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1

2 **Peak forelimb ground reaction forces experienced by dogs jumping**
3 **from a simulated car boot**

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17 **Abstract**

18

19 Many dog owners allow their pets to jump out of a car boot, however, to date
20 there has been no study that has investigated whether this places dogs at risk
21 of injury. The aim of this study was to investigate the relationship between
22 height and peak vertical ground reaction force (vGRF) in static start jumps.
23 Fifteen healthy adult dogs performed three jumps from a platform that
24 represented common vehicle boot sill heights (0.55m, 0.65m, 0.75m), landing
25 on a single force platform. Kinetic data (F_x , F_y and F_z) were normalised for
26 body weight and analysed via a one-way repeated analysis of variance
27 (ANOVA) and pairwise post-hoc tests with a Bonferroni correction applied.
28 There was a significant difference in peak forelimb vGRF between both the
29 0.55m (27.35 ± 4.14 N/Kg) and the 0.65m (30.84 ± 3.66 N/Kg) platform ($p=0.001$)
30 and between the 0.65m and 0.75m (34.12 ± 3.63 N/Kg) platform ($p=0.001$).
31 There was no significant difference in mediolateral or craniocaudal forces
32 between the heights examined. These results suggest that allowing dogs to
33 jump from bigger cars with a higher boot sill may result in augmented levels of
34 loading on anatomical structures. Further research is required to investigate
35 the kinematic effects of height on static jump down and how peak forelimb
36 vGRF relates to anatomical loading and subsequent injury risk.

37 **Introduction**

38

39

40 The percentage of households in the UK with pet dogs is estimated to be 24%,
41 with a population of around 8.5 million [1]. There are many reasons why a dog
42 will leave the home (trip to local park, vet visits, holidays, day boarding,
43 attending competitions or shows) which usually necessitate vehicular
44 transportation. UK legislation stipulates that dogs must be restrained when
45 travelling in a vehicle [2], both for the driver and dog's safety. In addition,
46 published guidance to handlers outlines specific environmental requirements
47 when transporting a dog in a vehicle [3, 4], yet neither provides direction on
48 appropriate methods of entry or exit into the back seat or rear compartment
49 (boot); the areas in which many owners confine their dogs [5]. Techniques vary
50 from manual lifting, allowing the dog to jump in and out, or employing the use
51 of a ramp. However, no studies currently exist that investigate the reasons to
52 opt for a particular method or the frequency with which each is used.

53

54 Lifting a dog can pose a risk of injury to both the owner and dog, dependent
55 on the technique used. For example, lifting an animate and unpredictable
56 object (such as a dog, weighing up to 50 kilograms) scores highly in a
57 workplace manual handling risk assessment particularly when
58 twisting/stooping postures are employed [6]. It is noteworthy that much
59 evidence is available in the human field investigating the prevalence and risk
60 factors associated with back pain [7–9], particularly in relation to lifting [6].
61 Guidance on the safe load limits when lifting has been published [6], and
62 therefore, from a health and safety perspective lifting larger dogs should
63 preferably be avoided.

64

65 With a wide variety of vehicle boot sill heights present in the UK [10], it is
66 unclear whether these heights have a direct impact on the risk of injury. In
67 allowing dogs to jump unaided out of vehicles, owners may be inadvertently
68 predisposing their dogs to the development of musculoskeletal pathologies.
69 Some studies have explored the biomechanics of competitive jump landings
70 in dogs [11–14], however minimal quantitative canine studies investigating the
71 effects of jump landing exist when investigating static start jump-downs. Given

72 the paucity of research in this area, it is important to consider the
73 biomechanical implications of jumping from a stationary position from a range
74 of heights.

75

76 There are no studies of dogs that directly investigate the relationship between
77 vertical ground reaction force (vGRF) and forelimb injury, however, equine
78 studies have attempted to relate the action of jumping to the injury of three
79 specific forelimb tendons [15]. Clear distinctions in loading were identified, with
80 the highest peak loading occurring at the superficial digital flexor tendon
81 (SDFT). Although the mechanical and functional properties of this tendon have
82 been reported [16] and in vitro studies suggest the mechanisms of
83 microtrauma [17, 18], no further clinical studies have been published for
84 comparison. Out of the three jump heights investigated (0.8m, 1.0m and 1.2m),
85 only the SDFT tendon absorbed substantially more force as height increased.

