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Knights, Holly; Williams, J. M.

Published in:

Journal of Veterinary Behavior: Clinical Applications and Research

Publication date:

2021

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The final published version is available direct from the publisher website at:
[10.1016/j.jveb.2021.05.011](https://doi.org/10.1016/j.jveb.2021.05.011)

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Citation for published version (APA):

Knights, H., & Williams, J. M. (2021). The Influence of Three Working Harnesses on Thoracic Limb Kinematics and Stride Length at Walk in Assistance Dogs. *Journal of Veterinary Behavior: Clinical Applications and Research*, 45, 16-24. <https://doi.org/10.1016/j.jveb.2021.05.011>

1

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

4

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19 **Abstract:**

20

21 Studies have investigated the kinematics of the healthy canine thoracic limb
22 (TL), but there is currently no research to the authors' knowledge investigating
23 the influence of the working harness on TL kinematics. The aim of this study
24 was to compare the TL stride length (SL) and shoulder, elbow and carpal joint
25 range of movement (ROM) of assistance dogs when wearing three different
26 harnesses (H1 and H2 Y-shaped harnesses; H3 the dog's original harness)
27 with differing handle designs (A and B type handles; all dogs used an A type
28 handle with H3, their original harness), in comparison to a standard collar at
29 walk. Thirteen dogs were analysed at walk in each condition: Harness 1, H1
30 (B-handle); Harness 2, H2 (A-handle); Harness 3, H3 (A-handle, and the
31 dog's original working harness); and the Collar with the lead held between 20-
32 40cm. A series of Friedman's analyses with post-hoc Wilcoxon Signed Rank
33 tests compared SL and joint ROM at peak protraction and retraction of the TL.
34 *Results:* The results show significant TL kinematic changes in H1 (B-handle):
35 SL in H1 was significantly reduced in comparison to the Collar (6%; $P=0.008$).
36 In TL protraction, a significant reduction in shoulder extension was recorded
37 for H1 in comparison to H3 (6%; $P=0.005$). In TL retraction, a significant
38 reduction in carpal extension was observed in H1 in comparison to the collar
39 (4%; $P=0.008$), H2 (2%; $P=0.005$) and H3 (4%; $P=0.005$). *Conclusions:*
40 Differences in canine locomotion were observed between conditions in
41 comparison to when the dog was at walk in the collar. Our findings suggest
42 the harness handle type may result in the TL kinematic changes observed.
43 Significant TL SL and ROM restrictions were noted in H1, the only harness in
44 the study with a specific handle design (B-handle type). The increase in
45 proximal TL joint ROM and a subsequent reduction in distal TL joint ROM
46 suggests an alteration to the energy efficiency of locomotion when compared
47 to previous literature. These results were seen only in H1 and not H2, a
48 similar design of harness, therefore suggesting the B-handle type may be the
49 key factor in the kinematic changes observed.

50

51 **Keywords:**

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

53 **Introduction**

54 Assistance dogs that guide the vision impaired are highly specialised dogs
55 (Calabró-Folchert, 1999) whose movements are communicated, detected and
56 interpreted by their handler through a harness and handle (Peham et al. 2013)
57 (Figure 1). An average working life for these dogs is typically 8.5 years, whilst
58 16% of the dogs are retired early due to health conditions, 28% of these are
59 due to musculoskeletal disease (Caron-Lormier et al. 2016). For working dogs
60 it is important to optimise musculoskeletal health by ensuring joints and soft
61 tissues are able to function optimally as the presence of any degree of
62 immobilisation could potentially impact on function resulting in joint
63 inflammation, impaired synthesis of joint cartilage and cartilage degradation
64 over time (Andriacchi et al. 2009; Cook, 2010; Millis and Ciuperca, 2015). The
65 maintenance of normal movement patterns can minimise compensatory
66 movement and has been shown to reduce the risk of injury (Fischer et al.
67 2013). Therefore, to optimise the musculoskeletal health and maximise the
68 longevity of working life for these assistance dogs, it is beneficial to reduce
69 the impact of any degree of immobilisation caused by equipment used during
70 locomotion, such as the harness and handle.

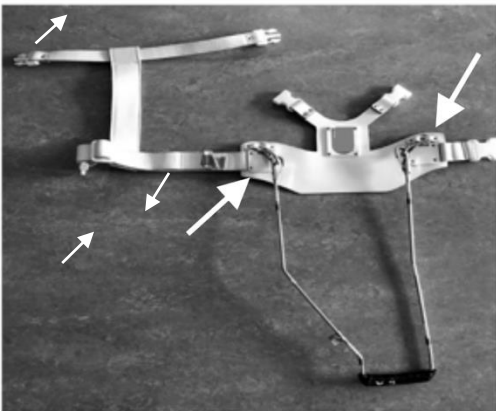
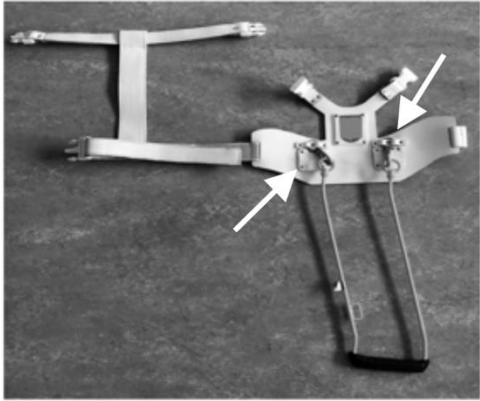

