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1 **The influence of fence height on joint angles of agility dogs.**

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38 **Abstract**

39 The Kennel Club (KC) and United Kingdom Agility (UKA) govern major dog
40 agility competitions in the UK. Dogs are categorised into different jump heights
41 depending on their withers height, with fence heights ranging from 300mm to 650mm
42 for both organisations. Dogs fall into one of three height categories when competing
43 under KC rules but one of four under UKA rules. The aim of this study was to
44 investigate the potential influence of an additional height category for those dogs
45 measuring over 430mm at the withers. Jump heights related to the possible percentage
46 of body height that dogs of 430mm (7% lower) and 431mm (51% higher) would be
47 asked to jump under UKA regulations without the addition of their fourth, Standard
48 height. Joint angles were determined through Dartfish software from anatomical
49 markers placed on the fore and hindlimb joints and at six points along the vertebral
50 column.

51

52 As fence height increased, flexion of the scapulohumeral joint significantly
53 increased for both the take-off ($P \leq 0.05$) and bascule phases ($P \leq 0.05$) of the jump.
54 Resultant flexion increase is likely to have resulted in intensified stretching of the
55 *Biceps brachii* and *Supraspinatus muscles*; potentially predisposing the onset of
56 bicipital tenosynovitis, a condition commonly seen in agility dogs. The sacroiliac joint
57 angle extended during take-off ($P \leq 0.05$) potentially predisposing to permanent nerve
58 damage through repeated over-extension strains. From these findings it is suggested
59 that although KC midi height fences are 450mm as opposed to 400mm as with UKA,
60 the KC should potentially consider the introduction of a fourth height category in to
61 their competitions to prevent risk of long term injury.

62

63 Key words: Dog, Agility, Kinematics, Joint, Heights

64

65 **Introduction**

66 An increasingly popular sport worldwide (Crufts, 2011) dog agility is governed
67 in the UK by the Kennel Club (KC) and United Kingdom Agility (UKA); both
68 associations holding mini, midi and full height classes. A fourth height between midi
69 and full height, standard height, is offered by UKA but is not present under KC rules
70 (UK Agility 2004; Kennel Club, 2012b). The potential for a fourth height has
71 previously been discussed by the KC Agility Liaison Council but no changes have yet
72 been agreed. The height a dog is required to jump depends on their height at the withers
73 (Table 1).

74

75 Under KC regulations dogs measuring between 350 and 430mm at the withers
76 are eligible for midi height (450mm) (Kennel Club, 2011); however a dog measuring
77 just 1mm more, 431mm, must jump full height (650mm). For a dog of 431mm in height
78 this is 51% greater than the dogs wither height. Those dogs of 430mm who are at the
79 top of the height category for midi are jumping 7% lower than their wither height under
80 UKA regulations but 5% higher than their wither height under KC regulations. This
81 same dog would only have to jump 550mm under UKA regulations (UK Agility, 2004;
82 Kennel Club, 2012b) and just 400mm under American Kennel Club (AKC) rules, which
83 has five height categories (America Kennel Club, 2011); 250mm less than under KC
84 rules. The additional height ranges offered by UKA and AKC illustrates their
85 recognition of the need for more staggered height increases, potentially to reduce injury
86 risk. Dogs only just measuring within the full height category are potentially at greater
87 risk of injury due to the greater size jump in relation to their body height.

88

89 Commonly injured areas in agility dogs are the shoulders (bicipital
90 tenosynovitis), the lumbar spine and the toes (O'Canapp 2007; Wernham et al, 2008).
91 Levy et al (2009) identified that 33% of overall injuries to dogs were as a result of
92 agility; of that, 58% were injured during competition. A-frames, bar jumps and the dog
93 walk elements equated for two-thirds of reported injuries. The bar jump led to
94 increased accelerative horizontal impulse and increased vertical loads, peak forces and
95 impulses in the forelimbs (Pfau et al. 2010). The concussive landing forces from bar
96 jumps are consequentially implicated in the prevalence of soft tissue injuries to the
97 shoulders and back (Levy et al, 2009).