86

87 Evidence relating to peak vGRF experienced by dogs jumping from a static
88 start would be of key interest to the veterinary profession in providing a clearer
89 picture of the aetiology of common musculoskeletal pathologies (osteoarthritis,
90 elbow dysplasia, hip dysplasia), where disease expression is reported to be
91 affected by environmental variables [19]. If there is a significant effect of height
92 on peak vGRF when dogs perform a static start jump, this would provide
93 suitable evidence to recommend the use of prevention measures such as
94 ramps.

95

96 Many studies have investigated the aetiology of conditions such as
97 osteoarthritis (OA) [20–22] with many concluding that there are both normal
98 and pathological adaptations of articular cartilage to joint loading. One study
99 compared bone specimens of dogs with fragmented medial coronoid
100 processes (FMCP) against those without (n=38) to demonstrate a significant
101 relationship between fatigue micro-damage and FMCP [23]. Given that the
102 repeated loading of bone leads to the formation of micro-cracks within
103 mineralised tissue [24, 25], and with a paucity of specifically designed studies,
104 it is plausible that elbow dysplasia could be partially a manifestation of
105 repeated loading of the forelimbs when jumping from vehicles. It has been

106 highlighted that increasing the load on ex-vivo elbow joints brings about
107 significant changes in several joint space measurements [26].

108

109 Several studies have examined the kinematics and kinetics of dogs jumping
110 over hurdles [11, 13, 27, 28], but not from a static start jump down. However,
111 as jumps from a static start are commonly performed by dogs (from furniture,
112 cars etc.), biomechanical studies are required to inform whether dogs should
113 be allowed to perform these activities.

114

115 The aim of this study was to investigate the effect of height on peak forelimb
116 vGRF when dogs perform a static start jump from a platform of equivalent
117 height to a car boot. Heights were selected to represent a range of boot heights
118 that exist in common car models. It was hypothesised that jumping from the
119 higher platforms would result in increased peak vGRF due to the increased
120 length of the aerial phase and the consequent change in downwards velocity
121 (due to gravitational acceleration) at impact [13].

122

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124
125

Materials and Methods

126 This study was approved by the ethics committee at University Centre,
127 Hartpury and all work was conducted in line with institutional ethical guidelines.
128 Fifteen dogs were recruited from a convenience sample through advertising at
129 local agility clubs and dog walking groups. Information sheets were provided
130 to owners along with a consent form. On receipt of signed consent forms, the
131 medical history of each canine participant was requested (permission granted
132 by owner) from their registered veterinarian. This enabled verification that
133 participants met the inclusion criteria. Consent from owners was also gained
134 verbally on the day at each stage of data collection once the research activity
135 had been re-explained to them.

136

137 Immediately prior to data collection, each canine participant was physically
138 assessed by the primary researcher (ACPAT Chartered Physiotherapist) to
139 ensure that no contraindications to participation were present (e.g. lameness,
140 musculoskeletal pain response, altered neurological state). All canine
141 participants were visually gait assessed for a minute at walk and trot for
142 soundness, together with spinal and peripheral limb palpation to exclude the
143 presence of anatomical tenderness suggestive of pain. Knuckling testing was
144 performed on all limbs since neurological deficit can affect gait parameters [29]
145 and each peripheral joint (including the scapulothoracic articulation) was
146 passively moved through the full range of motion to verify that no joint or soft
147 tissue restrictions were present.

148

Inclusion and Exclusion Criteria

149 Dogs were excluded from the study if they were less than two years of age, as
150 skeletal maturity of dogs occurs between the ages of 10 to 12 months and
151 sexual maturity between seven and 21 months [30]. No upper age limit was
152 set, however dogs were excluded if they had an underlying musculoskeletal
153 pathology or undiagnosed lameness, since these are known to alter gait
154 patterns [31–33] and may increase injury risk. Given this research
155 necessitated subjects performing multiple jumps and additionally that 'long and
156

157 low' conformation can predispose to intervertebral disc extrusion [34, 35],
158 chondrodystrophic breeds were excluded from the study. In line with other
159 studies [11, 12], guidelines provided by the UK Kennel Club outlining specific
160 dog height categories [36] in agility competition were utilised to inform the
161 inclusion criteria, with consideration taken for the specification of the three
162 jumping related obstacles (hurdle, table/pause box, hoop tyre). Given that
163 dogs classed in the medium height category are not permitted to jump from
164 heights higher than 0.45m, 0.40m and 0.55m for each of these obstacles
165 respectively, only dogs with a leg length greater than 0.43m were included in
166 the study. Although it is appreciated that dogs can be unpredictable, those
167 without basic obedience skills (being able to sit and wait until told to move)
168 were also not recruited.

