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RESEARCH ARTICLE

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Effect of harness design on the biomechanics of domestic dogs (*Canis lupus familiaris*)

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ABSTRACT

Harnesses have become increasingly popular and whilst there are benefits to harnesses, the impact of harness design on canine biomechanics, and thus physical health and welfare is largely unknown. The purpose of this study was to assess the effect of three popular commercially available harnesses on canine locomotion in 66 domestic dogs. Dogs were filmed moving on a loose lead over a Tekscan Strideway gait analysis system. Stride length as a proportion of limb length (calculated as distance from the elbow to the floor), body weight distribution in the front versus the hind limbs (%), and minimum and maximum apparent angles of the lateral epicondyle of humerus (LEH) and greater tubercle of humerus (GTH) during the motion cycle were measured. Except for GTH angles, there were significant differences in all the investigated metrics. Differences varied across breeds/breed types. It is recommended that, when purchasing and fitting harnesses for dogs, owners and harness fitters treat dogs on an individual basis. The impact of pulling in harness on dog gait requires investigation as dogs may experience greater restrictions when pulling than during locomotion on a loose lead.

KEYWORDS

Gait analysis; canine health and welfare; restraint device; canine locomotion; harness

Introduction

Dog ownership has increased in the UK in recent years. In 2022, 34% of households lived with a pet dog, with an estimated 13 million pet dogs in the UK (UK Pet Food, 2023). Increased engagement in physical activity by humans and dogs is a key target of medical and veterinary professionals (Degeling, Kerridge, & Rock, 2013), and the human-dog dyad is frequently reported as having benefits for human mental and physical health through increased activity and social support (Powell et al., 2018). Research also suggests that supporting physical activity for dogs may lead to a reduction in behavioural concerns (Tiira, Lohi, & Kavushansky, 2015) and problems of veterinary significance, such as obesity-related conditions (Frye, Shmalberg, & Wakshlag, 2016). There are thus many benefits to both dogs and owners from physical activity.

The prevalence of harness use in the UK

In the UK, it is a legal requirement for dogs to be under control in a public place (GOV.UK, 2023). This typically means physical management of a dog, usually by using a lead, but can also include

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responsiveness to vocal or other cues (PDSA, 2023). Leads can be attached to collars, head collars or harnesses. Research indicates that dogs may be more likely to pull in a neck collar than a head collar (Ogburn, Crouse, Martin, & Houpt, 1998) and that a neck collar may cause harm to soft tissues in the dog's neck if the dog pulls on the lead (Carter, McNally, & Roshier, 2020). Harnesses have become increasingly popular as an alternative to collars (Grainger, Wills, & Montrose, 2016). A recent survey by Carter et al. (*in prep*) found that 40% of the 1567 respondents were using a rear clip harness, whilst 30% were using a collar and lead. A number of manufacturers and bloggers are recommending harnesses as a means to achieve greater control over dogs (Alter, 2023; Company of Animals, 2023; Doyle, 2021; Puisis, 2022). A "well fitted harness" is now recommended by the Dogs Trust (Dogs Trust, 2023), and the American Kennel Club (Bauhaus, 2021) have suggested that harnesses are more appropriate than collars for walking dogs or undertaking other activities which may cause dogs to pull on the lead. Whilst manufacturers highlight the importance of the harness fitting properly (Julius, 2020), 82% of a total of 1567 dog owners said that their harness was not professionally fitted, and only 25% of owners had been given advice on their harness choice from someone/somewhere other than friends, family or social media (Carter & Williams, *in prep*).

Harnesses choices and uses within industry

Dog harness use varies widely, including for guide dogs (Peham, Limbeck, Galla, & Bockstahler, 2013), working dogs (Bray et al., 2021), sports (Pálya, Rácz, Nagymáté, Kiss, & Tomaszewska, 2022) and musculoskeletal injury support (Lawrence, 2006). However, the majority of dog owners purchase harnesses for dog and owner comfort when dog walking (Carter & Williams, *unpublished data*), as a training aid to reduce pulling (Blake, Williams, & Ferro de Godoy, 2019), to provide greater control over dogs (Pálya, Rácz, Nagymáté, Kiss, & Tomaszewska, 2022), and to prevent dogs from slipping their collars (Carter & Williams, *unpublished data*).

There are now many styles and brands of harness available for dog owners to choose between, with different harnesses being proposed as more suited to certain dogs or specific settings (Pálya, Rácz, Nagymáté, Kiss, & Tomaszewska, 2022). Harness styles can generally be classified into two main categories: Y-shape harnesses that form a Y-shape above the dog's scapula, and chest-strap harnesses with a single horizontal strap across the chest, usually sitting above the scapula (Lafuente, Provis, & Schmalz, 2019). These harnesses have front or rear attachments, or, in some cases, both. Different harness designs can cause different pressure distribution in dogs (Peham, Limbeck, Galla, & Bockstahler, 2013). Front clip harnesses can pull the harness to one side, and this may cause problems to dog musculature (Bauhaus, 2021) as can ill-fitting or otherwise inappropriate harnesses.

Impacts of harnesses on animal biomechanics

It is suggested that chest-strap harnesses may impair shoulder and thoracic limb extension more than Y-shape harnesses (Lafuente, Provis, & Schmalz, 2019) but the limited research undertaken to date has produced mixed results. A preliminary study by Lafuente, Provis, and Schmalz (2019) showed that both styles of harness resulted in significantly decreased extension of the shoulder, although Y-shape harnesses impeded shoulder extension more than chest-strap harnesses during movement on a treadmill. The authors suggest that these changes to canine gait could, over time, result in the development of shoulder muscle injury. Impact on a dog's natural gait may also be a contributing factor to degenerative joint disease and osteoarthritis, to which some breeds, such as Labrador Retrievers are more prone (Wiles, Llewellyn-Zaidi, Evans, O'Neill, & Lewis, 2017). Furthermore, long term alterations to gait can lead to repetitive strain and other injuries (Carr & Dycus, 2016). Pálya, Rácz, Nagymáté, Kiss, and Tomaszewska (2022) found changes in walking kinematics in dogs in harnesses as compared with dogs in collars. On the other hand, Kiss, Nagymáté, and Biksi (2018) found no differences between harness types on gait parameters and Weissenbacher, Tichy, Weissenbacher, and Bockstahler (2022) found no differences between guide dogs walked on a collar and those walked in a harness, although a shortened stride length was seen when the guiding handle was being used. Additional research in guide dogs has indicated changes to spinal movements in harnesses (Galla, Peham, Limbeck, & Bockstahler, 2013). Further research has been advocated to understand the impact of harnesses on gait parameters (Knights & Williams, 2021) and the impact of handling equipment on canine welfare (Cobb, Otto, & Fine, 2021).