71

72 The use of a harness has been anecdotally proposed to improve canine
73 welfare in comparison to the use of a collar and lead, which is considered to
74 exert increased and potentially damaging pressure on the dog's neck and
75 throat if the dog pulls (Pauli et al. 2006; Landsberg et al. 2013; Grainger et
76 al. 2016). However, few studies to date have investigated the physical
77 effects of collar or harness use in pet or assistance dogs. Shoulder range of
78 movement (ROM) has been investigated in harness and collar by Lafuente,
79 Provis and Schmalz (2018) however this was a treadmill study, thus the
80 kinematic findings may not be comparable to gait on land. The standard
81 harness used with assistance dogs is designed to lie over the TL proximal
82 musculature (Figure 2). These muscles are responsible for locomotion of the
83 TL and postural stability in weight bearing and weight transfer (Millis and
84 Levine, 2013). Peham et al. (2013) reported that a working harness
85 (comparable to H3 in this study, Figure 1) produced asymmetrical pressures

86 over the dog's sternal region secondary to the unilaterality of the handler.
87 This results from the dogs most commonly being led on the left of the
88 handler. In the equine literature, the girth which fixes the saddle in place, is
89 comparable to the position of the sternal chest strap of the canine harness.
90 The pressures exerted by the horses' girth have been shown to have a direct
91 effect on the horses' TL kinematics, with increased peak pressure of the
92 girth there is a subsequent reduction in the TL SL (Wyche, 2003; Wright,
93 2010; Murray et al. 2013; Murray et al. 2017). The equine and canine TL are
94 similar in their reliance on extrinsic musculature at the shoulder for body
95 weight support, transmission and economical movement (Wilson et al. 2003;
96 Carrier et al. 2006). The effect of harness design and the impact of its
97 influence on TL kinematics therefore requires further investigation to
98 optimise our understanding of how it functions and promote evidence-based
99 practice in this field.

100

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

Harness Design	
	<p>A. Harness 1 (H1) B-handle</p> <p>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.</p>
	<p>B. Harness 2 (H2) A-handle</p> <p>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.</p>
	<p>C. Harness 3 (H3) A-handle</p>

112

113 **Figure 1** Shows the harnesses utilised throughout the study. A: Harness 1 -

114 B handle, B: Harness 2 – A handle, C: Harness 3 – A handle

115

116 Various studies have analysed kinematics of the canine TL and pelvic limb

117 (PL) using joint range of movement (ROM), SL or ground reaction force

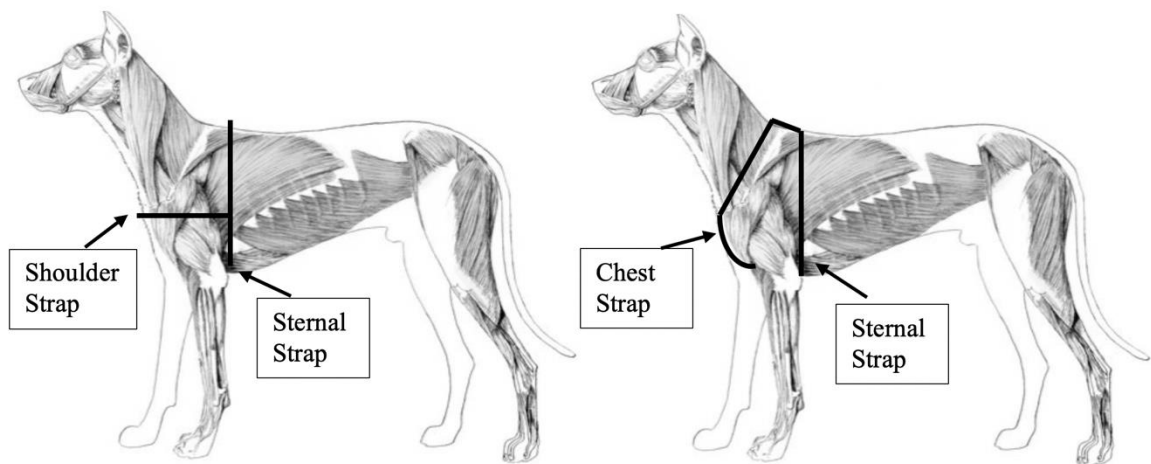
118 (GRF) (Bertram et al. 2000; Griffin et al. 2004; Holler et al. 2010; Carr et al.