169

170 *Study Population*

171 In order to account for potential sources of variation between dogs, baseline
172 recording of breed, age, gender, weight (measured within the week of data
173 collection) and forelimb length (measured from the distal phalanges to the top
174 of the scapulae) were measured and documented. Nine breeds of dog and
175 one mixed breed dog were recruited with ages ranging from two to nine years
176 (mean 5.9 ± 2.39 years). Eight dogs and seven bitches were included of body
177 mass ranging from 13.8 kg to 33.2 kg (mean 22.29 ± 5.26 kg). Forelimb length
178 (measured to the withers) of the participants ranged between 0.45m and
179 0.68m (mean 0.57 ± 0.07 m). Breeds included were Belgian Shepherd (4),
180 Border Collie (3), Labrador Retriever (1), Flat Coated Retriever (1), Cocker
181 Spaniel (1), English Springer Spaniel (1), Tibetan Terrier (1), Hungarian Vizsla
182 (1), Bavarian Mountain Hound (1) and Crossbreed (1).

183

184 *Jump Platform*

185 A height adjustable, stable platform (0.9m by 1.1m) was constructed from a
186 steel and aluminium alloy frame with a stiff medium-density fibreboard (MDF)
187 top-board insert (Figure 1). Interchangeable platform leg lengths enabled three
188 platform heights (0.55m, 0.65m and 0.75m) to be constructed. Setting 0.1m
189 linear increments enabled representation of the spectrum of vehicle boot sill
190 heights being investigated [10]. Non-slip rubber-backed carpeting was placed

191 underneath and on top of the platform with their thicknesses taken into account
192 to ensure the overall jump down heights were 0.55m, 0.65m and 0.75m.

193

194 *Kinetic Data*

195 The platform was positioned immediately in front of a single AMTI (Advanced
196 Mechanical Technology Incorporated[®] MA, US) force plate of dimensions
197 400mm x 600mm so that vertical (F_z), craniocaudal (F_y) and mediolateral (F_x)
198 forelimb landing ground reaction forces could be recorded. A capture rate of
199 500Hz and a time period of 10 seconds were used to ensure effective data
200 collection [13]. Non-slip rubber matting was placed over the force plate and the
201 surrounding area to ensure that dogs did not slip on landing. Two-dimensional
202 video recording (Canon EOS 600D, 1280x720, 60fps) of each trial took place
203 to enable confirmation of the validity of trials. The camera, mounted on a
204 tripod, was positioned 3 metres immediately lateral to the force plate.

205

206 *Experimental Protocol*

207 In addition to the gait assessment, a five minute warm-up (walking and trotting)
208 of each individual participant was performed to increase vascularisation and
209 reduce transient joint stiffness [27]. Each dog was instructed by its owner to
210 ascend a ramp onto the platform. As an acclimatisation procedure and
211 individual pilot study, each dog was instructed to sit on top of the platform in a
212 pre-determined start zone located towards the front edge of the platform,
213 facing forwards towards the force plate. The dog was commanded to sit and
214 stay while the owner positioned themselves four metres in front of the platform.
215 The force plate was configured and armed, the video recording commenced
216 and the researcher signalled to the owner to call their dog to jump off the
217 platform.

218

219 A successful trial was classified as one in which the first limb to contact the
220 ground (trailing limb) landed clearly within the rectangular target zone of the
221 force plate. This was a rectangular area (outlined using masking tape, Figure
222 1.) denoting the position of the force plate. For all trials, both forelimbs
223 contacted the force plate. Owing to variance in morphology and conformation,
224 altered postures when jumping can occur between dogs [12]. Therefore, to

225 ensure that the trailing forelimb landed consistently within the boundaries of
226 the force plate, the jumping style of each dog required observation. If on the
227 acclimatisation jump a dog did not land in the middle of the force plate, the
228 platform was then moved forward or back in increments of 0.01m for a second
229 acclimatisation jump [13]. The range of distances used was from 0.26m to
230 0.47m (mean 0.38 ± 0.05). Once a successful trial was observed this counted
231 as part of data collection and subsequent trials continued with the same
232 configuration.

