Altered distances between A-frame and the preceding jump affect dogs biomechanics of the approach but not A-frame contact biomechanics

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Abstract

A high proportion of agility injuries associated with an obstacle is due to the A-frame, however, there is limited research into the kinetics and kinematics of dogs traversing the A-frame. The aim of this research was to study kinematics and kinetics of agility dogs negotiating the A-frame when the preceding obstacle (in this case a jump) was placed at 10 m, 7.5 m and 5 m ahead of the A-frame. Runs of six competition standard agility dogs were recorded, each dog completed each distance three times. An inertial measuring unit was used to gather maximum velocity, acceleration and deceleration between jump landing and the A-frame. Video analysis and pressure sensors gathered carpal hyperextension and peak vertical forces for both forelimbs at the dogs' contact with the A-frame. The study found no difference in either carpal extension or PVF data between the different distances. However, maximum approach velocity decreased ($p<0.05$) with decreasing distance: 10 m (7.30±0.40 m/s), 7 m (6.61±0.34 m/s), and 5 m (5.74±0.62 m/s). Acceleration was also decreased at 5 m distance compared with 10 m distance ($p<0.05$). A notable finding was the -1.57 m/s^2 decrease in deceleration found between the 10 m (-5.92 m/s^2) and 5 m (-4.35 m/s^2) distances ($p<0.05$), the 10 m distance had 36% more deceleration than 5 m. As thoracic limbs have a role in deceleration, an increased distance between obstacles could be one of the factors involved in forelimbs injuries in agility dogs. Our recommendation is that the preceding obstacle is placed 5 m from the A-frame in agility courses to moderate speed, acceleration, and deceleration, and help to reduce reported injury rates.

Keywords: Agility, Canine, Kinematics, Kinetics

Introduction

Racing for the fastest time around a course with speed and precision, clearing obstacles and hitting contact points; the exhilarating sport of agility requires that dogs, directed by their handlers, complete a series of approved obstacles in a predetermined order under timed conditions (The Kennel Club, 2023b; UK Agility, 2023a). At the highest levels of competition these dogs may be operating close to their physiologic limits (Birch *et al.*, 2015; Appelgrein *et al.*, 2018). In terms of human and canine interaction, authors have identified an increase in physical exercise and strengthening of bond between owners and dogs training for agility, with positive emotional and social benefits to handlers participating in the sport also identified (Kerr, Fields and Comstock, 2014; Karvinen and Rhodes, 2021).

Considering that injury rates in agility have been reported as high as 41.7%, any improvements in safety of agility activities that reduced time-off for injury, would affect a significant number of dogs and their handlers (Pechette Markley, Shoben and Kieves, 2021; Holland *et al.*, 2022).

One obstacle purported to be responsible for higher-than-expected injury rates is the A-frame (Levy *et al.*, 2009; Cullen *et al.*, 2013; Sellon *et al.*, 2018). The A-frame is built of two 40º ramps hinged at the apex, which is 1.7 m from the ground, it has two contact areas at the base of the ramp, one on entry and one on exit, that the dogs must touch with at least part of a paw (The Kennel Club, 2023a). Researchers cite the A-frame as one of the most significant contributors to injury, with figures ranging from 14.7% to 29% of injuries attributed to contact with the obstacle, this is despite the obstacle usually occurring only once in the agility competition field compared to the bar jump featuring 11 to 18 times (Levy *et al.*, 2009; Cullen *et al.*, 2013; Sellon *et al.*, 2018; The Kennel Club, 2021; UK Agility, 2023b). Despite the high representation of the A-frame in reported injury rates, there is a scarcity of research into the impact of the A-frame on canine kinematics and kinetics.

Appelgrein *et al.* (2018) reported that reducing the angle of incline on the A-frame did not change maximum carpal joint extension of the dogs entering the A-frame and noted that, even at the decreased A-frame angle of 30^{o}, the physiologic limits for carpal extension may have been reached (Appelgrein *et al.*, 2018). It is recognised that repetition of amplified forces on the body, and irregular joint loading, may disrupt tissue structures and increase risk of injury, therefore this possibility that agility dogs are repeatedly operating at their physiologic extreme, may account for the relatively high number of injuries reported to be associated with the obstacle (Birch *et al.*, 2015; Pechette Markley, Shoben and Kieves, 2022).

