retraction

Shoulder flexion in TL retraction varied significantly between H1 in comparison to recordings in both the Collar and H3. Median shoulder ROM in H1 (127° iqr = 120-133) was 9% greater (P= 0.0004) than shoulder flexion recorded in the Collar (117° iqr = 110-126), and 5% greater (P= 0.001) than shoulder flexion in H3 (120° iqr = 112-127). H1 demonstrated the greatest degree of shoulder flexion throughout recordings (Figure 7). No significant differences were found between H1 and H2 (P > 0.05).

Elbow extension ROM was reduced most significantly in H1 (128° iqr = 124-133) in comparison to the other harness conditions, the elbow ROM observed in H1 was not significantly different to that recorded in the Collar (129º iqr = 124-134; P > 0.05). Elbow extension ROM was 7% lower in H1, in comparison to H3 (135° iqr = 130-139; P= 0.003); and 5% lower than H2 (134° iqr = 128-140; P = 0.017) (Figure 7).

The median carpal ROM during TL retraction recorded in H1 was significantly lower (176° iqr = 170-183) than in all other conditions by 4%; Collar (183.51° iqr = 180-188; P = 0.008), H2 (184° iqr = 178-189; P= 0.005) and H3 (184° iqr = 180-189; P = 0.005) (Figure 7).

Figure 7

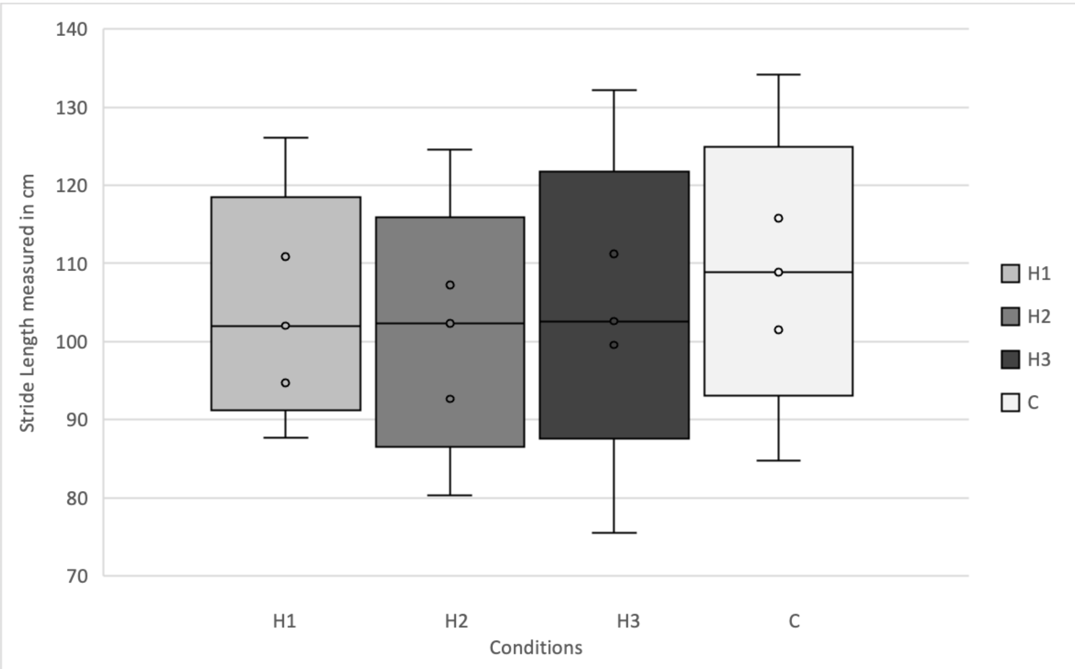


Shoulder, elbow and carpal joint ROM measurements in degrees at peak retraction of the left thoracic limb in harness 1 (H1), harness 2 (H2), harness 3 (H3) and collar (C). The box plot shows the maximum and minimum joint angle measurements, the median, and the first and third quartiles.