119 2013; Carr, et al. 2015; Volstad et al. 2016; Kopec et al. 2017). Gait is

120 defined as limb movement typically characterised by distinctive, coordinated

121 and repetitive movements of the feet and limbs (Decamp et al. 1997). Walk
122 is a symmetrical gait characterised by movements at one side of the body
123 and repeated on the other side, it is a four beat gait meaning each foot
124 strikes the floor at an independent time and the movement is typically in a
125 pattern of right PL, right TL, left PL, left TL (Griffin et al. 2004). Since
126 assistance dogs for people with vision impairment are usually worked in the
127 harness at walk, this gait pattern should be investigated, despite other gait
128 patterns having been shown to require greater TL SL in kinematic analysis
129 whilst not wearing a harness (Carr et al. 2015).

130
131



132
133

134 **Figure 2** Outline of annotated harnesses superimposed over muscular
135 anatomy of dog (Purpose Games, 2019). The dog on the reader's left shows
136 H3 design, whilst the dog on the reader's right depicts H1 and H2 designs.

137

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

146

147 **Methods:**

148 **Animals**

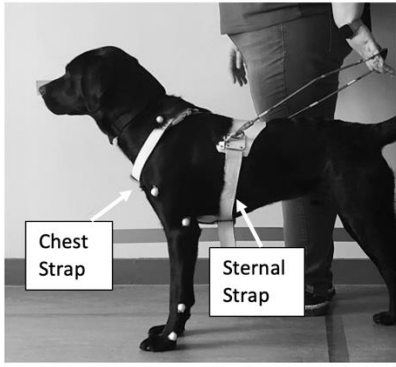



149 All study procedures were reviewed and approved by Hartpury University
150 Ethics Committee. A convenience sample of 13 healthy, neutered (desexed)
151 dogs, aged 15-22 months were used from an assistance dog training site. To
152 be included in the study dogs were required to be Labrador, Golden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

166

167 **Harness design**

168 Three harnesses were used: the dog's original working harness (H3) of
169 which all used an A-handle; and two harnesses of similar design one with a
170 B-handle (H1) and the other an A-handle (H2) (Figure 1 and 3). The handle
171 attachments on the harness differed between A and B, the A handle is
172 rectangular shaped handle which fits more upright onto the dorsal aspect of
173 the harness, whilst the B-handle is more triangular in shape fitting more
174 laterally around the sternal chest strap (Figure 1 and 3). Although there is no
175 current supporting research, in practice the B-handles are typically used for
176 handlers who require more obvious interpretation of the dog's movement for
177 safe guidance. The collar condition in this study was considered as the
178 control comparison. Each dog's own collar, which was a standard issue

179 leather collar, was used for standardisation. The tightness of the collar was
 180 standardised prior to data collection by ensuring two fingers fit under the
 181 collar, this is a procedure used in practice however there is no supporting
 182 evidence to underpin this. The dog's lead was used and marked to be held
 183 between 20 and 40cm from the collar attachment allowing adequate handler
 184 control which the dog was used to from training.

<p>HARNESS 1:</p> <p>Y-type harness with B-HANDLE.</p> <p>Lateral fitting of B handle onto harness shown.</p>	<p>HARNESS 2:</p> <p>Y-type harness with A-HANDLE.</p>
	
<p>HARNESS 3:</p> <p>Original design of harness, A-HANDLE.</p> <p>Dog's own harness was used.</p>	<p>COLLAR:</p> <p>Leather collar, standard issue.</p> <p>Dog's own was used.</p>
	

185
 186 **Figure 3** Shows the harnesses utilised throughout the study in situ. A:
 187 Harness 1 - B handle, B: Harness 2 – A handle, C: Harness 3 – A handle

188

189 **Marker placement**

190 During this procedure the dog's humeral (median 13.00 + 1.91cm) and radial
 191 lengths (median 18.50 ± 1.51cm), and wither height (median 60.00 ±