According to Birch *et al.* (2015), increased distance between obstacles was reported to increase jump velocity (p<=0.001), whilst Söhnel *et al.* (2020) found higher velocity to the hurdle significantly increased jump height (p=0.023) and peak vertical force (PVF) (p<0.001). This is in contrast to earlier research where increased distance and higher velocity were not linked to increased PVF of thoracic limbs on landing from jump obstacles (Pfau *et al.*, 2011). The author found no research that examined if distance between obstacles and velocity were a contributory factor to altered kinetics and kinematics on the entry-contact of the A-frame and therefore possibly influencing the injury rates attributed to the A-frame. Additionally, The Kennel Club have expressed their interest in research in this area (personal communication, Boyd, 7 April 2022).

Regulations from The Kennel Club and UK Agility, which are the two main agility associations in the UK, require that the preceding obstacle is placed between 5 m and 10 m from the entry-contact of the A-frame, or a maximum of 8 m if the preceding obstacle is a tunnel under UK Agility rules (The Kennel Club, 2021; UK Agility, 2023b). This study aimed to explore the effect of the distance of the preceding jump obstacle to the A-frame, for three different distances within the range of those ascribed by the agility associations (5m, 7.5m and 10m), specifically examining the effect of differing distances on velocity, acceleration, and deceleration during the approach and set-up for the A-frame; and carpal maximum hyperextension and peak vertical forces (PVF) on A-frame contact. And therefore, if changes in course design might be considered to reduce risk of injury to agility dogs. Our hypothesis is that decreasing the distance will reduce the impact on dogs' biomechanics.

Materials and methods

Ethical statement

Data collection methods heeded the guidelines laid out in the Animal (Scientific Procedures) Act 1986 (UK Home Office, 2020). Ethical approval was obtained from the Animal Welfare and Ethics Committee of Writtle University College, approval number 1627. Owners of the canine participants completed a form giving their written consent for participation in the study.

Study design

A within-subjects, repeated measure, cross-over study design was employed to compare velocity, acceleration, and deceleration between the obstacle and A-frame, and highest carpal extension and PVF on entry contact with the A-frame, with a jump obstacle placed at three different distances preceding the A-frame: 10 m, 7.5 m, and 5 m. A pilot study was completed ahead of the trial to check data collection software, harness fitting, general logistics and any evidence of impact on participant wellbeing (NC3Rs, 2023).

4.3 Subjects

Following the 3R principles of animal research the potential cohort size was calculated using the resource calculation for a repeated-measures analysis of variance (ANOVA) with acceptable degrees of freedom (DF) between 10 and 20. Number = DF/(r – 1) + 1, where *r* is the number of repeated measures, in this case three distances between fences; advising minimum number of six dogs and maximum number of eleven dogs (Arifin and Zahiruddin, 2017; Hubrecht and Carter, 2019). Seven current competition dogs of varying breeds, with their experienced handlers, were recruited via the Kennel Club agility network asking for volunteers who could travel to the study field on the given dates for the trial. All dogs were assessed on the day of their involvement in the trial by a Veterinary Surgeon and deemed fit to run prior to participation. During the trial one dog was removed as they became anxious of the study field. The resulting cohort consisted of six dogs (Table 1), aged 4.83±1.72 years and weighing 18.65±6.47 kg.

Table 1 Participant dog data, including the order the distances in the trial were completed

Dog Number	KC Category	KC Grade	Age (years)	Withers Height (mm)	Weight (kg)	Trial Jump Height (mm)
1	Intermediate	3	7	500	20	500
2	Intermediate	4	6	444	13.2	500
3	Intermediate	5	2	474	11.7	500
4	Large	7	5	520	18	600
5	Large	7	5	510	19	600
6	Large	3	4	630	30	600

Experimental set-up

The study field was prepared on a level grass field, replicating normal outdoor agility competition conditions, using a KC standard A-frame and a plastic lightweight canine jump obstacle which would be familiar to the participants (The Kennel Club, 2021).

Distance to the A-frame was measured and marker poles were placed 5 m, 7.5 m, and 10 m ahead of the A-frame (Figures 1 and 2). The marker poles identified the location for the jumps to be placed consistently. The jump height was set to the normal competition height for each competitor.

Two spotlights (Vision X, Genval, Belgium) were set up on each side of the A-frame to illuminate the reflective anatomical markers, and two high-speed cameras, collecting at 240fps were positioned on two opposite tripods at 1.75 m perpendicular to the entry-contact point of the A-frame (Figures 1 and 2) to capture images of the animals' carpal joint angles on contact with the A-frame. This is analogous to the recording technique used in similar studies (Williams *et al.*, 2017; Anthony, Blake and Blake, 2024).