98

99 Excessive joint movement may also be linked to agility injuries and are likely
100 to result from increased fence heights. To date, no research exists regarding the impact
101 of fence height, in relation to dog height on the kinematics of the jump. The aim of this
102 study was to identify changes in limb and spinal joint angles in agility dogs over fences
103 of two different heights, set in relation to their wither height. Angles were reviewed on
104 approach, take off, bascule, landing and get away phases of the jump stride. Any
105 increase in injury risk to dogs jumping excessively higher than their body height would
106 be indicated, potentially supporting the need for the addition of a fourth height within
107 current KC regulations. Joint flexion and extension was expected to become more
108 exaggerated over the larger fence particularly during the take-off and landing phases.
109 In accordance with previous injury related research, joint angles in the lumbar and
110 shoulder regions were hypothesised to demonstrate changes of a greater magnitude.

111

112 **Materials and Methods**

113 The study population consisted of four German Shorthair Pointers, one
114 Hungarian Visla, one Doberman, one Australian Kelpie and one mixed breed agility
115 dog, chosen through convenience sampling. The dogs used were of similar agility
116 competition experience and all competed within the full height category; wither heights
117 ranged from 460mm to 720mm. Each dog had previously, or was currently, competing
118 in agility competitions and none of the dogs were known to be suffering from any
119 disorders including musculoskeletal conditions.

120

121 A lightweight plastic bar jump was used with modified wings enabling the jump
122 to be set to any particular height in 1 cm increments. The jump heights were set
123 specifically for each dog at 7% lower and 51% higher than the dog's height. These
124 percentages were calculated by considering the height of fence in relation to withers
125 height, that dogs at the top of UKA midi height would have to jump without the
126 inclusion of the fourth, Standard height.

127

128 Markers were attached to specific anatomical points of the forelimbs (point of
129 shoulder, elbow, carpus, and metacarpal pad), the hindlimbs (sacroiliac joint, base of
130 tail, tuber coxae, stifle, tarsus and metatarsal pad) and vertebral column (external
131 occipital protuberance, C2, T6, T13) (Gradner et al, 2007; Marsh et al, 2009). In the
132 forelimb, angles were calculated on the cranial aspects of the elbow joint, and on the
133 caudal/palmar aspect of the shoulder and carpal joints. In the hind limb, angles were
134 calculated on the cranial/dorsal aspect of the hip and tarsal joints, and the caudal/palmar
135 aspects of the stifle joint. Spinal angles were calculated from the ventral aspect of the
136 spinal column.

137

138 The data were collected in an indoor equine arena on a Prowax surface. The
139 fence was placed at the midpoint of the long side of the arena and the camera (JVC GY-
140 HM700U HD; 60fps) positioned perpendicular to the fence at a distance of six metres.
141 This distance enabled approach, take-off, bascule, landing and get away phases of the
142 jump to be captured. The positioning of the fence with the arena wall to the left of the
143 fence supported the dogs in attaining a right canter lead in both take-off and landing.

144

145 Owners warmed-up their dog for five minutes prior to data collection and were
146 asked to follow their normal pre-competition warm-up protocol. The warm up period
147 enabled each dog become accustomed to the feel of the markers (Leach, 2006). On
148 completion of the warm up, each dog jumped the fence set at a height 7% lower than
149 its height at the withers. The dog was set up four metres in front of the jump and the
150 owner positioned four metres after the jump to ensure each dog had the same distance
151 either side of the fence. A jump was deemed as unsuccessful if the dog ran under or
152 around the jump, or knocked the pole down. If a dog had failed to complete the jump
153 successfully five times then it would have been withdrawn from the study to ensure its
154 welfare was not compromised. Once the lowest height was completed three times, the
155 bar was raised in 10 cm increments until the calculated highest height (51% greater than
156 height at withers) for each dog was reached. Dogs were recorded for three repetitions
157 over the fences 7% lower and 51% higher than their height at the withers. The
158 intermediate 10cm increments were only jumped once, successfully, at each increment
159 and were not recorded.