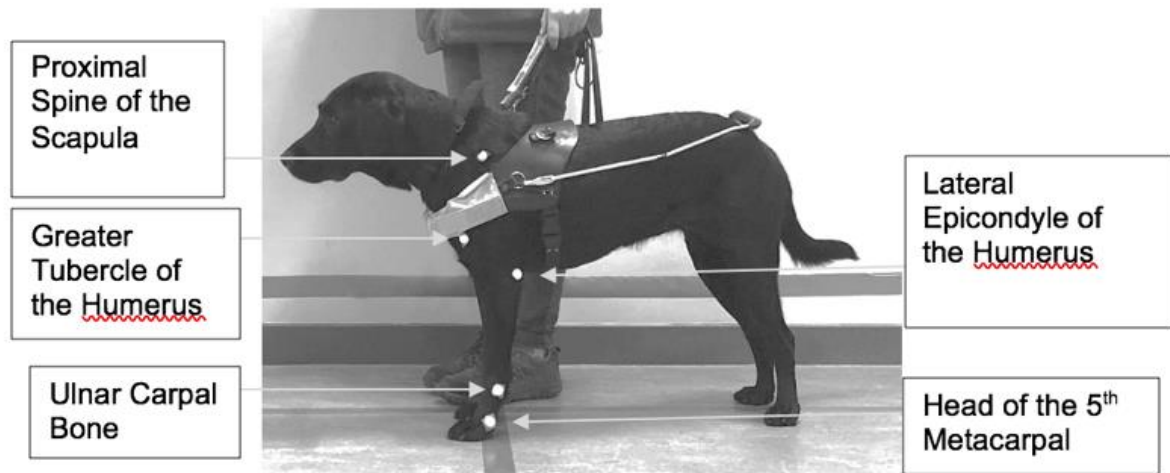
192 3.21cm) were recorded by the ACPAT Chartered Physiotherapist.
193 Polystyrene hemi-sphere markers (diameter 1 centimetre; negligible weight)
194 were applied prior to data collection by an experienced ACPAT Chartered
195 Physiotherapist, to optimise intra-observer reliability. Marker placement was
196 completed in the study room following acclimatisation and using double
197 sided tape which had been pre-prepared; this was a standardised method to
198 minimise the effect of skin displacement on marker positioning as reported
199 by (Kim et al. 2017). Markers were placed on the left side of the dog on the
200 proximal aspect of the spine of the scapula, greater tubercle of the humerus,
201 lateral epicondyle of the humerus, lateral aspect of the ulnar carpal bone and
202 the lateral aspect of the fifth metacarpal bone in accordance with the method
203 used in Kopec et al. (2017) (Figure 4). In reducing variability a standardised
204 approach to marker application was used (Kim et al. 2017). To minimise
205 marker displacement dogs with longer hair were trimmed with scissors in the
206 marker placement areas listed above. Scissor trimming was favoured over
207 clippers as the dogs had not been exposed to clippers previously and the
208 study required the dogs to be relaxed (Simpson, 1997; Beerda et al. 2000;
209 Döring et al. 2009; Grainger et al. 2016).

210

211 **Experimental Design**

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

224



226

227

Figure 4 Placement of the thoracic limb markers on the dog.

228

229 The equipment set up was calibrated and standardised across four days of
 230 data collection in order to maximise external validity of the study design. The
 231 experimental set-up was comparable to that used in previous kinematic
 232 studies (Holler et al. 2010; Millard et al. 2010; Carr et al. 2013; Kopec et al.
 233 2017). The recording was videoed with a 12-megapixel iPhone 8 camera
 234 (Apple; Infinite Loop, Cupertino, CA) on a mounted tripod at 240 frames per
 235 second (fps) by the researcher in the sagittal plane, which differs to that
 236 used by other studies (Carr et al. 2013; Kopec et al. 2017). 240fps recording
 237 aimed to optimise visibility of subtle differences at end range TL protraction
 238 and retraction during each condition at analysis. One camera was used with
 239 a panning distance of 3.6-metres, a 2-metre length was marked centrally on
 240 the walkway for the dog's gait data to be analysed to ensure minimisation of
 241 acceleration/ deceleration alterations to movement (Walter and Carrier,
 242 2009). Kinovea™ 2-D kinematic analysis software has been shown to have
 243 high reliability of results for sagittal plane recording in comparison to 3-D
 244 software with the limitation of inability to detect rotational movement (Schurr
 245 et al. 2017), whilst the goniometry tool has recorded high intra and inter
 246 reliability (Elrahim et al. 2016). The dog was walked on the left of the handler
 247 allowing full visibility of the left TL. Previous studies have shown that any
 248 differences in kinematic analysis measurements between right and left were
 249 non-significant (Agostinho et al. 2011).

250

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

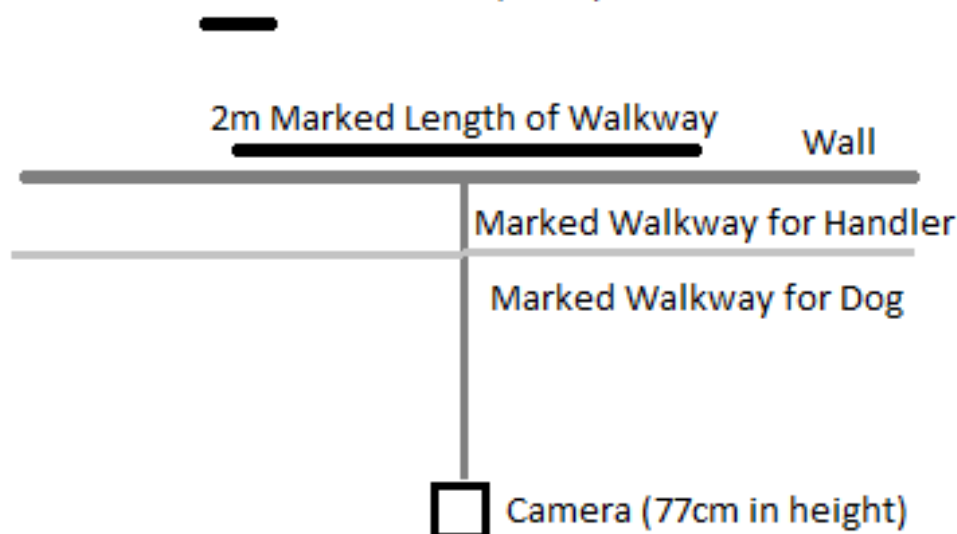
259

260 **Video Analysis**

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

280

Premeasured Calibration Marker (10cm)



281

282 **Figure 5** A schematic diagram of the data collection study set-up. This is not
283 to scale.