In this research, due to the cohort being a volunteer group of privately owned, actively competing agility dogs, the dogs' coat hair was not shaved, but was parted and markers were applied as close as possible to the skin over laying the lateral epicondyle of the humerus, styloid process, and lateral aspect of metacarpal V (Figure 3), furthermore positioning of reflective markers was carried out by the same researcher throughout to reduce variability (Blake and Godoy, 2021).

To gather velocity, positive acceleration, and deceleration data, each dog was allocated an inertial measurement unit (IMU), with tri-axial accelerometers, tri-axial magnetometers, and tri-axial gyroscopes (Catapult Vector S7, Melbourne, Australia), which sampled up to 1 kHz and returned data via ultra-wide band communication to Open Field software on a standard laptop

(Vector Device Overview *(S7/G7)*, 2023). Akin to Hayati *et al.* (2019), the IMU was placed in a pouch at the base of the neck, on a bespoke harness that was adjusted for the comfort of each dog (Figures 3 and 4).

A pressure sensor mat (CONFORMat by Tekscan Inc., Norwood, USA) was used to measure PVF of lead and trailing limb contact with the A-frame, with a method directly gleaned from recent research on the dog walk obstacle (Anthony, Blake and Blake, 2024). With a capacity to measure 64 kPa and sampling rate of 100 Hz, the 471.4 mm by 471.4 mm sensor panel contained 1027 sensors at a density of 0.5 sensors/cm^2. The mat was calibrated according to the manufacturer's instructions.

The pressure sensor mat was secured to the yellow contact region of the A-frame, secured by double-sided tape, it was then covered with a sheet of yellow 2 mm self-adhesive foam to provide grip and protection (Figure 5). Gaffer tape (Houghton, Cambridgeshire, UK) was applied to prevent distal phalanges of the dogs catching on the upper intersection.

The dogs were brought into the study field individually to acclimatise and warm up prior to anatomical markers and the IMU being applied. Once the harness and markers were in place, the dog completed a practice run to check that none of the equipment caused a distraction or affected wellbeing (Birch and Leśniak, 2013). After the practice run, videographic, IMU, and pressure mat data were recorded for each dog as they completed three runs with the jump obstacle at each of the three distances from the A-frame, thereby each dog completed nine runs in total. The jump distance order was semi-randomised between dogs, three ran with the jump placed at 5 m first, then 7.5 m, and lastly 10 m, and three ran with the jump placed at 10 m first, then 7.5 m, and lastly 5 m.

Data collection and analysis

Carpal extension on A-frame contact

Video data was recorded bilaterally for each run as the trail and lead thoracic limb contacted the A-frame. Data was uploaded to Quintic Biomechanics v33 (Quintic Consultancy, Birmingham, UK) for analysis by the same researcher, reducing variability. Distances and position in run sequence of the videos for each dog were unknown, therefore blinding the trial to reduce risk of bias in the results.

The video was analysed frame by frame and the angle at the point of maximum carpal extension measurements were taken between the anatomical markers, for lateral epicondyle of the humerus, styloid process, and lateral aspect of metacarpal V (Figure 6). Data was collected for maximum carpal extension of both leading and trailing limb for each of the three runs and a mean figure for maximum carpal extension each trailing and leading thoracic limb of each dog calculated and recorded for each distance (Birch and Leśniak, 2013).

Data collected from the IMUs were downloaded via the Open Field software and analysed by synchronising with the videos. Maximum velocity was identified for each dog on each of the three runs at each distance and a mean figure was calculated for each distance for each dog. Similarly, maximum acceleration during each run at each distance was identified and a mean maximum acceleration was calculated for each distance for each dog. Maximum deceleration data, considered as the maximum deceleration between approach and take-off, was also extracted for each dog at each distance and a mean maximum deceleration for each dog at each distance was recorded.

PVF of trailing and leading thoracic limb landing on the A-frame

Data from the pressure mat was collected via a laptop connected wirelessly and then uploaded to proprietary software (CONFORMat Research v7.60, Tekscan). Each data recording was run, and the peak forces for the trail and lead paw readings were recorded separated. Successful runs where both front feet had landed on the pressure mat were included in the study. The aim was to report two to three runs per dog at each distance, where full paw contact was achieved for both trail and leading thoracic limb by the pressure mat. The mean PVF for trailing and leading limbs for each dog at each distance was then calculated in Newtons. These data were normalised to the dog body weight in Newtons (N/N) to reduce PVF correlations with bodyweight and enable comparison for distances (Voss *et al.*, 2010).