160

161 From the anatomical markers, the angles of the spine at the base of the skull and
162 the base of the neck, and the carpal, radio-humeral, scapulohumeral, tarsal, stifle,

163 coxofemoral, sacroiliac and thoracolumbar joints were determined using Dartfish
164 software. Angles were measured for approach (all four feet in contact with the ground
165 during the final approach stride immediately prior to the forelimbs leaving the ground),
166 take-off (forelimbs off the ground, immediately prior to the back feet leaving the
167 ground), bascule (the midpoint over the jump), landing (initial forelimb contact with
168 the ground) and get away phases (all four feet in contact with the ground immediately
169 following landing). Take-off and landing distances from the base of the fence were also
170 determined using Dartfish. Angles reported for each phase of the jump were maximal
171 points of anatomical flexion or extension that occurred during that phase.

172
173 For each measured parameter at each phase over both heights of jump, mean
174 values were determined for each dog from the three repetitions. These mean values for
175 the joint angles, take-off distances and landing distances captured at the lower jump
176 height were compared against those captured at the higher fence height for each phase
177 of the jump under investigation to determine the existence of any difference resulting
178 from the increase in fence height. Data were examined for statistically significant
179 differences between the two fence heights using the Wilcoxon- Matched Pairs analysis.

181 **Results**

182 For six of the eight dogs, significantly increased extension ($P \leq 0.05$) was
183 recorded at the base of the neck between the 7% lower jump ($\bar{x} = 208.10^\circ$; $SD \pm 6.99$)
184 and 51% higher jump height ($\bar{x} = 213.55^\circ$; $SD \pm 7.43$) during the approach phase. When
185 the data was reviewed with outliers removed ($\bar{x} \pm 2SD$), one of the two dogs which did
186 not demonstrate extension at the base of the neck was excluded for the angles of the
187 tarsus and the base of the neck, and this dog was the cross breed. The result of its

188 exclusion was that the base of the neck no longer demonstrated a significant difference
189 in angle; however the tarsus angle demonstrated a significant increase in extension
190 ($P \leq 0.05$) during take-off as the fence height increased.

191

192 During the take-off phase, significantly increased extension of the hock
193 ($P \leq 0.05$) and the sacroiliac region ($P \leq 0.05$) were identified from the lowest to the
194 highest height. However, significantly increased flexion was recorded for the radio-
195 humeral ($P \leq 0.05$) and scapulohumeral ($P \leq 0.05$) joints and the base of the neck ($P \leq 0.05$)
196 (Table 2). No statistically significant differences were found between the take-off
197 distances for the two heights of jumps.

198

199 Greater flexion was recorded for the scapulohumeral joint ($P \leq 0.05$) and the
200 radiohumeral joint ($P \leq 0.05$) angles during the bascule phase from the lowest ($\bar{x} =$
201 107.95° ; $SD \pm 5.93$; $\bar{x} = 52.09^\circ$; $SD \pm 18.13$ respectively) to the highest height fence ($\bar{x} =$
202 88.25° ; $SD \pm 9.33$; $\bar{x} = 39.04^\circ$; $SD \pm 15.40$ respectively).

203

204 No significant changes in flexion or extension of any joints were recorded
205 between the two heights of fence during the landing or get away phases, however
206 landing distance increased significantly with an increase in fence height ($P \leq 0.05$).

207

208 Discussion

209 Although few changes were recorded for joint angles during the approach phase,
210 the increased extension at the base of the neck indicated that on the approach the dogs
211 were raising their heads. Although this change was not significant with the outlier
212 removed, the means demonstrated a trend for this extension across six of the seven

213 remaining dogs and the P-value was close to the significance level ($P=0.063$). This
214 change in head position is potentially to better determine the height of the fence (Zinc
215 and Daniels, 1996); however, as a consequence it puts this region of the spine in
216 extension.