284

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

290

291 **Data Analyses**

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

302

303 **Results**

304 **Participants**

305 To ensure sample homogeneity, the wither height, humeral and radial
306 lengths were recorded for each dog in centimetres (cm) using the TL surface
307 anatomy outlined by Kopec et al. (2017) (Table 1). Measurements were
308 taken consistently by the researcher using a tape measure and were aligned
309 with breed standards for Golden Retrievers (GR) and Labradors (Lab) (The
310 Kennel Club, 2019a; The Kennel Club, 2019b). This approach enabled
311 generalisation to the wider dog population which consisted predominately of
312 Labrador and Golden Retriever- Labrador cross breeds (Caron-Lormier et al.
313 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

314 The median wither height of dogs in the sample was 60.00cm (iqr 58-64),
315 median humerus length was 13.00cm (iqr = 12-14.5), and median radius
316 length was 18.50cm (iqr =18-20). The median weight of the dogs was
317 29.25kg (iqr = 25.1-29.63).

318 (Table 1).

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

322

323

324

325 **Thoracic Limb Protraction**

326 Shoulder extension in TL protraction varied across collar and harness use.

327 Median shoulder ROM was greater in H3 (145° iqr = 135–152) and in H1

328 (136° iqr = 130-142) than in the Collar (130° iqr = 121-136) (Figure 6).

329 Shoulder extension was found to be significantly reduced by 10% during TL

330 protraction in the Collar (130° iqr = 121-136) compared to trials in H3 (145°

331 iqr = 135–152; P = 0.0004) and by 6% in comparison to H1 (136° iqr = 130-

332 142; P = 0.005). However no significant differences were found between the

333 collar and H2 (P>0.05).

334

335 Elbow extension during TL protraction showed a general trend towards

336 increased ROM in H3 (120° iqr = 112-127) in comparison to that observed in

337 the Collar (114° iqr = 108-120), however no significant differences were

338 observed between the conditions (P > 0.05).

339

340 Carpus ROM in TL protraction was greatest in the Collar. Median carpal

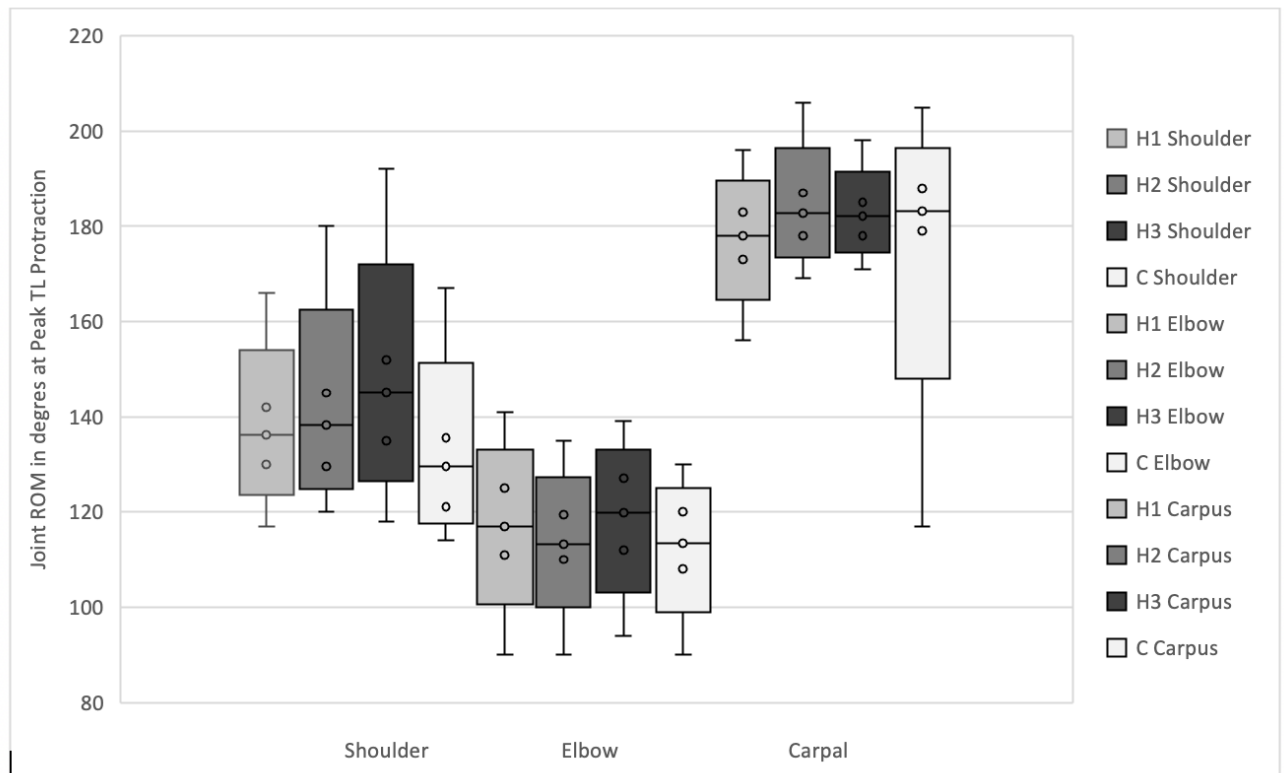
341 recordings were significantly increased in the Collar (184° iqr = 179-188) in

342 comparison to H1 (178° iqr = 173-183; 4%; $P=0.008$), but not for H2 and H3
343 ($P >0.05$).