233

234 Dogs were required to complete three valid trials at each platform height.
235 Comparable studies have recorded five trials [27], however given the nature
236 of the experimental task and the height of the platforms, for ethical reasons
237 only three trials were performed. The order in which a participant attempted
238 the two lower platform heights was randomised and a five-minute break was
239 scheduled between each trial in an attempt to remove any fatigue or potential
240 cumulative joint loading effects. After the 0.55m and 0.65m platform trials,
241 each subject was then considered for the 0.75m platform height trial. This third
242 platform height was only permitted with explicit verbal consent of the owner
243 and if the researcher was willing to proceed after observation of the individual
244 dog's previous trials. It is appreciated that true randomisation in relation to the
245 order of the three platform heights did not occur, however the method used
246 was felt to be justified on ethical grounds.

247

248 *Statistical Analysis*

249 The kinetic data collected (mediolateral force (Fx), craniocaudal force (Fy) and
250 vertical force (Fz)) were transferred to Microsoft® Excel® for Mac Version
251 14.5.3. Normalisation of ground reaction force (GRF) [37] by body mass (kg)
252 was performed. A mean value of the three normalised peak GRF values (for
253 Fx, Fy and Fz per platform height) was calculated for each dog (N/Kg). All
254 data were analysed in SPSS Statistics (Version 23) To test for normality, a
255 Kolmogorov-Smirnov Test was performed and data were found to be normally
256 distributed ($p > 0.05$). A one-way repeated measures analysis of variance
257 (ANOVA) was used to test for statistically significant differences between the
258 three heights. Post hoc testing was performed where significant differences

259 were identified. Pairwise tests, with the Bonferroni adjustment were applied
260 such that the criterion of significance was divided by the number of
261 comparisons (3). Therefore a new criterion of significance ($p < 0.017$) was
262 applied to avoid spurious positive results [38].

263

264
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Results

267 Following a physical assessment on each day of data collection, all 15 dogs
268 recruited fulfilled the inclusion criteria and were eligible to participate. All dogs
269 required no more than one acclimatisation jump in order to complete a
270 successful trial. All fifteen dogs completed three trials at each of the platform
271 heights. The distance between platform and force-plate that was set for each
272 dog following a successful acclimatisation jump-down was recorded. In total,
273 135 successful jump-downs were recorded.

274

275 The first trial performed by subject one at the 0.55m platform was found to be
276 invalid when retrospectively studying the raw data. Consequently, a mean
277 value of the two subsequent valid trials completed by this dog, for this height,
278 was calculated. All other 134 trials were valid and taken forward for analysis.
279 An example of the GRF data for an individual subject can be seen in Figure 2.
280 All peak limb forces reported are for pairs of forelimbs.

281

Vertical Ground Reaction Force (vGRF)

283

284 Peak forelimb vertical ground reaction forces (F_z) were significantly different
285 between the different platform heights examined ($F_{(2,28)}=89.749$, $p = 0.001$,
286 partial $\eta^2=0.865$; Figure 3). There was a significant difference ($p = 0.001$) in
287 forelimb vGRF from $27.35 \pm 4.14\text{N/Kg}$ at platform height 0.55m to 30.84
288 $\pm 3.66\text{N/Kg}$ at platform height 0.65m. From platform height 0.65m to 0.75m
289 there was also a significant difference ($p = 0.001$) in vertical ground reaction
290 force (F_z) from $30.84 \pm 3.66\text{N/Kg}$ to $34.12 \pm 3.63\text{N/Kg}$. Between the 0.55m and
291 0.75m platforms a significant difference ($p = 0.001$) in vGRF was observed
292 from $27.35 \pm 4.14\text{N/Kg}$ to $34.12 \pm 3.63\text{N/Kg}$.

293

Craniocaudal Ground Reaction Forces (cGRF)

295

296 There was no significant difference in peak forelimb craniocaudal ground
297 reaction forces (F_y) between the different platform heights examined
298 ($F_{(2,28)}=2.546$, $p=0.422$, partial $\eta^2=0.154$).

299

300 *Mediolateral Ground Reaction Forces (mGRF)*

301

302 There was no significant difference in peak forelimb mediolateral ground
303 reaction forces (F_x) between the different platform heights examined
304 ($F_{(2,28)}=0.947$, $p=0.400$, partial $\eta^2=0.063$).