Whilst harnesses are now widely used as restraint devices, the impact of harness design on canine biomechanics and behaviour, and thus on their physical health and welfare is largely unknown. Motion (gait) analysis enables a detailed and objective understanding of the impact of handling equipment on animals, and it has been increasingly employed within canine science (Colborne, 2007). Research into the impacts of harness-use on the biomechanics of domestic dogs has been limited and the results may have been confounded by small sample numbers (e.g., Lafuente, Provis, and Schmalz (2019) $N = 9$; Peham, Limbeck, Galla, and Bockstahler (2013) $N = 8$; 8; Weissenbacher, Tichy, Weissenbacher, and Bockstahler (2022) $N = 12$) and the use of varying breeds/breed types (Pálya, Rácz, Nagymáté, Kiss, & Tomaszewska, 2022). The purpose of this study was to assess the effect of three different harness types on the movement of dogs alongside their handler in a comparatively large sample of domestic dogs, and to investigate whether there were differences between breeds. We hypothesized that harness type would have an impact on gait parameters, and that there would be differences in recorded effects between breeds.

Methods

Study subjects

Subjects were five popular breeds of dog: Cocker Spaniels ($n = 28$), Springer Spaniels ($n = 6$), Labrador Retrievers ($n = 14$), Staffordshire Bull Terriers ($n = 6$) and French Bulldogs ($n = 4$) in addition to "mixed breed" ($n = 9$). These dogs had a range of naturally differing gaits, resulting from different conformation and body size. Dogs were recruited via promotion on the social media sites Facebook and Twitter, and e-mails to staff and students from Nottingham Trent University and Harper Adams University. Detection dogs belonging to HM Prison Service were also recruited. All dogs were aged between 1 and 10 years and their owners/handlers were asked to confirm that their dogs had no known orthopedic or neurological issues and that their dogs had been fitted with and/or were used to walking in a harness. The dogs had a mean weight of 18.99 ± 7.6 kg. Forty-one dogs were male and twenty-five were female. Data were collected over 11 days between 26/05/22 and 28/06/22 at four locations in the UK. An overview of the study dogs is provided in the supplementary materials, Table S1.

Experimental setup

Dogs were fitted with three popular, commercially available harnesses (Ruffwear Y-shape; Perfect Fit Y-shape; Julius K9 chest-strap; Figure 1). Dogs were also assessed wearing only their collar and, where they already had one, their own harness (unless the model was one of those already tested in the study). Once the dog was fitted with a harness, all measurements within that harness were taken. The order in which dogs wore the harness batches was randomized.

Stride length and body weight distribution in the front versus rear paws

A pressure sensing mat (Tekscan Strideway gait analysis system) was used to study the gait of the dogs. This is a validated means of analyzing dog gait (Carr & Dycus, 2016). The gait parameters measured included stride length and body weight distribution (%) across the front versus the back paws. As per the operating instructions, the mat was calibrated daily using a known weight (of one of the research team). Dogs were also filmed moving over the mat using four high-definition video

Figure 1. Harness types tested in the study. (from left to right: 1. Ruffwear single piece Y-shape harness with a Y-shaped chest strap sitting above the dog's shoulders. 2. Perfect Fit fully adjustable Y-shape harness (20mm) with a Y-shaped chest strap sitting above the dog's shoulders. The Perfect Fit Y-shape harness had thinner straps (20mm) than the Ruffwear Y-shape and was more open at the shoulders. 3. Julius K9 chest-strap harness with a strap sitting across the dog's shoulders).

cameras (JVC-GC P× 10HD, 300 fps, JVC, Watford, UK) placed 0.8 m meters from the mat. One camera was placed either side of the mat and one camera was placed at each end of it. To control for natural variation in limb length across the breeds, the distance from point of elbow to the mat surface (EFD) was calculated for each dog. Three stills were taken at random from the captured video footage for each dog, the length between the elbow and the point at which the paw touched the mat was measured in Kinovea Version 0.9.3 (Figure 2), and an average value for the EFD for each dog was calculated (Table 1). Stride length was calculated as a proportion of the measured EFD to enable comparison between dogs.

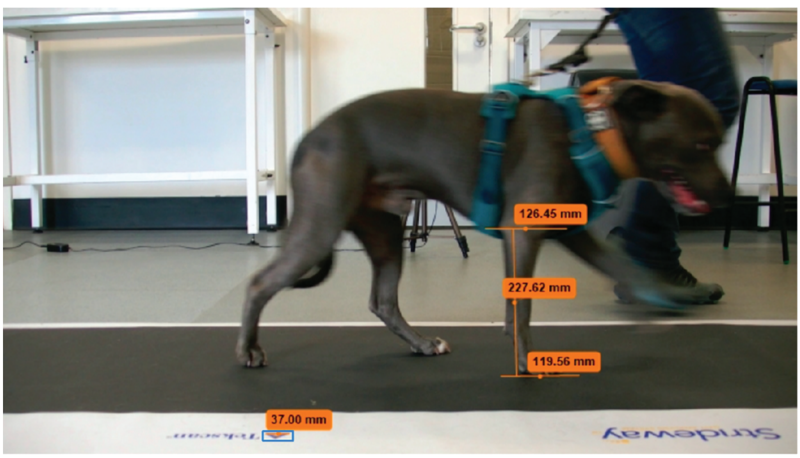

Figure 2. The length between the elbow and the point at which the paw touched the mat was measured in Kinovea Version 0.9.3. The program was calibrated against a known length on the mat (Tekscan logo, highlighted in blue). To control for differences in the distance the dog was from the camera, three stills from the video footage were taken at random and an average elbow to floor (EFD) distance (mm) was calculated from these.

Table 1. Elbow to floor distance (as measured from point of elbow to the mat surface) and stride length as a proportion of EFD by breed (mean and standard deviation).

	Elbow to floor distance (mm)		Stride length as a proportion of EFD	
	Mean	SD	Mean	SD
French Bulldog	119.29	10.89	4.51	0.74
Cocker Spaniel	182.50	26.57	3.68	0.62
Labrador Retriever	267.35	30.95	3.07	0.38
Mixed Breed	254.50	47.50	3.07	0.57
Springer Spaniel	254.87	22.92	2.94	0.50
Staffordshire Bull Terrier	222.83	43.39	3.34	0.61

In order to encourage a natural gait, dogs were given time to acclimatize to the equipment before data collection began. Dogs were then led on a loose lead at their handler's walking pace across the mat by their owner/handler, who was positioned to one side of the mat. The lead was attached to the top attachment point of each harness and no tension or pressure was applied to the lead. If a dog pulled, or left the mat, then this replicate was repeated, until five usable replicates had been taken per condition.