344

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

347



348

349 **Figure 6** Shoulder, elbow and carpal joint ROM measurements in degrees at
350 peak protraction of the left thoracic limb in harness 1 (H1), harness 2 (H2),
351 harness 3 (H3) and collar (C). The box plot shows the maximum and minimum
352 joint angle measurements, the median, and the first and third quartiles.

353

354 Thoracic Limb Retraction

355 Shoulder flexion in TL retraction varied significantly between H1 in
356 comparison to recordings in both the Collar and H3. Median shoulder ROM
357 in H1 (127° iqr = 120-133) was 9% greater ($P= 0.0004$) than shoulder flexion
358 recorded in the Collar (117° iqr = 110-126), and 5% greater ($P= 0.001$) than
359 shoulder flexion in H3 (120° iqr = 112-127). H1 demonstrated the greatest

360 degree of shoulder flexion throughout recordings (Figure 7). No significant
361 differences were found between H1 and H2 ($P > 0.05$).

362

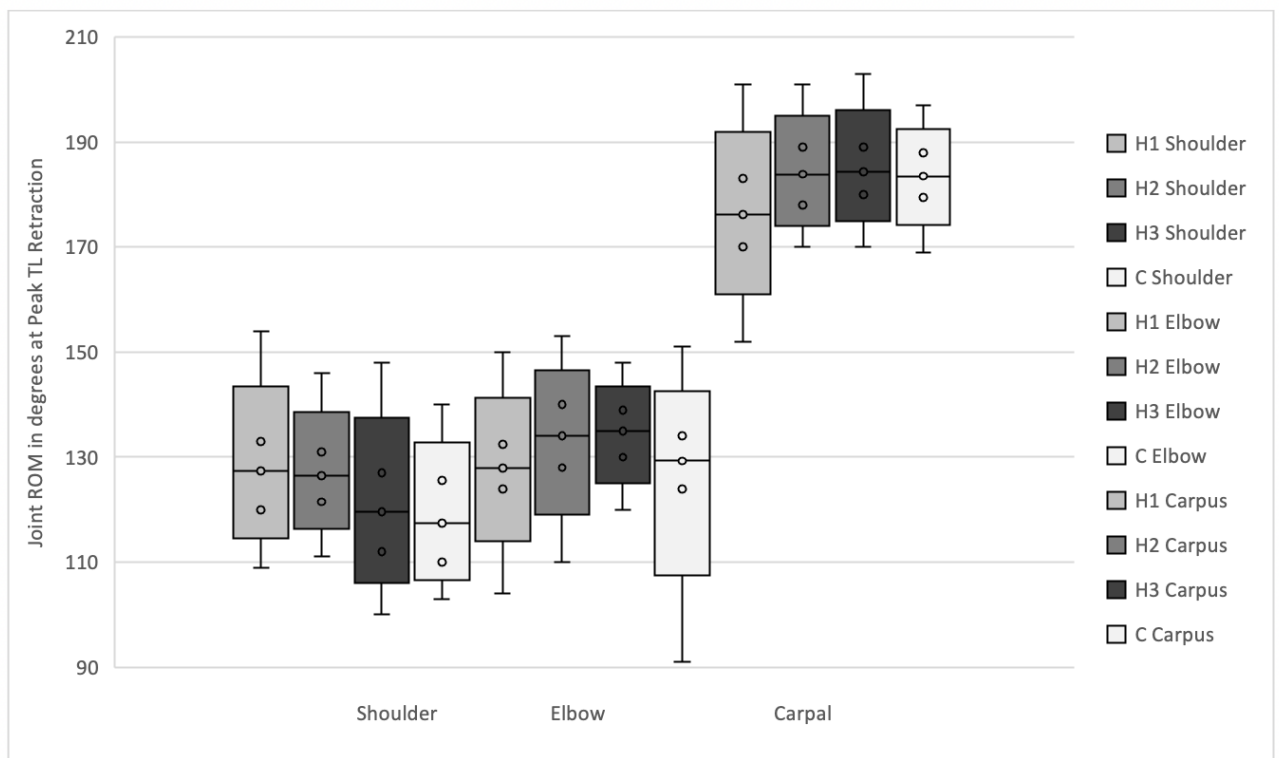
363 Elbow extension ROM was reduced most significantly in H1 (128° iqr = 124-
364 133) in comparison to the other harness conditions, the elbow ROM
365 observed in H1 was not significantly different to that recorded in the Collar
366 (129° iqr = 124-134; $P > 0.05$). Elbow extension ROM was 7% lower in H1,
367 in comparison to H3 (135° iqr = 130-139; $P = 0.003$); and 5% lower than H2
368 (134° iqr = 128-140; $P = 0.017$) (Figure 7).