Thoracic Limb Stride Length

Stride length varied between conditions although this was only significantly different between the Collar and H1 conditions (P = 0.008). A significant increase in SL measurements were found in the Collar, in comparison to H1. Median SL in the Collar was recorded as 108.87cm (iqr = 101-116), and in H1 102.02cm (iqr = 95-111), however no differences were found in subsequent Wilcoxon Signed Rank test post hoc analyses (P>0.05) (Figure 8).

Figure 8



Stride length (SL) measurements (in centimetres) of the left thoracic limb at walk in harness 1 (H1), harness 2 (H2), harness 3 (H3) and collar (C). The box plot shows the maximum and minimum SL measurements, the median, and the first and third quartiles.

Speed

There were no significant differences observed within or between participants during each condition trial (P>0.05). Median speed in the collar was greatest at 0.76m/s (iqr = 0.73-0.85) whilst speed in H1 was 0.69m/s (iqr = 0.66-0.81), differences were non-significant (P = 0.114)

Discussion

Wearing a harness can influence the TL kinematics of the dog at walk, most notably H1 (with a B-handle type) resulted in the most significant restriction to TL SL and a reduction in joint ROM into TL protraction. The findings of H1 may be attributed to an alteration in peak pressures exerted through the use of the B-handle, as the same findings were not observed in H2, a similar design harness with an A-handle. Peham et al. (2013) found maximal peak pressures exerted through the 'stiffer fitting' harness studied; however this was related to the rigidity of handle attachment to the harness and did not consider the shape of the handle. Whilst the original aim of this study was to investigate whether the harness type impacted on the TL kinematics, an interesting finding emerged regarding the potential influence of the handle type associated with the harness design. Further research measuring pressure exertion would be necessary to clarify any differences between peak pressures exerted by differing handle types.

For H3 shoulder ROM in TL protraction was increased significantly in comparison to that recorded in the Collar or H1; whilst elbow extension in TL retraction was significantly greater in H3 and H2 > H1. Previous research has demonstrated a reduction in proximal joint ROM and an increase in distal joint ROM in minimising muscular effort with locomotion, and is thought to be an energy efficient adaptation (Carrier et al. 1998; Carrier et al. 2006; Carrier et al. 2008; Nielsen et al. 2003; Holler et al. 2010; Roberts and Belliveau, 2005). The findings of the current study are not supported by Lafuente, Provis and Shmalz (2018) in a study of comparably designed pet-dog harnesses; however a strength in the methodology of the current study is the sample homogeneity and standardised lead-walking training minimising variance within the sample, and maximising external validity of results. The findings of the current study show an increase in proximal joint

ROM in H3, and an increase in distal joint ROM in the collar in comparison to H1. Further 3-D kinematic analysis and EMG studies would be required in clarifying whether there is any influence of the harness conditions on energy efficient movement (Murray et al. 2013; Murray et al. 2017) and whether this is influenced by harness handle type.

In TL retraction shoulder flexion ROM was significantly greater in H1 in comparison to the collar and H3, the more laterally fitting B-handle may alter the flexibility of the harness though there is currently no literature to support this. This measurement observed in H1 is in contrast to the low shoulder ROM observed during TL protraction. In the equine field, tactile stimulators have been found to have a significant effect on increasing joint flexion and improving the flight arc during the swing phase of both the TL and PL when applied to the distal limb of the horse, with no accompanying significant increases on proximal limb joint ROM (Clayton et al. 2008; Clayton et al. 2010). It may be hypothesised that the B-handle increases the proprioceptive input to the dog from the harness, and thus the influence of this harness is comparable to that created by equine tactile stimulators, albeit proximally, on joint flexion (seen in the shoulder with TL retraction); due to the nature of the harness fit in comparison to the distal application of the tactile stimulators. In contrast to this, both the elbow and carpal ROM observed in H1 were lower than in other conditions which is likely compensatory due to the increase in proximal joint ROM which may be associated with potential for increased energy expenditure in H1.