Apparent lateral epicondyle and greater tubercle of humerus angles during the motion cycle

Dogs were filmed for one motion cycle (defined by Fischer and Lilje (2016) as the retraction of the limb during the stance phase and the protraction during the forward swing phase). For the purposes of this study the start of the motion cycle was defined as the point when the limb furthest away from the camera was at a right angle to the floor and the foot was flat. Apparent angulation from the lateral epicondyle (Figure 3) and greater tubercle (Figure 4) of humerus angles during the motion cycle were measured using Kinovea Version 0.9.3. Anatomical landmarks were identified and labeled as per Fischer and Lilje (2016). Angles were measured on each video frame (30 frames per second) during the motion cycle. Minimum and maximum angles of all angles taken during a single motion cycle were used for analysis.

Data analysis

Data were analyzed to investigate the impact of each type of harness on the different dog breeds. Data were analyzed using gamma GLMMs to determine whether breed or harness type impacted on stride length and body weight distribution in the front versus back paws (hereafter body weight distribution). Two models were created with stride length and body weight distribution as the response variable. Harness type and breed were fitted as fixed effects. With the exception of body weight distribution, all models looked at these as interactions between the two, as in recognition of the wide variation in the dog breed types included, it was felt that it was most important to assess the impact of harness design within breed type. Body weight distribution was assessed across all the study dogs and also within breeds. Dog was fitted as a random factor to control for replicates in the analysis. Tukey corrected post hoc tests were undertaken to identify differences. Significance values were set at $p < 0.05$ for all analyses. Model results are reported as model estimate (β1) ±SE. Statistical analysis for GLMMs was undertaken in R Studio (Version 2022.07.1) (Studio Team, 2020) with a log

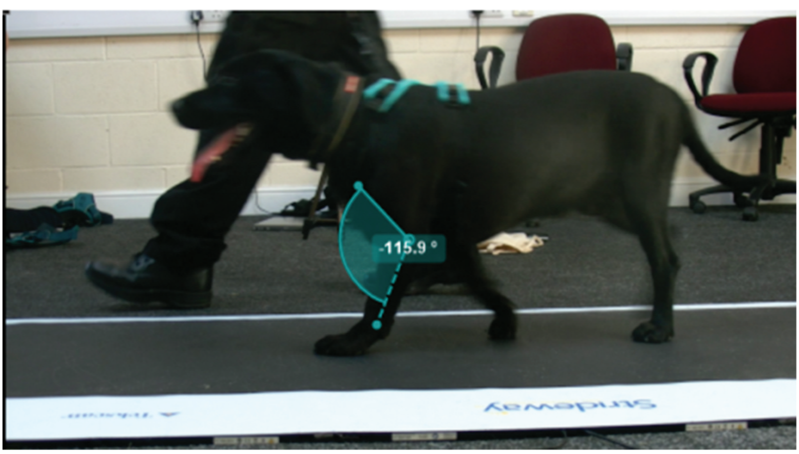

Figure 3. The lateral epicondyle of humerus angle, measured during one motion cycle, starting from when the leg furthest from the camera was perpendicular to the mat. Angles were measured in Kinovea Version 0.9.3.

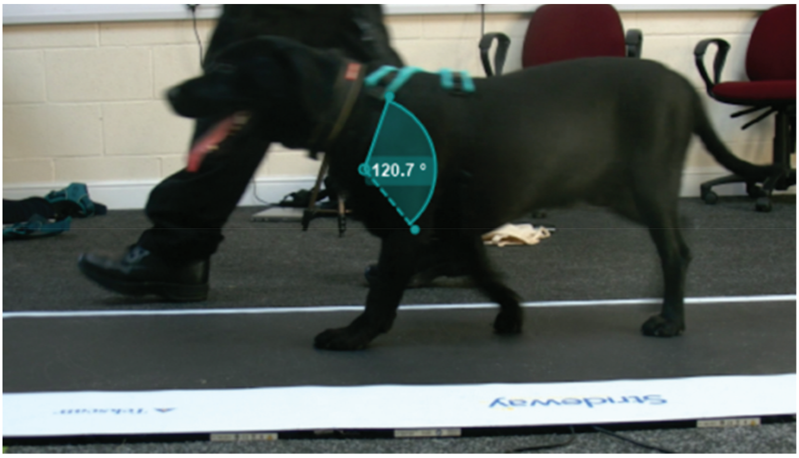

Figure 4. The greater tubercle of humerus angle, measured during one motion cycle, starting from when the leg furthest from the camera was perpendicular to the mat. Angles were measured in Kinovea Version 0.9.3.

link using "lmertest" (Kuznetsova, Brockhoff, & Christensen, 2017). Appropriateness of models was assessed using visual assessment of residuals in a residual by predictor plot and histogram of residuals. Outliers were identified using a Cook's plot and removed if appropriate. Graphs were produced using the package "ggplot2" (Wickham, 2016).

A Spearman's correlation was used to assess whether there was a relationship between body weight distribution on the fore and hindlimbs. Chi squared tests were undertaken to determine whether dogs were more front-or rear loaded in the different harnesses, and whether this differed from what would be expected by chance. Bonferroni corrected post-hoc analyses were undertaken to determine the significant differences resulting from the chi-squared analyses. Statistical analysis for other data exploration was undertaken in IBM SPSS Statistics (Version 28.0.0.0).

Results

Initially, 67 dogs were enrolled in the study, 40 pet dogs and 27 HM Prison Service detection dogs. One prison detection dog was excluded from the study due to persistent pulling on the lead over equipment and resulting inability to collect reliable loose lead movement data. Data analysis is based on the remaining 66 dogs unless stated otherwise.

Stride length

Nine dogs (eight Cocker Spaniels and one French Bulldog) were removed from the stride length analysis owing to not being able to take accurate measurements of the distance from their elbow to the floor on the cameras. No mixed breeds wore their own harnesses, so it was not possible to assess the difference between this and other harnesses. Stride length in Staffordshire bull terriers was not impacted by any of the harnesses. For all other breeds, significant differences were seen (Figure 5).