369

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

374

375



376

377 **Figure 7** Shoulder, elbow and carpal joint ROM measurements in degrees at
378 peak retraction of the left thoracic limb in harness 1 (H1), harness 2 (H2),

379 harness 3 (H3) and collar (C). The box plot shows the maximum and minimum
380 joint angle measurements, the median, and the first and third quartiles.

381

382 Thoracic Limb Stride Length

383 Stride length varied between conditions although this was only significantly
384 different between the Collar and H1 conditions ($P = 0.008$). A significant
385 increase in SL measurements were found in the Collar, in comparison to H1.

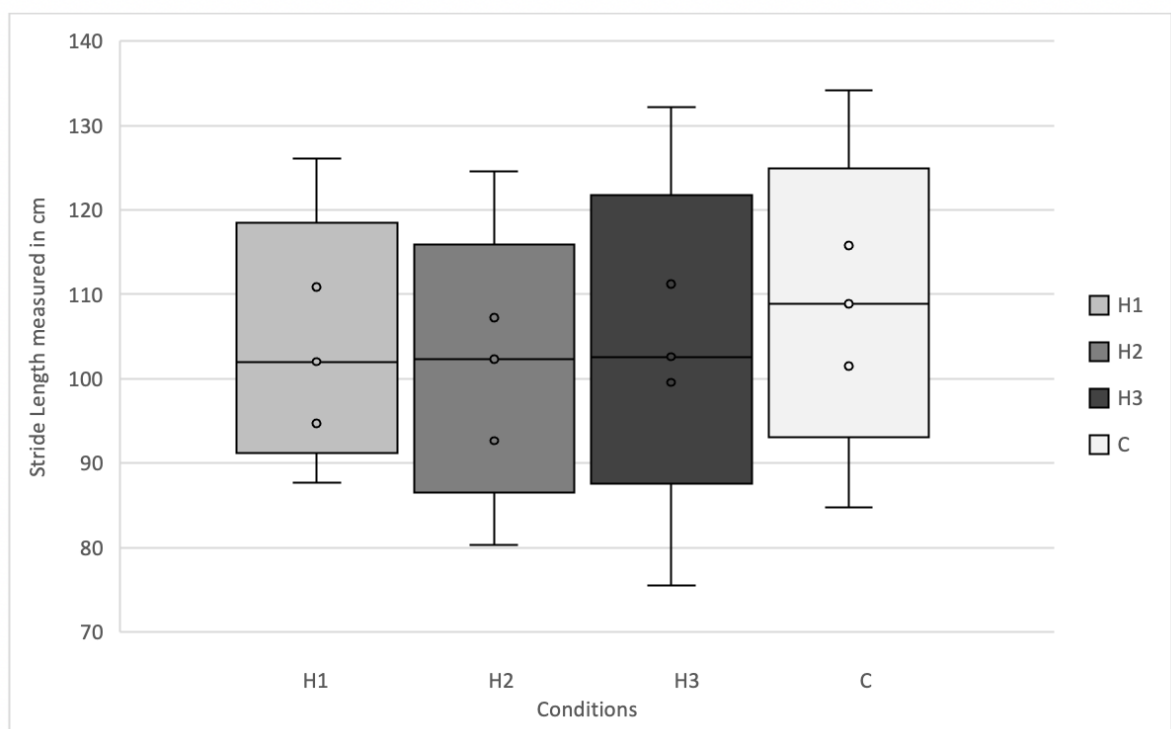
386 Median SL in the Collar was recorded as 108.87cm (iqr = 101-116), and in
387 H1 102.02cm (iqr = 95-111), however no differences were found in

388 subsequent Wilcoxon Signed Rank test post hoc analyses ($P > 0.05$) (Figure
389 8).

390

391

392



393

394 **Figure 8** Stride length (SL) measurements (in centimetres) of the left thoracic
395 limb at walk in harness 1 (H1), harness 2 (H2), harness 3 (H3) and collar (C).

396 The box plot shows the maximum and minimum SL measurements, the
397 median, and the first and third quartiles.

398

399

400 **Speed**

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

405

406

407 **Discussion**

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

422

423 For H3 shoulder ROM in TL protraction was increased significantly in
424 comparison to that recorded in the Collar or H1; whilst elbow extension in TL
425 retraction was significantly greater in H3 and $H2 > H1$. Previous research
426 has demonstrated a reduction in proximal joint ROM and an increase in
427 distal joint ROM in minimising muscular effort with locomotion, and is
428 thought to be an energy efficient adaptation (Carrier et al. 1998; Carrier et al.
429 2006; Carrier et al. 2008; Nielsen et al. 2003; Holler et al. 2010; Roberts and
430 Belliveau, 2005). The findings of the current study are not supported by
431 Lafuente, Provis and Shmalz (2018) in a study of comparably designed pet-
432 dog harnesses; however a strength in the methodology of the current study

433 is the sample homogeneity and standardised lead-walking training
434 minimising variance within the sample, and maximising external validity of
435 results. The findings of the current study show an increase in proximal joint
436 ROM in H3, and an increase in distal joint ROM in the collar in comparison
437 to H1. Further 3-D kinematic analysis and EMG studies would be required in
438 clarifying whether there is any influence of the harness conditions on energy
439 efficient movement (Murray et al. 2013; Murray et al. 2017) and whether this
440 is influenced by harness handle type.