Study limitations

Due to the size of the study room where data were collected, it was only possible to collect two complete strides of walk per dog per trial. Previous studies have ranged from 1-12 complete strides per trial in canine kinematic analysis (Holler et al. 2010; Carr et al. 2015; Kopec et al. 2017; Lafuente, Provis and Schmalz, 2018); and in equine literature considering the impact of fatigue on SL 5 strides have been used (Wickler et al. 2006).

The use of one camera for data collection may also have introduced parallax error on strides analysed that were not perpendicular to the angle of the camera as per Kim et al. (2008) whilst this was minimised by collecting data across the 2 metre walkway only. Perspective error was minimised as the calibration plane was located a small distance behind the dog's walkway (Kim et al. 2008). The introduction of these errors could create data artefacts and these may be addressed in future research with the use of more advanced recording equipment.

Prior to data collection, dogs were habituated to the unfamiliar harnesses by an acclimatisation period of 2 minutes whilst being led by their handler and observed for known stress behaviours (Simpson, 1997; Beerda et al. 2000; Döring et al. 2009; Grainger et al. 2016). No significant differences were found in joint ROM or SL recordings within dogs, suggesting the effect of a short period of habituation in dogs.

Industry application

The results of the current study show the influence of the harness conditions on the TL kinematics of the dog at walk. In H3 (original harness of each dog) the results demonstrate an increase in proximal joint ROM in comparison to the TL kinematics observed at walk in the Collar, further research would allow conclusions to be drawn as to the impact of the harness on the thoracic sling function (Carrier et al. 2008; Holler et al. 2010; Nielsen et al. 2003). Assistance dogs in the UK typically wear the harnesses for short lengths of time and thus any impact on the energy efficiency of their movement may be negated. There is currently no evidence to support the daily length of work amongst UK assistance dogs, information from The Guide Dogs for the Blind Association (2020) criteria for application for an assistance dog is for a handler to be able to walk for 'around 40 minutes' which may be suggestive of a typical length of work for a dog in the harness. These findings may however be pertinent when considering harness design choice for pet dogs who may wear the harnesses for an undefined length of time during more exerting movement and play, any reduction to their energy efficiency may elicit early onset fatigue which has been shown to increase the risk of musculoskeletal injury in humans (Small et al. 2010; Gorelick et al. 2003), horses (Boston and Nunamaker, 2000; Pinchbeck et al. 2002; Pinchbeck et al. 2004) and dogs (Yoshikawa et al. 1994). The variation in guiding a handler and walking a pet dog would require further exploration in considering any differences in canine locomotion.

The most significant restrictions to canine TL joint ROM and SL were observed in H1 in comparison to the other harness conditions; H1 and H2 harness designs were the same, except H1 had a B-handle type. It is therefore hypothesised that the reductions observed in joint ROM and SL in H1 are associated with the B-handle which secures more laterally to the harness. There is such a possibility that this may influence peak pressures exerted on the thoracic sling musculature, as when findings in equine research are extrapolated increased peak pressure elicited by the girth strap (comparable to the canine harness sternal chest strap) reduced the horses' TL SL significantly (Murray et al. 2013). In making this comparison the variation in use of this equipment and cross-species must be acknowledged.

The findings relating to the use of harnesses with the B-handle are particularly pertinent for dogs that are expected to walk daily in a harness and their good health is vital in maintaining the independence and quality of life of the handler (Calabró-Folchert, 1999). Maintaining optimal joint ROM is necessary to maximise the orthopaedic health of joints (Beraud et al. 2010; Henderson et al. 2015; Millis and Levine, 2013), particularly in the management of the breeds used within the current study which are genetically predisposed to TL orthopaedic abnormalities (Woolliams et al. 2011; Morgan et al. 1999).