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339 **Discussion**

340

341 Despite evidence of injuries occurring in dogs specifically participating in agility
342 [39], little is known about the epidemiology of other canine sporting injuries
343 [40]; a consequence most likely of the paucity of quantitative research
344 available [41]. A range of sporting activities, including hunting [42], and
345 greyhound racing [43], are yet to be fully investigated with preliminary data
346 suggesting that dogs may be at risk of injury. Dogs are routinely transported in
347 vehicles to participate in sports and complete their daily exercise routines, yet
348 the effect of jumping out of a car boot is unknown. It is also worthy of note that
349 dogs jumping from a vehicle may have undergone an extended period of
350 recumbency meaning that they lack the warm up that is essential for injury
351 prevention [44].

352

353 Results obtained in this study indicated that over three progressively
354 increasing platform heights, peak forelimb vGRF significantly increased. There
355 was a 12.8% increase from platform 0.55m to 0.65m and a 10.7% increase
356 with a further 10cm rise in height. Overall, the peak forelimb vGRF from lowest
357 to highest platforms increased by almost a quarter (24.80%).

358

359 To the authors' knowledge, this is the first canine study investigating the
360 kinetics of a static start jump. However, these findings concur with previous
361 research relating to jump height [13, 15] and illustrate that even a relatively
362 small increase in jump-down height can significantly alter landing kinetics.
363 However, it is worthy of note that the changes in peak vGRF were smaller in
364 terms of percentage increase (12.8% (0.55m to 0.65m) and 10.7% (0.65m to
365 0.75m)) than the increase in jump down height, which was 18.18% for the
366 0.55m to 0.65m height and 15.38% for the 0.65m to 0.75m height. It would be
367 expected that peak vGRF would be higher when jumping from the higher
368 platforms due to the increased length of the aerial phase and the consequent
369 change in downwards velocity (due to gravitational acceleration) at impact [13].
370 Jumping from a higher height could result in a steeper landing angle, which
371 has been shown to correlate with increased peak vGRF and impulse in dogs

372 jumping hurdles [13]. Considering this, peak vGRF increased comparatively
373 less with increasing jump down height than might be expected.

374

375 Given that loading cadaveric forelimbs has resulted in significant changes
376 ($p < 0.05$) in humero-radio-ulnar congruency [26], particularly at 100% of
377 bodyweight, it follows that when jumping down repeatedly from a vehicle boot,
378 internal structures of the locomotor system are subject to increased loading.
379 This might contribute to the higher risk of injury observed in agility dogs [39]
380 who are transported frequently to training and competition events and to dogs
381 who perform this task as part of their working role. In this study, the exclusion
382 of dogs below 0.43m in height at the withers enhanced cohort homogeneity
383 permitting more accurate comparisons. Further research should take place to
384 confirm that these findings are consistent with smaller but equally popular
385 breeds of dog. This could nevertheless be ethically problematic, given the
386 known significant variance in temporospatial and kinetic variables between
387 small and larger breeds [45].

388

389 The lack of any significant effect on mediolateral GRF seen in this study is
390 perhaps a demonstration of the lack of variance in sagittal movement when
391 landing on a perfectly level surface. Unlike cross-slope walking which can
392 result in variability in mediolateral forces [46], dogs in this study were not
393 required to markedly adapt to their landing conditions, given the force plate
394 and rubber matting was level and stable. Furthermore, the dogs were not
395 required to stop abruptly upon landing which would require more complex co-
396 contraction of musculature [47] and increase the potential for multidirectional
397 sway. There is a possibility that some dogs jumped slightly more to the left or
398 right whilst still landing on the force plate. Further work is required to
399 investigate jumping strategies in dogs and the effect of these on mediolateral
400 forces. In addition, this study only reported peak mediolateral landing forces
401 for paired limb contacts, which will not reflect that changes in body posture that
402 occur throughout the duration of the stance period.

403

404 While most dogs were observed to continue to travel forwards under
405 momentum, there was variance across subjects with some landing in an

406 efficient manner, coming to a halt only one or two footfalls later. This variability
407 may explain the insignificant findings ($p=0.422$) for the craniocaudal GRF data
408 collected. In a domestic setting, both of these kinetic measures could vary if,
409 for instance, a dog routinely jumps laterally away from a vehicle, perhaps
410 towards the direction of a familiar building.