Statistical analysis

Data were analysed on IBM SPSS v.28 (IBM, Armonk, USA). The mean data for each of seven parameters were then each compared for the three jump distances (5 m, 7.5 m, and 10 m). A Shapiro-Wilk test for normality was carried out. Where data were not normally distributed ($p<0.05$), a Friedman's Two-Way Analysis of Variance by Ranks was run with significance determined as $p<0.05$. Where significance was met, pairwise comparisons with Bonferroni correction for multiple comparisons was run and median results were reported. Where Shapiro-Wilk test showed data were normally distributed ($p>0.05$), data were reported as mean ± standard deviation (SD). A one-way repeated measures ANOVA was run to investigate the effect of the three different distances on the parameters being investigated. Where a significant result ($p<0.05$) was returned from the within-subjects test with the three different distances, pairwise comparisons with Bonferroni correction for multiple comparisons was run to explore where significant differences occurred. All results report SPSS Bonferroni adjusted *p*-values.

Results

Parametric data are mean±SD and represented by M, non-parametric data are median and represented by Mdn.

Kinematics

Carpal extension of the trailing limb was statistically different between the different distances, (χ^2 (2)=6.33, *p*=0.042), although there were no significant pairwise comparisons. However, there were no significant differences for the leading limb for carpal extension between the distances (F(2,10)=0.568, *p*=0.584).

Velocity between the jump and A-frame was statistically significantly different with the different distances (F(2,10)=29.043, *p*=0.000068), with statistically significant reduction in velocity at each reduction in distance. Explicitly, approach velocity decreased at the 5 m distance when compared with the 7.5 m distance (-0.865 (95% CI, -1.560 to -0.170) m/s, *p*=0.021) and with the 10 m distance (-1.562 (95% CI, -2.524 to -0.599) m/s, *p*=0.007). The 7.5 m distance has also shown a lower velocity when compared with the 10 m distance (-0.697 (95% CI, -1.108 to -0.285) m/s, *p*=0.006) (Figure 7).

When looking at the acceleration developed by the dog between the jump and the A-frame, a statistically significant difference with the differing distances was also observed (*F*(2,10)=10.033, *p*=0.004), with a decrease in acceleration at the 5 m distance compared to the 10 m distance (-1.057 (95% CI, -1.654 to -0.460) m/s^2, *p*=0.005) (Figure 8).

Likewise, the deceleration was statistically significantly different at the different distances, (F(2,10)=20.057, *p*=0.000316) with the 5 m distance eliciting less deceleration than the 10 m distance (-1.568 (95% CI, -2.300 to -0.836) m/s^2, *p*=0.002) (Figure 9).

Kinetics

Peak vertical forces of the trailing limb at contact with the A-frame were statistically significantly different with the three different distances ($F(2,8)=5.029$, $p=0.039$), however, no differences were noted on the pairwise comparisons, whilst for the leading limb there were no statistically significantly different with the three different distances ($F(2,6)=0.882$, $p=0.462$).

Discussion

This study set out to identify if changing the distance between the A-frame and the preceding jump obstacle influenced maximum carpal extension of trailing and leading limbs, velocity, acceleration, deceleration, or PVF of trailing and leading limbs. Our results have shown that there is a relationship between distance and kinematic changes: acceleration and deceleration were all significantly decreased between the 10 m and 5 m distances and velocity was decreased at each reduction in distance. Thus, the data indicates that decreasing the distance from jump obstacle to A-frame in an agility course would positively alter one or more of the measured kinematic parameters. The study found no significant effect on PVF or carpal extension by changing distance between the obstacle and the A-frame.

Maximum carpal extension and PVF, that were measured when the dogs made contact with the A-frame, were not significantly different for the three distances between the obstacles. These measurements are remarkably similar to those observed by Appelgrein *et al.* (2018), 242.3º (240.2º - 244.4º) who, in their experiment, placed a jump closer to the A-frame at 3 m to control speed. Appelgrein *et al.* (2018) surmised that maximum carpal extension may already have been reached at the lowest gradient that they tested (30º), which would have accounted for there being no statistically significant differences in their results for the trailing or leading limb carpal extension in their experiment. Similarly, the lack of significant difference between the results in this research could be due to the dogs working at their physiologic limits at all three distances. In likeness to the trailing limb results, these are also strikingly similar to the angles identified by Appelgrein *et al*. (2018): 241.4^{o} (239.3^{o} - 243.5^{o}). When taken in isolation from the rest of the results from this study, these findings would appear to support the theory by Appelgrein *et al.* (2018) that the dogs were already working at their physiologic extreme.