Conclusion

Differences in canine locomotion were observed when walking on a collar and lead, compared to a harness and handle. When walking on a collar and lead a reduction in proximal joint ROM and increase in distal joint ROM was found. Our findings suggest the harness handle type (A or B) may result in the TL kinematic changes observed, we would therefore recommend further research utilising advanced recording equipment, 3-D kinematic analysis and EMG to allow clearer assessment of the impact of the harness handles on canine locomotion. Research may also consider comparisons with the single-bar handles from France and the US in order to evidence the optimisation of canine welfare for assistance dogs internationally.

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CONFLICT OF INTEREST STATEMENT

No conflicts of interest apply to this study.

CONTRIBUTION DISCLOSURE

Designing the project (HP; JW), reviewing the literature (HP), analysing data (HP; JW), manuscript construction and editing final article (HP;JW).

AUTHORSHIP STATEMENT

The idea for the paper was conceived by **Holly Platten**

The experiments were designed by **Holly Platten, Jane Williams**

The experiments were performed by **Holly Platten**

The data were analysed by **Holly Platten, Jane Williams**

The paper was written by **Holly Platten, Jane Williams**

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REFERENCE LIST

Agostinho, F., Rahal, S., Miqueleto, N., Verdugo, M., Inamassu, L. and El-Warrak, A., 2011. Kinematic Analysis of Labrador Retrievers and Rottweilers Trotting on a Treadmill. Vet. Comp. Orthop. Traumatol. 3, pp. 185-191.

Andriacchi, T., Koo, S. and Scanlan, S., 2009. Gait Mechanics Influence Healthy Cartilage Morphology and Osteoarthritis of the Knee. J. Bone Jt. Surg. 91 (1), pp. 95-101.

Beerda, B., Schilder, M., Bernardina, W., van Hooff, J., de Vries, H. and Mol, J., 2000. Behavioural and Hormonal Indicators of Enduring Environmental Stress in Dogs. Animal Welfare 9, pp. 49-62.

Beraud, R., Moreau, M. and Lussier, B., 2010. Effect of Exercise on Kinetic Gait Analysis of Dogs Afflicted by Osteoarthritis. Vet. Comp. Orthop. Traumatol. 23 (2), pp. 87-92.

Bertram, J., Lee, D., Case, H. and Todhunter, R., 2000. Comparison of the Trotting Gaits of Labrador Retrievers and Greyhounds. Am. J. Vet. Med. Res. 61 (7), pp. 832-838.

Besancon, M., Conzemius, M., Derrick, T. and Ritter, M. 2003. Comparison of Vertical Forces in Normal Greyhounds Between Force Platform and Pressure Walkway Measurement Systems. Vet. Comp. Orthop. Traumatol. 15, 153-157.

Boston, R. and Nunamaker, D., 2000. Gait and Speed as Exercise Components of Risk Factors Associated with Onset of Fatigue Injury of the Third Metacarpal Bone in 2-year-old Thoroughbred Racehorses. Am. J. Vet. Med. Res. 61 (6), pp. 602-608.

Calabró-Folchert, S., 1999. Aspekte Einer Besonderen Mensch-tier Beziehung in Geschichte Und Gegenwart. Dissertation Veterinärmedizinische. Justus-Liebig-Universität, Gießen, Germany. Wissenschaft und Technik Verlag., p. 424.

Caron-Lormier, G., England, G. and Asher, G., 2016. Using the Incidence and Impact of Health Conditions in Guide Dogs to Investigate Health Ageing in Working Dogs. Vet. J. 207, pp. 124-130.

Carr, J.G., Millis, D. and Weng, H., 2013. Exercises in Canine Physical Rehabilitation: Range of Motion of the Forelimb during Stair and Ramp Ascent. J. Small Anim. Pract. 54, pp. 409-413.

Carr, B., Canapp, S. and Zink, M., 2015. Quantitative Comparison of the Walk and Trot of Border Collies and Labrador Retrievers, Breeds with Different Performance Requirements. Plos One 21, pp. 1-13.