Labrador Retrievers had a shorter stride length in the Ruffwear harness than their collar (-0.039 ± 0.009, $Z = -4.599$, $p < 0.001$) and in the Perfect Fit in comparison to their collar (-0.019 ± 0.007, $Z = -2.946$, $p = 0.03$). They had a longer stride length in their collar as compared to their own harness (0.040 ± 0.010, $Z = 3.869$, $p = 0.001$) and in the Perfect Fit as compared to Ruffwear (0.020 ± 0.007, $Z = 2.897$, $p = 0.03$). Cocker Spaniels had a longer stride length in the Perfect Fit (0.038 ± 0.013, $Z = 2.866$, $p = 0.03$), Ruffwear (0.054 ± 0.015, $Z = 3.561$, $p = 0.003$) and their collar (0.065 ± 0.015, $Z = 4.418$, $p = 0.0001$) in comparison to their own harness. They had

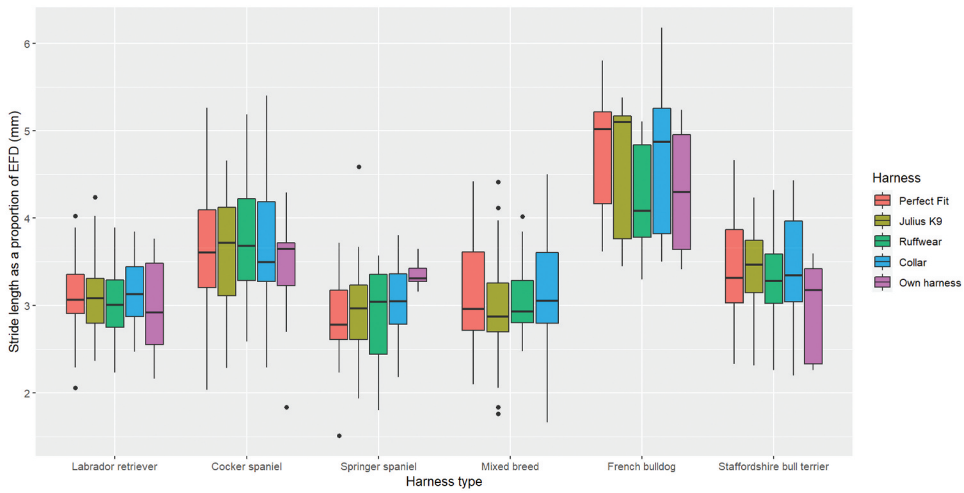

Figure 5. Stride length as a proportion of elbow to floor distance (as measured from point of elbow to the mat surface) across the study population (*n*=57 dogs).

a shorter stride length in the Julius K9 as compared to their collar (−0.034 ± 0.011, Z = −3.135, $p = 0.01$). Springer Spaniels had a significant reduction in both the Perfect Fit (−0.153 ± 0.050, Z = −3.053, $p = 0.02$) and the Ruffwear (−0.158 ± 0.050, Z = −3.141, $p = 0.01$) as compared to their own harness. They also had a shorter stride length in the Perfect Fit harness (−0.042 ± 0.011, Z = −3.812, $p = 0.001$) and the Ruffwear harness (−0.047 ± 0.014, Z = −3.269, $p = 0.01$) as compared to their collar. Mixed breeds had a longer stride length in the Perfect Fit (0.044 ± 0.012, Z = 3.570, $p = 0.003$) and the Ruffwear harnesses (0.049 ± 3.418, $p = 0.006$) as compared to the Julius K9. French Bulldogs had a significantly longer stride length in Perfect Fit than Julius K9 (0.057 ± 0.011, Z = 5.185, $p < 0.0001$), Ruffwear (0.127 ± 0.012, Z = 10.957, $p < 0.001$), their collar (0.035 ± 0.012, Z = 3.037, $p = 0.02$) and their own harness (0.195 ± 0.013, Z = 14.961, $p < 0.0001$). They also had a longer stride length in the Julius K9 than the Ruffwear (0.069 ± 0.015, Z = 4.623, $p < 0.0001$) and their own harness (0.138 ± 0.017, Z = 8.256, $p < 0.0001$). They had a longer stride length in the Ruffwear than their own harness (0.068±-0.017, Z = 3.993, $p = 0.001$), and a longer stride length in their collar than the Ruffwear (0.092 ± 0.015, Z = 5.964, $p < 0.0001$) or their own harness (0.160 ± 0.017, Z = 9.449, $p < 0.0001$).

Body weight distribution

Two data points (identified via Cook's distance as influential outliers) were removed from the body weight distribution analysis (one Cocker Spaniel in their own harness and one Springer Spaniel in their collar). There was a significant negative correlation between body weight distribution on the fore- and hindlimbs (Rs = −0.965, $p < 0.001$). Most dogs (97% observations) had greater weight distribution on the forelimbs than the hind (Figure 6). Chi squared analysis showed that Springer Spaniels had greater body weight distribution on their forelimbs more frequently than would be expected by chance ($X^2 = 57.76$, $p < 0.001$). Increased body weight distribution in their forelimbs as compared to their hindlimbs was observed more frequently than expected when dogs were moving wearing only their collar ($X^2 = 25$, $p < 0.001$). There was no difference from what would be expected by chance in terms of whether dogs had greater weight distribution on their forelimbs or hindlimbs in any of the types of harness.

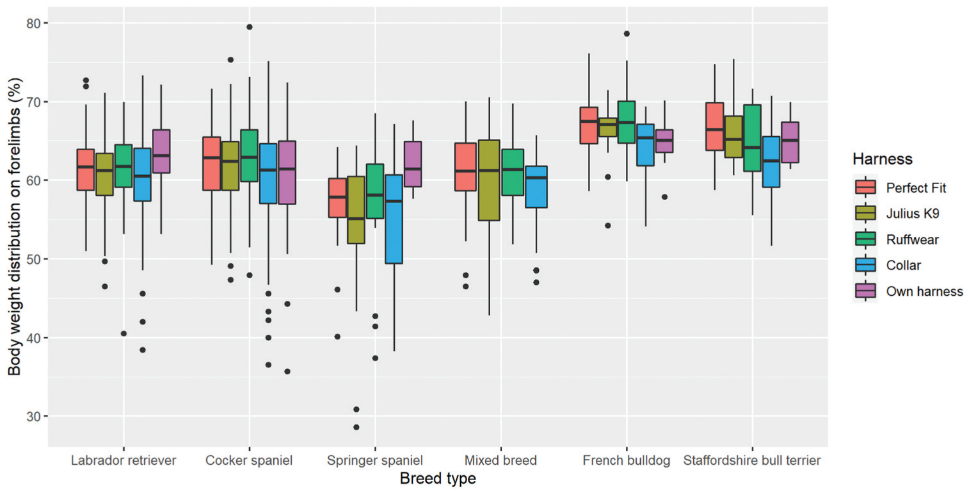

Figure 6. Impact of harness type on body weight distribution (%) across the forelimbs within dog breed (n=66 dogs).