The increase in approach velocity as the distance increases supports findings by Birch *et al.* (2015) in that as distance increased, take-off and landing speed increased. It could be considered that at the shorter distances the dogs' attention quickly focussed on adjusting their gait in preparation for making contact with the A-frame and, due to the close proximity of the up-coming obstacle, did not have the time and distance to reach an increased velocity.

The research by Söhnel *et al*. (2020) found that dogs who were faster on take-off jumped higher (p=0.023). As the dogs in our experiment were travelling fastest at the 10 m distance the author anticipated that, similarly, an increase in kinetic or kinematic measurements would be seen at engagement with the obstacle. In particular, as identified in aspects of recent research into kinetic and kinematics of the dog walk by Anthony, Blake and Blake (2024), the author anticipated that PVF would be higher in dogs landing on the contact point from higher speed. The author conjectured that the dogs would use the contact with the A-frame to rapidly decelerate, with increased GRF, resulting in higher forces travelling through the forelimbs to the body. Additionally, it was considered a possibility that the faster dogs had exerted a greater level of control over their trajectory to land within the contact point, rather than further up the frame as may be their natural course of direction, and the result would be an increase in PVF on landing; this is a consideration that the author extrapolated from the findings of the study by Birch *et al.* (2015) which indicated that the faster dogs jumped higher. However, this did not appear to be the case, as PVF of the trailing limb and leading limb were not found to be statistically different between the three distances. Interestingly, this is a similar finding to the earlier research by Pfau *et al.* (2011) whose study of agility dogs of mixed ability landing from a jump also found no significant difference in PVF between the two distances that were assessed (3.6 m and 5 m). Moreover, in their research, higher velocity was not linked to increased PVF of the thoracic limbs on landing.

In this A-frame research, the recorded mean PVF of the trailing limb was between 3.10 and 4.20 N/N, and the leading limb mean PVF was between 4.57 and 5.56N/N; the range for each of the trailing and leading limbs is comparable to those found by Pfau *et al.* (2011) during landing from a jump. In their study, PVF values within this range were reported for thoracic limbs landing after a 0.6 m jump obstacle with 4.59 N/N reported at their 5 m distance between obstacles, and 4.08 N/N at their 3.6 m between obstacles trials. They used a jump obstacle height of 0.6 m, which is Kennel Club standard height for large agility dogs (Table 1); these jumps account for approximately 10 to 15 of the obstacles on the course. If the A-frame is returning similar PVF values to jump obstacles, which are completed at a much higher frequency than the A-frame, it could be considered unlikely that PVF on contact with the A-frame is the parameter influencing the relatively high incidence of injuries attributed to the A-frame of between 14.7% and 29% that has been reported by earlier surveys (Levy *et al.*, 2009; Cullen *et al.*, 2013a).

One possible explanation for why PVF and carpal extension angles appear unaffected by the change in distance and velocity may be delivered by the findings for acceleration and deceleration, where results were significantly greater at the 10 m compared to the 5 m (p=0.005,

p=0.002 respectively). In both acceleration and deceleration, the difference between the results for 5 m and 7.5 m, and 7.5 m and 10 m, were not significant.

Of note is the difference of -1.57 m/s^2 in deceleration between 10 m and 5 m representing a deceleration rate that is 36% higher at the 10 m distance compared to the 5 m. The author proposes that no significant difference in carpal extension or PVF of either thoracic limb was seen when the dog landed on the A-frame because of the increased rate of deceleration as the dogs prepared to make contact with the obstacle. In effect, velocity, and the potential effect of increased velocity on PVF, had been significantly moderated down by deceleration before the dogs contacted the A-frame.

These results seem to indicate that regardless of the velocity developed at approach, the dog reduces it in a sufficient manner to contact the A-frame with a similar impact, which could indicate an adjustment to prevent high impact and show some level of cognition in the execution of the task. In the last two decades, much research on dog cognition has focused specifically on processes related to social cognition, yet little of this work has been integrated into applied training protocols. Through understanding dogs' cognition, we can determine which training practices interface best with their understanding of the physical world. For instance, they have a basic understanding of object solidity (Pattison et al., 2010) and object permanence (Triana and Pasnak, 1981). Training and experience may be just as important as genetics in determining the cognitive performance of dogs (Foraita et al., 2021). Studies on the impact of training background (discipline and training level) on problem solving ability have shown differences between dogs trained to a high level in working or sporting roles and pet dogs that have received little or no training (Marshall-Pescini et al., 2008; Marshall-Pescini, Frazzi and Valsechi, 2016). It seems that amongst the sport obstacles, dogs' kinetics and kinematics are mainly affected during jump landing, when there are changes in height and length of the obstacles, possibly because landing adaptations to reduce impact are not always possible (Pfau et al., 2011; Carter et al., 2022; Williams et al., 2022).