Carrier, C., Gregersen, C. and Silverton, N., 1998. Dynamic Gearing in Running Dogs. J. Ex. Biol. 201, pp. 3185-3195.

Carrier, D., Deban, S. and Fischbein, T., 2006. Locomotor Function of the Pectoral Girdle 'Muscular Sling' in Trotting Dogs. J. Ex. Biol. 209, pp. 2224-2237.

Carrier, D., Deban, S. and Fischbein, T., 2008. Locomotor Function of Forelimb Protractor and Retractor Muscles of Dogs: Evidence of Strut-like Behaviour at the Shoulder. J. Ex. Biol. 211, pp. 150-162.

Clayton, H., White, A., Kaiser, L., Nauwelaerts, S., Lavagnino, M. and Stubbs, N., 2008. Short-term Habituation of Equine Limb Kinematics to Tactile Stimulation of the Coronet. Vet. Comp. Orthop. Traumatol. 21 (3), pp. 211-214.

Clayton, H., White, A., Kaiser, L., Nauwelaerts, S., Lavagnino, M. and Stubbs, N., 2010. Hindlimb Response to Tactile Stimulation of the Pastern and Coronet. Equine Vet. J. 42 (3), pp. 227-223.

Clements, D., Owen, M., Carmichael, S. and Reid, S. 2005. Kinematic Analysis of the Gait of 10 Labrador Retrievers During Treadmill Locomotion. Vet Record 156, 478-481.

Cook, J., 2010. Cranial Cruciate Ligament Disease in Dogs: Biology Versus Biomechanics. Vet. Surg. 39 (3), pp. 270-277.

DeCamp, C., Soutas-Little, R., Hauptman, J., Olivier, B., Braden, T. and Walton, A., 1997. Kinematic gait analysis of the trot in healthy greyhounds. Am. J. Vet. Res. 54(4), pp.627-634

Döring, D., Roscher, A., Scheipl, F., Küchenhoff, H. and Erhard, M., 2009. Fear-related Behaviour of Dogs in Veterinary Practice. Vet. J. 182, pp. 38-43.

Elrahim, R., Embaby, E., Ali, M. and Kamel, R., 2016. Inter-rater and Intra-rater Reliability of Kinovea Software for Measurement of Shoulder Range of Motion. Bulletin of Physical Therapy 21 (2), pp. 80-87.

Gillette, R. and Angle, C., 2008. Recent Developments in Canine Locomotor Analysis: A Review. Vet. J. 178, pp. 165-176.

Gorelick, M., Brown, J. and Groeller, H., 2003. Short-duration Fatigue Alters Neuromuscular Coordination of Trunk Musculature: Implications For

Injury. Appl. Ergon. 34 (4), pp. 317-325.

Grainger, J., Wills, A. and Montrose, T., 2016. The Behavioural Effects of Walking on a Collar and Harness in Domestic Dogs (Canis Familiaris). J. Vet. Behav. 14, pp. 60-64.

Griffin, T., Main, R. and Farley, C., 2004. Biomechanics of Quadrupedal Walking: How Do Four-legged Animals Achieve Inverted Pendulum-like Movements? J. Ex. Biol. 207, pp. 3545-3558.

The Guide Dogs for the Blind Association, 2020. Guide Dogs: Frequently Asked Questions. URL https://www.guidedogs.org.uk/services-we-provide/guide-dogs (Accessed 03.03.20).

Henderson, A., Latimer, C. and Millis, D., 2015. Rehabilitation and Physical Therapy for Selected Orthopaedic Conditions in Veterinary Patients. Vet. Clin. North Am. Small Anim. Pract. 45 (1), pp. 91-121.

Holler, P., Brazda, V., Dal-Bianco, B., Lewy, E., Mueller, M., Peham, C. and Bockstahler, B., 2010. Kinematic Motion Analysis of the Joints of the Forelimbs and Hindlimbs of Dogs during Walking Exercise Regimens. Am. J. Vet. Res. 71, pp. 734-740.