217

218 During take-off the base of the neck moved from the extended orientation seen
219 in the approach phase, to a more neutral, or slightly flexed orientation; with
220 significantly greater flexion when the higher fence was jumped compared to the lower
221 fence. This flexion, and the concurrent extension of the sacroiliac region, results in the
222 spinal column appearing visually straighter. This alignment would support the transfer
223 of energy required during take-off and also the increase in vertical trajectory needed to
224 get over the taller fence. This increase in vertical trajectory is also reflected by the
225 increase in tarsal joint extension for the larger fence where greater vertical propulsion
226 is required.

227

228 Very little research into the biomechanics of dog agility exists and none have
229 investigated the kinematic effects of fence heights on joint angles. Much research
230 however has been undertaken in jumping horses and such research has identified that
231 during the take-off phase the equine sacroiliac joint angle increases when jumping
232 higher fences compared to those of a smaller height, and the lumbar spine consequently
233 becomes more extended (Dyson and Murray 2003). Sacroiliac joint injuries are a
234 common cause of nonspecific hindlimb lameness in horses (Tucker et al, 1998) and
235 show jumping horses are at a significantly greater risk of developing sacroiliac joint
236 disease (Dyson and Murray 2003). Significant damage to the sacroiliac joint can lead
237 to permanent nerve damage and, in smaller species such as dogs and cats, severe

238 damage can result in the joint needing to be pinned (Johnson and Dunning, 2005). The
239 significant increase in extension of this region due to the higher jump height within the
240 current study indicates that injury to this region is a significant concern in dogs being
241 required to jump fences which are substantially greater than their withers height.

242

243 In addition to the spinal extension, simultaneous and significant flexion in the
244 scapulohumeral and radiohumeral joint angles was observed within the take-off phase.
245 These alterations demonstrate increased flexion, and therefore tucking-up, of the
246 forelimbs to support clearance of the fence. This significant forelimb flexion originating
247 from the scapulohumeral and radiohumeral joints remains during the bascule phase.
248 Increased flexion of the scapulohumeral joint compounds the strain on the highly
249 tendinous *Biceps brachii* which runs over the dorsum of the joint. Repeated strain of
250 this structure has been linked to bicipital tenosynovitis, a condition common in agility
251 dogs (O'Cannapp, 2007). The potential for damage to this structure in agility dogs, in
252 addition to a failure to appropriately diagnose and rehabilitate the injury, can lead to
253 permanent degeneration of the tendon.

254

255 The link between the increase in height of the fence and increase in
256 scapulohumeral joint flexion reinforces some concerns that within KC competitions,
257 dogs that only just meet the full height category could be putting excess strain on their
258 soft tissues through jumping fences that are large in comparison to their body height.
259 The lack of a clavicle in the dog results in the shoulder muscles playing an important
260 role in passive as well as athletic movement (Budras et al, 2007) and are consequently
261 required to stabilise, generate, absorb and transfer forces to accomplish movement in
262 the forelimbs (Farrow, 2005; Giacomo et al, 2008). Damage to these muscles will

263 negatively impact the muscles efficiency at recoiling and pulling the leg forward
264 (Budras et al, 2007). Further research is needed to investigate the incidence of injuries
265 in agility dogs in relation to their height and the height classification in which they are
266 competing in an effort to avoid permanent damage through degeneration.

267

268 Interestingly, the increased flexion in the forelimbs during the bascule phase is
269 not reflected in the hindlimbs nor are there significant differences in the angles
270 measured within the vertebral column. This indicates that the increased upward
271 trajectory and the increased forelimb flexion to ensure clearance are satisfactory up to
272 this point of the jump sequence to ensure clearance of the fence.

273

274 Pfau et al's (2010) findings suggest that differences in joint angles should have
275 been expected on landing over the bar fence due to the more acute landing angle and
276 higher vertical loading forces identified within their investigation of agility dog injuries
277 in relation to fence type. The lack of significant differences found during the landing
278 and get away phases of the current study may be influenced by the low sampling rate
279 within this study (60Hz), potentially preventing maximal angled from being detected.
280 However, it also illustrates how research in this area could benefit from the concurrent
281 use of force plates alongside angle data to accurately determine the influence of various
282 fence heights on biomechanical adaptations of the landing phase. Differences in the
283 landing distances and angulations could also be related to the speed of approach and
284 this is therefore another area where further research is needed. Within competition dogs
285 would have a longer approach and would be encouraged to complete the fence in a
286 hurdling form of jump at a higher speed and may also be encouraged to turn on landing.
287 These factors are, however, likely to increase the risk of injury rather than decrease it.