441

442 In TL retraction shoulder flexion ROM was significantly greater in H1 in
443 comparison to the collar and H3, the more laterally fitting B-handle may alter
444 the flexibility of the harness though there is currently no literature to support
445 this. This measurement observed in H1 is in contrast to the low shoulder
446 ROM observed during TL protraction. In the equine field, tactile stimulators
447 have been found to have a significant effect on increasing joint flexion and
448 improving the flight arc during the swing phase of both the TL and PL when
449 applied to the distal limb of the horse, with no accompanying significant
450 increases on proximal limb joint ROM (Clayton et al. 2008; Clayton et al.
451 2010). It may be hypothesised that the B-handle increases the
452 proprioceptive input to the dog from the harness, and thus the influence of
453 this harness is comparable to that created by equine tactile stimulators,
454 albeit proximally, on joint flexion (seen in the shoulder with TL retraction);
455 due to the nature of the harness fit in comparison to the distal application of
456 the tactile stimulators. In contrast to this, both the elbow and carpal ROM
457 observed in H1 were lower than in other conditions which is likely
458 compensatory due to the increase in proximal joint ROM which may be
459 associated with potential for increased energy expenditure in H1.

460

461 **Study limitations**

462 Due to the size of the study room where data were collected, it was only
463 possible to collect two complete strides of walk per dog per trial. Previous
464 studies have ranged from 1-12 complete strides per trial in canine kinematic
465 analysis (Holler et al. 2010; Carr et al. 2015; Kopec et al. 2017; Lafuente,

466 Provis and Schmalz, 2018); and in equine literature considering the impact
467 of fatigue on SL 5 strides have been used (Wickler et al. 2006).

468

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

477

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

484

485 **Industry application**

486 The results of the current study show the influence of the harness conditions
487 on the TL kinematics of the dog at walk. In H3 (original harness of each dog)
488 the results demonstrate an increase in proximal joint ROM in comparison to
489 the TL kinematics observed at walk in the Collar, further research would
490 allow conclusions to be drawn as to the impact of the harness on the
491 thoracic sling function (Carrier et al. 2008; Holler et al. 2010; Nielsen et al.
492 2003). Assistance dogs in the UK typically wear the harnesses for short
493 lengths of time and thus any impact on the energy efficiency of their
494 movement may be negated. There is currently no evidence to support the
495 daily length of work amongst UK assistance dogs, information from The
496 Guide Dogs for the Blind Association (2020) criteria for application for an
497 assistance dog is for a handler to be able to walk for 'around 40 minutes'
498 which may be suggestive of a typical length of work for a dog in the harness.

499 These findings may however be pertinent when considering harness design
500 choice for pet dogs who may wear the harnesses for an undefined length of
501 time during more exerting movement and play, any reduction to their energy
502 efficiency may elicit early onset fatigue which has been shown to increase
503 the risk of musculoskeletal injury in humans (Small et al. 2010; Gorelick et
504 al. 2003), horses (Boston and Nunamaker, 2000; Pinchbeck et al. 2002;
505 Pinchbeck et al. 2004) and dogs (Yoshikawa et al. 1994). The variation in
506 guiding a handler and walking a pet dog would require further exploration in
507 considering any differences in canine locomotion.

508

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

520

521 The findings relating to the use of harnesses with the B-handle are
522 particularly pertinent for dogs that are expected to walk daily in a harness
523 and their good health is vital in maintaining the independence and quality of
524 life of the handler (Calabro-Folchert, 1999). Maintaining optimal joint ROM is
525 necessary to maximise the orthopaedic health of joints (Beraud et al. 2010;
526 Henderson et al. 2015; Millis and Levine, 2013), particularly in the
527 management of the breeds used within the current study which are
528 genetically predisposed to TL orthopaedic abnormalities (Woolliams et al.
529 2011; Morgan et al. 1999).

530

531 **Conclusion**

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

542

543 **ACKNOWLEDGEMENTS**

544

545 This project would not have been possible without the support of Guide Dogs
546 UK, namely Rachel Moxon and Vicki White. Thank you to all of the handlers
547 and their dogs for participation at Atherton Training Centre.

548

549 **CONFLICT OF INTEREST STATEMENT**

550 No conflicts of interest apply to this study.

551

552 **CONTRIBUTION DISCLOSURE**

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

555

556 **AUTHORSHIP STATEMENT**

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

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

559 The experiments were performed by **Holly Platten**

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

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

562

563

564 **ROLE OF FUNDING SOURCE**

565 The author received no specific funding for this work.

566

567 **REFERENCE LIST**

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