The Kennel Club., 2019a. Border Collie Breed Standard. URL https://www.thekennelclub.org.uk/services/public/breed/standard.aspx?id=5166 (Accessed 15 Jan 2019).

The Kennel Club., 2019b. Labrador Retriever Breed Standard. URL https://www.thekennelclub.org.uk/services/public/breed/standard.aspx?id=2048 (Accessed 15 Jan 2019).

Keebaugh, A., Redman-Bentley, D. and Griffon, D. 2015. Influence of Leash Side and Handlers on Pressure Mat Analaysis of Gait Characteristics in Small-Breed Dogs. JAVMA. 11,1,pp. 1215-1221.

Kim, S., Rietdyk, S. and Breur, G., 2008. Comparison of Two-dimensional and Three-dimensional Systems for Kinematic Analysis of the Sagittal Motion of the Canine Hind Limbs during Walking. Am. J. Vet. Res. 69, pp.1116-1122.

Kim, S., Kim, J., Hayashi, K. and Kapatkin, A., 2011a. Skin Movement During the Kinematic Analysis of the Canine Pelvic Limb. Vet. Comp. Orthop. Traumatol. 24 (5), pp. 326-332.

Kim, J., Kazmierczak, K. and Breur, G., 2011b. Comparison of Temporospatial and Kinetic Variables of Walking in Small and Large Dogs on a Pressure-sensing Walkway. Am. J. Vet. Res. 72, pp. 1171-1177.

Kopec, N., Williams, J. and Tabor, G., 2017. Kinematic Analysis of the Thoracic Limb of Health Dogs During Descending Stair and Ramp Exercises. Am. J. Vet. Res. 79 (1), pp. 33-41.

Lafuente, M., Provis, L. and Schmalz, E. 2018. Effects of Restrictive and Non-Restrictive Harnesses on Shoulder Extension in Dogs at Walk and Trot. Vet Record.184 (2), 1-7.

Landsberg, G., Ackerman, L. and Hunthausen, W., 1995. Behavioural Problems of the Dog and Cat, 3rd ed. Saunders Elsevier, London.

Lee, S. and Hidler, J. 2008. Biomechanics of Overground vs. Treadmill Walking in Healthy Individuals. J. Appl. Physiol. 104 (3), 747-755.

Millard, R., Headrick, J. and Millis, D., 2010. Kinematic Analysis of the Pelvic Limbs of Healthy Dogs during Stair and Decline Slope Walking. J. Small Anim. Pract. 51, pp. 419-422.

Millis, D. and Ciuperca, I., 2015. Evidence for Canine Rehabilitation and Physical Therapy. Vet. Clin. North Am. Small Anim. Pract. 45, pp. 1-27.

Millis, D. and Levine, D., 2013. Canine Rehabilitation and Physical Therapy, 2nd ed. Saunders: Elsevier Inc, St Louis.

Morgan, J., Wind, A. and Davidson, A., 1999. Bone Dysplasias in the Labrador Retriever: A Radiographic Study. J. Am. Anim. Hosp. Assoc. 35 (4), pp. 332-340.

Murray, R., Guire, R., Fisher, M. and Fairfax, V., 2013. Girth Pressure Measurements Reveal High Peak Pressures That Can Be Avoided Using an Alternative Girth Design That Also Results in Increased Limb Protraction and Flexion in Swing Phase. Vet. J. 198, pp. 1-6.

Murray, R., Guire, R., Fisher, M. and Fairfax, V., 2017. Reducing Peak Pressures Under the Saddle Panel at the Level of the 10th to 13th Thoracic Vertebrae May Be Associated with Improved Gait Features, Even When Saddles Are Fitted to Published Guidelines. J. Equine Vet. Sci. 54, pp. 60-69.