288

289 Although no changes in the angles of joints were observed, the landing distances
290 increased significantly with the increase in fence height. This again contradicts the
291 findings by Pfau et al (2010) who suggest a more acute landing angle with the bar fence;
292 however their investigation compared fence types rather than fence heights and this
293 may account for the difference in results. The results from the take-off phase of the
294 current study suggest that greater propulsive forces are employed to jump higher fences.
295 The increased power required to clear the jump may propel the dog further over the
296 fence and thus account for the longer landing distance.

297

298 The tallest dog used in the study measured 720mm to the withers and as such
299 the higher jump (51% greater than height at withers) for this dog was 1090mm. A dog
300 of this height would not normally be asked to jump a fence of this size, and during
301 competition would be asked to jump a maximum of 650mm. This is a difference of
302 440mm; 9cm greater than the wither height of the smallest dogs in this category. This
303 discrepancy demonstrates how much higher, as a percentage of body height, a dog of
304 431mm would be expected to jump during competition, and as such how much the risk
305 of injury is increased.

306

307 **Study Limitations**

308 As has been identified in equine kinematic studies (van Weeren et al., 1992; Sha
309 et al., 2004), movement of the skin over the bony landmarks used for marker placement
310 within results in biological errors in measurement; particularly within full retraction, or
311 protraction, of the limb. Correction models have been calculated for some anatomical
312 landmarks in the horse; however there are currently no similar correction models for

313 canine kinematic investigations. Such biological noise is likely to have influenced the
314 measurements within this study.

315

316 To further understand the findings of this investigation force measurements
317 would have ideally been taken on take-off and landing; this would have enabled further
318 comparisons to be drawn with this study and the findings of Pfau *et al.* (2010) who
319 looked at take-off and landing forces over different fence types.

320

321 Although the sample size could be considered as small, it was comparable to
322 most equine kinematic investigations where sample sizes can be as few as four or five
323 horses. The generalizability of the current findings would however be enhanced
324 through the inclusion of a wider range of breeds and anatomical types within the study
325 population. This would, as a consequence, require the need for a larger sample size to
326 be used.

327

328 **Conclusion**

329 The findings demonstrate that an increase in fence height results in significant
330 changes to the excursions of joints in the forelimb and vertebral column, areas already
331 identified in previous agility dog research as the most commonly injured. These
332 findings indicate that agility dogs that are required to jump fences excessively higher
333 than their own with height are potentially being put at a greater risk of developing
334 injuries such as bicipital tenosynovitis or sacroiliac strain. Those dogs likely to be at
335 most risk within the current height categories are those just above the KC midi category
336 (431mm) and are require to jump full height (650mm) which is 51% bigger than their
337 wither height and 200mm higher than the midi height category. Further research is

338 needed to confirm injury location and prevalence in relation to the height of the dog
339 and the height category they are competing at. Should a relationship be found, it would
340 support findings from the current study and add emphasis to the suggestion that fence
341 height categories, where dogs are required to jump large fences in comparison to their
342 body size, need to be reviewed to support injury prevention.

343

344 **Conflict of interest statement**

345 None of the authors of this paper has a financial or personal relationship with
346 other people or organisations that could inappropriately influence or bias the content of
347 the paper

348

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Table 1: Jump category and fence height depending on height at withers for both UK

437 Agility and Kennel Club competitions.

Height at withers	UK Agility	Kennel Club
≤ 350mm	Mini - 300mm	Mini - 300mm
351-430mm	Midi – 400mm	Midi – 450mm
431-500mm	Standard – 550mm	Full – 650mm
>500mm	Full – 650mm	

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457 Table 2: Mean (\pm SD) values for all joint angles at each phase of the jump (Significant differences in mean values in bold).