There were significant differences in body weight distribution on the forelimbs between breeds; Springer Spaniels had lower body weight distribution on their forelimbs than Cocker Spaniels (0.097 ± 0.0.032, Z = 3.028, p = 0.03), French Bulldogs (−0.168 ± 0.046, Z = −3.644, p = 0.003) and Staffordshire Bull Terriers (−0.145 ± 0.041, Z = −3.517, p = 0.006).

Cocker Spaniels had greater body weight distribution across the forelimbs in a Perfect Fit harness as compared to their collar (0.032 ± 0.001, Z = 3.385, p = 0.006) and also in a Ruffwear harness as compared to their collar (0.044 ± 0.010, Z = 4.575. p < 0.0001). Springer Spaniels had lower body weight distribution on their forelimbs when wearing a Julius K9 harness compared to a Perfect Fit (0.057 ± 0.020, Z = 2.840, p = 0.04) and a Ruffwear harness (0.064 ± 0.020, Z = −3.234, p = 0.01). Mixed breeds had greater body weight distribution in their forelimbs when wearing a Ruffwear harness than when wearing a collar (0.046 ± 0.015, Z = 3.010, p = 0.02). Staffordshire Bull Terriers had greater body weight distribution in their front paws when wearing a Perfect Fit harness than when wearing a collar (0.061 ± 0.020, Z = 3.093, p = 0.02). There were no significant changes to body weight distribution on the forelimbs of Labrador Retrievers or French Bulldogs in any harness condition.

Apparent lateral epicondyle and greater tubercle of humerus angles during the motioncycle

Apparent minimum (min) and maximum (max) angles were calculated during one motion cycle for both the lateral epicondyle (LEH) and greater tubercle of humerus (GTH). Due to circumstances outside of the research teams' control (e.g., lighting or owner positioning), it was not possible to capture accurate data on joint angulation for all of the study dogs. As a result of this, 27 dogs were removed from the GTH analyses (14 Cocker Spaniels, 5 Labrador Retrievers, 3 Staffordshire Bull Terriers and 5 Mixed breeds) and 21 dogs were removed from the LEH analyses (12 Cocker Spaniels, 3 Labrador Retrievers, 2 Staffordshire Bull Terriers and 4 Mixed breeds). As with the stride length and body weight distribution, models used were those which included both harness and breed type.

Lateral epicondyle of humerus

For most of the breeds there was no impact of harness type on min lateral epicondyle of humerus (LEH) angle (Figure 7). The only breed that showed a difference was the Cocker Spaniel. Reduced

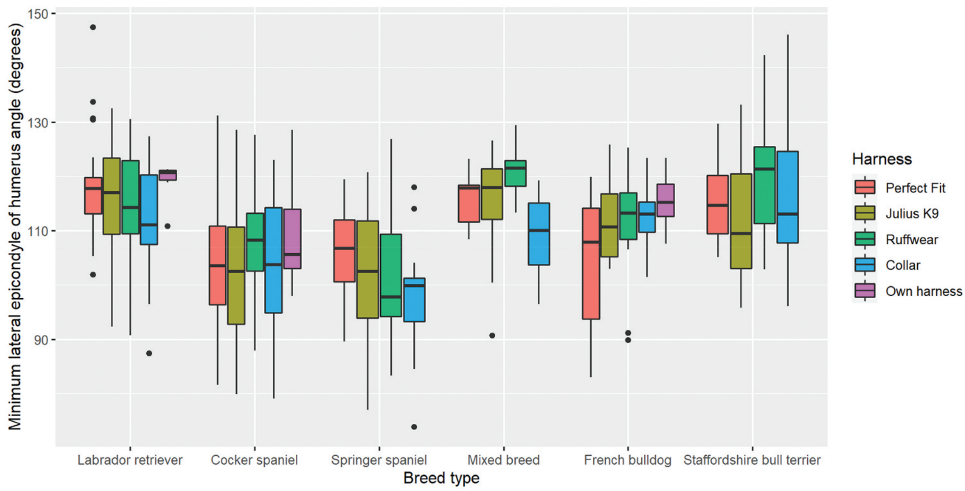

Figure 7. Minimum lateral epicondyle of humerus angle across breed types within the tested harnesses (*n*=43 dogs).

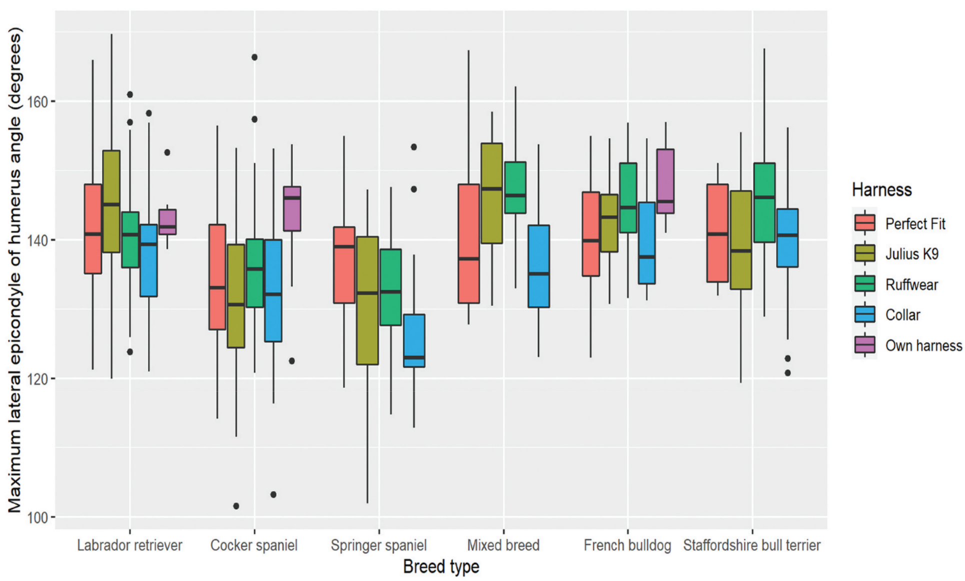

Figure 8. Maximum lateral epicondyle of humerus angle across breed types within the tested harnesses (*n*=43 dogs).

min LEH angles were seen in the Julius K9 as compared to the Ruffwear (-0.041 ± 0.013, $Z = -3.072$, $p = 0.02$). No other significant differences were seen ($p > 0.05$).