411

412 In this study, the highest mean peak vGRF was recorded to be 42.2N/Kg (at
413 the 0.75m platform), which is directly comparable to the 45N/Kg vertical forces
414 previously recorded of galloping dogs jumping over hurdles [13]. The forces
415 sustained from a single jump in this study, therefore, have the potential to be
416 withstood by the limbs, given that at gallop these forces can be exerted and
417 absorbed during each galloping gait cycle [48]. In general, relatively few dogs
418 jump hurdles or fences regularly, with those that do undertaking specific
419 training techniques [39, 44]. Therefore, the comparable peak forelimb landing
420 limb forces do suggest that consideration should be taken when allowing dogs
421 to repeatedly jump from cars unaided.

422

423 This study did not attempt to investigate the consequences of vGRF on joints
424 and soft tissues within the kinetic chain. As such, no evidence can be provided
425 defining the relationship between the increased vGRF and potential injury.
426 However, given the known variance in loading and viscoelastic properties of
427 anatomical structures [49], failure will occur when loading limits are reached.
428 This study only utilised healthy dogs, hence the data may not be applicable to
429 all dogs, particularly those with pre-existing pathology that might affect their
430 gait [50, 51].

431

432 One difference between the data collected in this study and jumping from cars
433 is that some vehicles will have a raised boot sill relative to their compartment
434 floor. In such circumstances, the dog would be performing a countermovement
435 jump [52], albeit the ascension phase is relatively minimal. This could
436 potentially reduce the landing distance, particularly given that there is no
437 opportunity for significant momentum to be generated. Furthermore, the
438 internal surface of a car boot (carpet, plastic) can differ in addition to the degree

439 of damping offered by different landing surfaces which may impact on limb
440 loading patterns [53].

441

442 Many of the previous canine studies examining jumping have used agility dogs
443 as their sample population [12, 27]. This study, although including some dogs
444 with agility experience, also included non-agility dogs, since it was believed
445 this would improve applicability of the findings to the companion dog. While
446 most dogs were able to follow instruction readily, it was observed that one or
447 two non-agility dogs performed several trials before it was perceived they had
448 been accustomed to the requirements of the task. Although this habituation
449 effect witnessed by other authors [54, 55] occurred, it is likely that its effects
450 were negligible, since the hesitancy shown by dogs was witnessed prior to
451 their jump-down but did not appear to change the mechanics of the jump itself.

452

453 This study provides the first objective evidence to support the commonplace
454 belief that allowing dogs to repeatedly jump clear from vehicles with high boot
455 compartments may be inadvisable. However, further work is needed to
456 definitively link increased peak forelimb vGRF to common canine forelimb
457 pathologies. Although at present relevant authorities do publish guidance over
458 the safe transportation of dogs [2–4], methods of entry and exit into or out of
459 the vehicle are not explicitly outlined. It is hoped that this paper will increase
460 the awareness of the potential for harm and promote positive changes in
461 canine husbandry.

462

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464

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466 public, commercial or not for profit sectors. The authors would like to thank
467 Mark Cox for his assistance with data collection and all the dog owners who
468 kindly allowed their animals to participate in this study.

469

470 **Figure Legends**

471

472 Figure 1. Experimental set-up depicting the platform (0.9m x 1.1m) from which
473 dogs performed a static start jump down and the force plate. The area of the
474 force plate is indicated with tape on the rubber mat. The height of the platform
475 was adjustable and was set to either 0.55, 0.65 or 0.75m. The distance (d)
476 from the platform to the plate was dependent on the individual subject and the
477 range of distances used was from 0.26m to 0.47m (mean 0.38 ± 0.05).

478

479 Figure 2. Force plate data from one dog. All trials are shown for each jump
480 down height (0.55, 0.65 and 0.75m) with the mean overlaid (solid line).
481 Summed vertical forelimb landing forces (F_z) for pairs of limbs is shown in
482 green, summed craniocaudal forelimb landing forces (F_y) is shown in red and
483 summed peak mediolateral (F_x) forelimb landing forces is shown in blue.

484

485 Figure 3. Mean (of the three trials at each jump down height) peak vertical
486 forelimb GRF (F_z) for all subjects. Lines represent the median and diamonds
487 represent the mean.

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489

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