Nielsen, C., Stover, S., Schulz, K., Hubbard, M. and Hawkins, D., 2003. Two-dimensional Link-segment Model of the Forelimb of Dogs at a Walk. Am. J. Vet. Res. 64 (5), pp. 609-617.

Pauli, A., Bentley, E., Diehl, K. and Miller, P., 2006. Effects of the Application of Neck Pressure by a Collar or Harness on Intraocular Pressure in Dogs. J. Am. Anim. Hosp. Assoc. 42 (3), pp. 207-211.

Peham, C., Limbeck, S., Galla, K. and Bockstahler, B., 2013. Pressure Distribution Under Three Different Types of Harnesses Used for Guide Dogs. Vet. J. 198, pp. 93-98.

Pinchbeck, G., Clegg, P., Proudman, C., Morgan, K. and French, N., 2002. Risk Factors and Sources of Variation in Horse Falls in Steeplechase Racing in the UK. Prev. Vet. Med. 55, pp. 179-192.

Pinchbeck, G., Clegg, P., Proudman, C., Stirk, A., Morgan, K. and French, N., 2004. Horse Injuries and Racing Practices in National Hunt Racehorses in the UK: The Results of a Prospective Cohort Study. Vet. J. 167, pp. 45-52.

Purpose Games., 2019. Muscle Anatomy of the Dog. URL https://www.purposegames.com/game/muscle-anatomy-of-the-dog-game (Accessed 19.05.2019).

Roberts, T. and Belliveau, R., 2005. Sources of Mechanical Power for Uphill Running in Humans. J. Exp. Biol. 208, pp. 1963-1970.

Schurr, S., Marshall, A., Resch, J. and Saliba, S., 2017. Two-dimensional Video Analysis Is Comparable to 3d Motion Capture in Lower Extremity Movement Assessment. Int. J. Sports Phys. 12 (2), pp. 163-172.

Simpson, B., 1997. Canine Communication. Vet. Clin. North. Am. Small Anim. Prac. 27 (3), pp. 445-464.

Small, K., McNaughton, L., Greig, M. and Lovell, R., 2010. The Effects of Multidirectional Soccer-Specific Fatigue on Markers of Hamstring Injury Risk. J. Sci. Med. Sport. 13, pp. 120-125.

Volstad, N., Nemke, B. and Muir, P., 2016. Variance Associated with the Use of Relative Velocity for Force Platform Gait Analysis in a

Heterogeneous Population of Clinically Normal Dogs. Vet. J. 207, pp. 80-84.

Walter, R. and Carrier, D., 2009. Rapid Acceleration in Dogs: Ground Forces and Body Posture Dynamics. J. Exp. Biol. 212, pp. 1930-1939.

Wickler, S., Greene, H., Egan, K., Astudillo, A., Dutto, D., Hoyt, D., 2006. Stride Parameters and Hindlimb Length in Horses Fatigued on a Treadmill and at an Endurance Ride. Equine Vet. J. Suppl. 36, 60-64.

Wilson, A., Watson, J. and Lichtwark, G., 2003. Biomechanics: A Catapult for Rapid Limb Protraction. Nature 421, p. 36.

Winter, E., Eston, R. and Lamb, K., 2001. Statistical Analyses in the Physiology of Exercise and Kinanthropometry. J. Sports. Sci. 19, pp.761-775.

Wooliams, J., Lewis, T. and Blott, S., 2011. Canine Hip and Elbow Dysplasia in UK Labrador Retrievers. Vet. J. 189 (2), pp. 169-176.

Wright, S., 2010. Girth Tensions and Their Variability While Standing and During Exercise. Comp. Exerc. Physiol. 7, pp. 141-148.

Wyche, S., 2003. The Horse's Muscles in Motion. Crowood Press Ltd., Malborough.

Yoshikawa, T., Mori, S., Santiestaban, J., Sun, T., Hafstad, E., Chen, J. and Burr, D., 1994. The Effects of Muscle Fatigue on Bone Strain. J. Exp. Biol. 188, pp. 217-238.