There was no change in the max LEH for Cocker Spaniels, French Bulldogs or Staffordshire Bull Terriers (Figure 8). In Labrador Retrievers the max LEH was greater in the Julius K9 than their collar (0.043 ± 0.012, $Z = 3.438$, $p = 0.005$). In Springer Spaniels their max LEH angle was greater in the Perfect Fit than in the Julius K9 harness (0.056 ± 0.018, $Z = 3.184$, $p = 0.013$) and their collar (0.080 ± 0.019, $Z = 4.223$, $p = 0.0002$). Mixed breeds had greater max LEH in the Julius K9 (0.066 ± 0.021, $Z = 3.160$, $p = 0.014$) and the Ruffwear harness (0.073 ± 0.020, $Z = 3.698$, $p = 0.002$) than their collar.

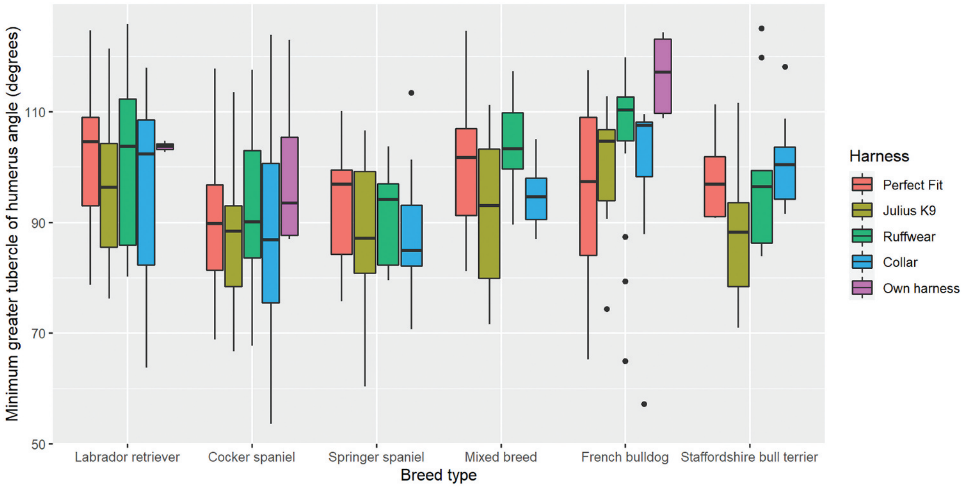

Figure 9. Minimum greater tubercle of humerus angle across breed types within the tested harnesses (n=37 dogs).

Greater tubercle of humerus

The min greater tubercle of humerus (GTH) in Cocker Spaniels and Springer Spaniels was not impacted by any of the harness types (Figure 9, $p > 0.05$). The min GTH angle in Labrador Retrievers was smaller in the Julius K9 (0.058 ± 0.020, $Z = 2.906$, $p = 0.03$) and their collar (0.063 ± 0.020, $Z = 3.069$, $p = 0.02$) than the Perfect Fit harness. The min GTH angle was smaller in the Julius K9 than the Ruffwear for mixed breed dogs (-0.110 ± 0.033, $Z = -3.293$, $p = 0.01$). French Bulldogs had a smaller min GTH angle in their collar than in the Ruffwear harness (0.107 ± 0.037, $Z = 2.917$, $p = 0.03$) or their own harness (-0.155 ± 0.048, $Z = -3.242$, $p = 0.01$). Staffordshire Bull Terriers had smaller GTH angles in the Julius K9 harness than the Perfect Fit harness (0.148 ± 0.046, $Z = 3.214$, $p = 0.01$) and their own collar (-0.152 ± 0.038, $Z = -3.988$, $p = 0.001$).

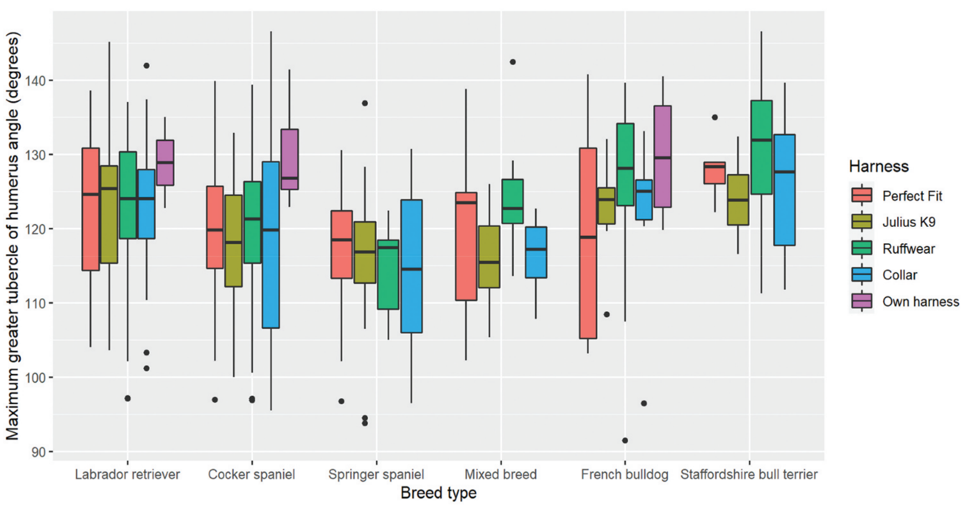

Figure 10. Maximum greater tubercle of humerus angle across breed types within the tested harnesses (n=37 dogs).

Two influential outliers (identified via Cook's distance) were removed from the max GTH data set. Analysis of the remaining data revealed there were no impacts of harness on max GTH angles through the motion cycle ($p > 0.05$; Figure 10).

Discussion

Differences were seen in body weight distribution, stride length and greater tubercle of humerus (GTH) and lateral epicondyle of humerus (LEH) estimated angulation, but this variation was not consistent across dog breeds or harness designs.