Phase of jump	Approach		Take Off		Bascule		Landing		Get away	
	7% lower	51% higher	7% lower	51% higher	7% lower	51% higher	7% lower	51% higher	7% lower	51% higher
Hock	118.5 (\pm 9.0)	122.2 (\pm 14.1)	134.5 (\pm 14.7)	151.6 (\pm 5.2)	86.2 (\pm 10.7)	78.8 (\pm 21.6)	70.6 (\pm 9.5)	76.8 (\pm 16.1)	134.7 (\pm 12.1)	132.9 (\pm 18.6)
Stifle	107.3 (\pm 8.8)	105.9 (\pm 4.1)	104.8 (\pm 7.6)	110.4 (\pm 5.5)	50.0 (\pm 12.0)	44.4 (\pm 10.6)	51.5 (\pm 9.9)	50.2 (\pm 10.7)	131.6 (\pm 17.2)	136.6 (\pm 24.6)
Hip	90.5 (\pm 4.2)	86.4 (\pm 6.8)	119.9 (\pm 4.4)	122.1 (\pm 5.3)	97.8 (\pm 11.9)	92.8 (\pm 12.9)	81.5 (\pm 12.9)	82.4 (\pm 10.9)	97.3 (\pm 11.5)	93.5 (\pm 8.0)
Sacroiliac	154.6 (\pm 4.3)	155.3 (\pm 6.0)	179.4 (\pm 5.3)	186.6 (\pm 6.2)	173.2 (\pm 7.0)	174.6 (\pm 7.7)	158.9 (\pm 12.0)	163.4 (\pm 10.4)	141.8 (\pm 11.1)	144.8 (\pm 7.5)
Thoracolumbar	165.1 (\pm 8.9)	165.7 (\pm 9.3)	183.3 (\pm 4.7)	184.5 (\pm 5.6)	193.0 (\pm 5.9)	194.2 (\pm 5.5)	193.2 (\pm 6.4)	201.2 (\pm 7.0)	166.3 (\pm 8.7)	166.9 (\pm 10.4)
Base of neck	208.1 (\pm 6.9)	213.6 (\pm 7.4)	168.2 (\pm 8.8)	162.1 (\pm 6.5)	182.4 (\pm 9.6)	177.7 (\pm 10.8)	211.9 (\pm 12.5)	216.1 (\pm 17.1)	182.2 (\pm 19.5)	177.6 (\pm 17.5)
Base of skull	178.7 (\pm 5.7)	181.2 (\pm 7.6)	170.4 (\pm 5.2)	174.9 (\pm 9.4)	176.6 (\pm 4.4)	173.9 (\pm 6.0)	183.0 (\pm 11.0)	184.1 (\pm 8.4)	172.9 (\pm 9.9)	177.9 (\pm 13.8)
Radiohumeral	126.8 (\pm 9.5)	128.9 (\pm 9.7)	44.5 (\pm 18.6)	23.2 (\pm 13.2)	52.1 (\pm 18.1)	39.0 (\pm 15.4)	112.3 (\pm 14.6)	119.3 (\pm 10.9)	90.5 (\pm 25.9)	95.4 (\pm 23.8)
Scapulohumeral	98.1 (\pm 8.9)	98.3 (\pm 9.1)	83.9 (\pm 12.4)	72.3 (\pm 8.1)	107.9 (\pm 5.9)	88.3 (\pm 9.3)	118.0 (\pm 14.5)	125.6 (\pm 13.2)	104.1 (\pm 8.0)	99.4 (\pm 9.2)
Carpal joint	197.9 (\pm 18.3)	196.2 (\pm 25.9)	90.1 (\pm 24.5)	89.5 (\pm 24.7)	136.1 (\pm 22.9)	124.5 (\pm 18.7)	212.3 (\pm 5.3)	207.4 (\pm 14.2)	208.2 (\pm 13.5)	224.1 (\pm 14.0)

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