There is evidence of increased shoulder muscle activity before and after landing of the trailing limb in gallop to give stability as the forequarters lowered, as thoracic limbs perform a strut-like balancing function engaged in braking (Tokuriki, 1974; Walter and Carrier, 2007; Deban, Schilling and Carrier, 2012; Hayati, Mahdavi and Eager, 2019). Researchers characterising the gallop of greyhounds using accelerometers also highlighted that rapid gait change may be linked to an increased risk of injury (Hayati, Mahdavi and Eager, 2019). Cullen *et al.* (2016) has used electromyography to measure *m. biceps brachii, m. supraspinatus, m. infraspinatus,* and *m. triceps brachii-caput longum* activation across the A-frame, as these muscles were previously reported as having high risk of injury (Cullen *et al.*, 2013). There was an increase of muscle activation in all studied muscles, in comparison with the walking baseline, during the A-frame approach ranging from 2.8 times walking to more than 7.4 times walking. The findings of high muscular activation on the A-frame approach their study are linked with the high deceleration and braking ahead of the A-frame, which can be a contributing factor towards the high reported incidence of shoulder injury (20.0% to 30.1%). Future research could go so far as to isolate trailing and leading limb data, to explore for any significant differences in PVF or horizontal impulses as the dogs decelerate between different distances of obstacle.

This experiment recruited a heterogenous group of agility dogs, the resource calculation for a repeated measures ANOVA indicated that a minimum number of six dogs and a maximum number of eleven dogs were required for the trial. On the day only seven volunteer dogs attended, one of which was removed from the trial by the researchers on ethical grounds. The resulting group contained four large dogs and two intermediate dogs of varying Kennel Club grades (KC Grades 3 to 7) and skill level. Reports of variation of kinematic parameters between experienced and inexperienced agility dogs have been reviewed earlier in this study, such as exaggerated patterns of movement and greater limb compression in inexperienced dogs (Williams *et al.*, 2017; Söhnel *et al.*, 2020). It is reasonable to surmise that the varying skill level of this cohort may have affected the results and potentially research that involved a greater number of dogs divided into groups by Kennel Club grade could be considered.

Given the increased velocity and rates of acceleration and deceleration, and the subsequent increase in braking function required of the thoracic limbs of dogs at the 10 m distance compared to the 5 m distance, the author recommends that the Kennel Club consider amending the course regulations. The author proposes that the jump obstacle that precedes the A-frame should be placed 5 m from the base of the A-frame to moderate speed, acceleration, and deceleration, in an endeavour to reduce potential injury rates.

This would appear to be the first research that looked at the effect of different distances between the A-frame and preceding obstacle on velocity, acceleration, and deceleration of agility dogs as they travelled between the obstacles, and PVF and maximum carpal extension as the dogs subsequently contacted the A-frame. This study found that changes in distance did not affect the PVF or carpal extension as the dogs contacted the A-frame. Greatest kinematic changes in response to the increase in distance occurred before the dogs contacted the A-frame. Results showed higher acceleration and higher deceleration at the increased distance, informing the author that the dogs were able to moderate their velocity significantly on approach to the A-frame, resulting in no change in PVF or carpal extension on contact with the A-frame itself. Therefore, high deceleration and thoracic limb braking forces, required to control trajectory in order to meet the required contact point of the A-frame, could be the catalyst of injuries. Fundamentally, this research has revealed a strategy that may help reduce the high frequency of reported injuries in agility dogs that are related to the A-frame. Using the minimum distance allowed under the UKKC regulation (5 m) between the A-frame and the preceding obstacle is advocated as a reduction deceleration and braking forces could help reduce the high frequency of A-frame related injuries reported in agility dogs.

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Authors Contributions

Claire Bidwell: investigation, data curation, formal analysis, writing-original draft; **Scott Blake**: conceptualisation, methodology, investigation, supervision, writing- review and editing**,** project administration; David Marlin: methodology, resources, **Roberta Blake**: conceptualisation, methodology, investigation, formal analysis, writing-original draft, supervision, resources.

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