Impacts of harness design on stride length

With the exception of Staffordshire Bull Terriers, there were significant differences in stride length when dogs were wearing some of the harness designs. Cocker Spaniels and mixed breeds had a shorter stride length in the chest-strap harness than in Y-shaped harnesses or their own harness. Labrador Retrievers and Springer Spaniels were not impacted by the chest-strap harness but had a reduction in stride length in the Y-shaped harness as compared to their collar. French Bulldogs had a longer stride length in a Perfect Fit harness than in any of the other designs, or their own harness and collar. These differences suggest that the distance from the dog's elbow to the floor is a key consideration when determining the restrictive nature of different harnesses on stride length. For breeds with relatively longer limb length in relation to height to withers (Fischer & Lilje, 2016), such as retrievers and spaniels, the often-anticipated restrictive nature of the chest strap harness may be relieved by the position of the chest strap relative to the legs. This may impact the efficacy of the harness in reducing pulling or it may be that greater changes are seen when these breeds pull into this type of harness but that these changes are lost when dogs are on a loose lead. It has also been suggested that dogs may be inclined to pull into harnesses because of enhanced comfort resulting from increased distribution of pressure over the body, rather than the pressure being localised to the neck area (Shih et al., 2021). In smaller dog breeds, the shoulder blade is proportionally longer in the total forelimb measurements. The French Bulldog's shoulder blade makes up 31% of the total limb length compared to the average dog (Fischer & Lilje, 2016), affecting the relative position (i.e., comparatively higher or comparatively lower on the functional limb length) of the chest strap harness.

In addition to the short-term impact of different harness designs, consideration should also be given to the longer-term impact of altering gait through continued harness use, and the impact of pulling into the harness. Whilst research into the latter has produced mixed results, there is a lack of data pertaining to the pet dog population on a standard surface. In guide dogs, harnesses and handle angulation affected the range of movement compared to a collar and lead (Knights & Williams, 2021). Compared to walking with a collar and lead, harnesses used with a lead did not influence the stride length of twelve guide dogs. However, stride length was shortened if the Y-harness with handles was used (Weissenbacher, Tichy, Weissenbacher, & Bockstahler, 2022). Dogs walked and trotted on a treadmill had a reduced range of movement in chest-strap harnesses as compared to a Y-shaped harness, but the unnatural nature of the treadmill itself is likely to alter gait (Knights & Williams, 2021). Whilst the results of this study were not consistent across breeds, it is important to recognise that harnesses have the potential to alter canine stride length. This study supports the mixed impact of harnesses and harness design on canine gait to date (Lafuente, Provis, & Schmalz, 2019; Pálya, Rácz, Nagymáté, Kiss, & Tomaszewska, 2022; Shih et al., 2021). As has been suggested by Pálya, Rácz, Nagymáté, Kiss, and Tomaszewska (2022), it is possible that there is no "correct" harness for all dogs. Instead, it is important to consider a dog's conformation when choosing a harness, and not to assume that a particular harness most suits a specific breed of dog.

Impacts of harness design on body weight distribution

The body weight of healthy dogs is typically distributed as 60% on their fore-limbs and 40% on their hind-limbs (Carr & Dycus, 2016), although breed-level differences have been identified (Abdelhadi et al., 2013). In our study, most dogs (97% of observations) had greater weight distribution on the forelimbs than the hind-limbs. It has been suggested that the discomfort resulting from the use of harnesses can cause dogs to shift weight to their hind-end (Rosenberg, 2019) but there has been no published work to confirm this. Although we found that harness type impacted body weight distribution in some breeds, body weight distribution increased in the forelimbs, rather than the hind-limbs. In our study, Cocker Spaniels, mixed breed dogs and Staffordshire Bull Terriers increased body weight distribution on their forelimbs when wearing at least one of the Y-shaped harnesses as compared to their collar. Springer Spaniels increased body weight distribution on their forelimbs in the two Y-shaped harnesses as compared to the chest-strap design. No differences were seen in body weight distribution on the forelimbs of Labrador Retrievers and French Bulldogs. These results suggest that the shape of the harness could be a contributing factor to changes in body weight distribution in some, but not all, breeds.

Harness design and fit could impede movement and forelimb extension in dogs with certain conformations, especially if the harness sits on spinous processes or the shoulder blades. This would be similar to evidence exploring saddle fit in racehorses, where pressure on thoracic vertebrae and spinous processes affected forelimb kinematics (Murray, Mackechnie-Guire, Fisher, & Fairfax, 2019b). If this is extrapolated to dogs, it could be that some harnesses fit some dog breeds better than others, and it is the fit of the harness in relation to the shoulder blade that is impacting body weight distribution, in the same way in which it is impacting stride length. However, as has been highlighted previously, it is likely that this effect would change if dogs were pulling into the harness, where the predicted increase in body weight distribution to the hind legs may be due to the dog resisting against harness design.

Impacts of harness design on apparent joint angulation

Minimum greater tubercle of humerus (GTH) showed the greatest variation across breeds and harnesses. No changes were detected in Cocker Spaniels and Springer Spaniels, regardless of the harness being used. In Labrador Retrievers, the min GTH was lower in the Julius K9 harness than in a collar or the Perfect Fit harness. Mixed breeds had smaller GTH angles in the Julius K9 than the Ruffwear. Staffordshire Bull Terriers had a smaller min GTH angle in the Julius K9 than the Perfect Fit harness, or a collar. French Bulldogs had a smaller min GTH in a collar than when they were wearing a Ruffwear harness or their own harness. There were no impacts on max GTH in any of the breeds. Only Cocker Spaniels showed changes in min lateral epicondyle of humerus (LEH), with lower min LEH angles in the Julius K9 harness as compared to the Ruffwear harness. Changes were seen in max LEH for Labrador Retrievers, Springer Spaniels and mixed breed dogs. For Labrador Retrievers and mixed breeds, the max LEH was greater in the Julius K9 harness than in their collar. For mixed breeds the max LEH was also greater in the Julius K9 than the Ruffwear harness. Springer Spaniels had a greater max LEH in the Perfect Fit than the Julius K9 harness or their collar.

In equestrianism, the girth is a strap which is tightened around the horse's thoracic sling to hold the saddle in place. The girth is equivalent to the thoracic strap of canine harnesses. Research has demonstrated that increased peak pressures exerted by a tightened girth affects the kinematics of the thoracic limb by shortening stride length (Murray, Guire, Fisher, & Fairfax, 2013, 2017). This finding, which has been seen in some, but not all, of the dog breeds in this study, suggests some potential comparative effects between canines and equines. In horses, breastplates have also been shown to inhibit gait and shorten stride with pressure across the shoulders being greatest at maximum stride extension (Murray, Mackechnie-Guire, Fisher, & Fairfax, 2019a).

The changes in the minimum GTH and the maximum LTH for most breeds when wearing the chest-strap harness suggests that they were retracting their leg further in the motion cycle in the chest-strap harness than in the Y-shaped harness (mixed breeds) or their collar (Labrador Retrievers, Springer Spaniels and mixed breeds). However, Springer Spaniels appear to also be retracting their forelimb more in a Y-shaped harness than the chest-strap harness or their collar. It is unlikely that the increased pressure seen at maximum stride extension in horses was replicated in this study population as increases in the minimum LEH (which may reflect discomfort at maximum stride length) were not observed, and, in Cocker Spaniels, this decreased in the chest-strap harness. It was beyond the scope of this study to investigate, but the changes in apparent joint angulation could be due to the differing widths of straps, or the type of material around the strap, in the various harness designs (Blake, Williams, & Ferro de Godoy, 2019). For example, the Perfect Fit harness is made of flexible fleece fabric and nylon straps in contrast to the comparatively rigid design of the Ruffwear and Julius K9. The Perfect Fit harness comes in different strap widths, but, for the sake of consistency and also due to the build of the study dogs, Perfect Fit harnesses of the same width (20 mm) were used, and this could have altered the way the harness fitted and moved on the dog during the gait cycle, potentially influencing joint angulation (Blake, Williams, & Ferro de Godoy, 2019). The fact that changes were seen in joint angulation is an important area to consider in future research. Consistent alteration to a gait cycle may have long-term ramifications for animals, and consequently it is important to consider whether there are any factors which predict this.

Limitations and areas for future research

The main limitations in this study relate to consistency of measuring canine joint apparent angulation, and the velocity at which dogs were moving across the mat. With a view to ensuring consistency, the measurements of apparent joint angulation were made by eye by a single trained observer and as part of the analysis five measures were taken for each harness design. A marker-less method of measuring apparent joint angulation was used with a view to preventing changes to dog gait by the use of markers. There is the potential for there to be natural variation beyond that which was caused by the experimental conditions. However, a markerless method has been recognized as an appropriate noninvasive method of capturing the relevant data (Birch, Boyd, Doyle, & Pullen, 2015; Carter, Boyd, & Williams, 2022; Feeney et al., 2007; Williams, Carter, & Boyd, 2021). To ensure that dogs were moving at their handler's walking pace, handlers were asked to guide their dog across the mat at their usual "steady" pace. It is recognized that variation in breed types and limb length could result in different locomotory velocities and gaits. Whilst a difference in velocity in each replicate may have had a minor impact on the results, to ensure consistency, dogs were guided by their handler at their handler's natural walking pace. All dogs wore the same harness designs and dog was included as a random factor in statistical modeling, thus limiting the impact on the results of the work. This study specifically sought to understand the impact of harness design on dogs moving on a loose lead, and to develop methodologies to reliably measure this impact. Since we know that collars are potentially harmful for dogs that pull (Carter, McNally, & Roshier, 2020), determining the safest means of controlling them is important. One study found that 82.7% of U. K. and Irish dog owners surveyed owned dogs which pull on the lead (Townsend, Dixon, & Buckley, 2022), which may change the relationship between the dog and the owner and the desire for owners to walk their dog (Westgarth, Christley, & Christian, 2014). It is likely that many dog owners purchase harnesses to help them to reduce the impact of the dog pulling (Townsend, Dixon, & Buckley, 2022). Research in guide dogs has shown the importance of the angle of the handle between the dog harness and the guide dog handler (Weissenbacher, Tichy, Weissenbacher, & Bockstahler, 2022). The action of pulling may lead to uneven pressure distribution, especially if dogs consistently walk on one side of the handler (Weissenbacher, Tichy, Weissenbacher, & Bockstahler, 2022). An important next step for research is to study dogs that pull and to consider the attachment point between the lead and the harness, the height of the handler and the corresponding angle of lead attachment. The purpose of this research would be to determine whether these factors are impacting the dogs experience of moving in the harness.

This study did not investigate the pressure of the harness on different parts of the dog. It only focused on alterations to gait parameters and pressure distribution through the front legs. Different harnesses are likely to cause different pressures for different dogs, and it could be this that led to alterations in joint angulation as dogs adapted their behaviour to the restriction of the harness. It is possible that the alterations to gait were a product of the experimental environment. However, consistency was maintained as to the environment and all harness designs, so this finding is unlikely. This study aimed to capture the response of dogs to different harness constraints in a controlled environment, but in a setting where dogs were not altering their gait to cope with the underlying movement of treadmills. It is recommended that, in future work, consideration is given to measurement of pressure distribution on the body of the dog, to determine whether all dog breeds are affected in the same way, whether they respond to altered pressure in the same way and whether this is affected by the type of restraint device they are wearing (e.g., collar, harness, headcollar). It is further recommended that this type of work is undertaken in natural environments, such as by marker-less analytical systems, to capture "natural" gait.

Another limitation was the variety of shape, size and conformation of available dogs and breeds enrolled for this study, including "mixed breed" dogs, which may have impacted the results. This is representative of real-life variation in terms of canine confirmation, even within-breed, and is important to consider in research studies moving forwards. Ideally, the sample sizes in this study could have been larger to provide greater statistical power. It is important to capture breed variation in order to understand the impacts on dogs at an individual level. We controlled for variety by calculating stride length as a proportion of the distance from the point of elbow to the mat surface, and by including dog as a random factor in analytical models to control for individual variability. Whilst there are many recommendations arising from this work, the primary one is to consider dogs as individuals, and to assess their specific needs in relation to harness design. It is therefore recommended that future work captures more detailed physiological data and assesses how this relates to the suitability of harness design for the individual dog.

Conclusion

Differences were seen in stride length, body weight distribution and GTH and LEH estimated angulation, but this variation was not consistent across dog breeds or harness types. Harnesses have certain natural advantages over neck collars in that they can remove pressure from the dog's neck. However, based on the findings of this study, it is recommended that owners and harness fitters treat dogs on an individual basis, with consideration being given to age, breed conformation, predisposition to injury, musculoskeletal impairments, and the harness functionality. Factors which may affect the impact of harnesses on dogs could include pulling or, for assistance dogs, to be in a particular position in relation to the handler. It is recommended that research is undertaken in respect of dogs which are pulling into the harness and for the removal of blanket recommendations on harness types.

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Data availability statement

Data is available from the corresponding author upon reasonable request.

Ethics

This research project was approved by the Harper Adams University ethics committee (0321–202203-STAFF) and received favorable approval from the Nottingham Trent University School of Animal, Rural and Environmental Sciences ethics committee (application #. ARE212239). All owners/handlers gave written permission for their dogs to be involved in the research.

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